THE ONION

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भाकृअनुप
ICAR

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Foreword

Onion is an important vegetable-cum-condiment. Humorously said "Onion brings tears to policy-makers when it is absent (in the market) and rocks administration". Thus is the importance of this crop.

Onion belongs to the genus *Allium*, which is one of the oldest cultivated plant species. Onion and garlic are the most important crops in use as an ingredient in various dishes since ages by many cultures across the world. India is the second largest producer of onion after China. It is estimated that onion is grown in India over 9.92 lakh hectares (22.4% of the world area) with a total production of 166.54 lakh tonnes. Maharashtra, Karnataka, Gujarat, Bihar, Madhya Pradesh, Rajasthan, Andhra Pradesh and Tamil Nadu are the main onion-growing states. In general, barring north-easten states and Kerala, all other states grow onion. Onion consumption is very common in our daily dietary habits and any fluctuation in its price has great ramifications at the National level.

Systematic research on onion was started in 1960 at Pimpalgaon, Baswant and Nashik and later at the Indian Agricultural Research Institute (IARI), New Delhi, and Indian Institute of Horticultural Research (IIHR), Bengaluru. With the establishment of the National Research Centre for Onion and Garlic (NRCOG), later christened as the Directorate of Onion and Garlic Research (DOGR), the research on onion intensified further. The DOGR is also the nodal agency for the All-India Network Research Project on Onion and Garlic (AINRPOG). The National Horticultural Research and Development Foundation (NHRDF), Nashik, is another organization contributing significantly in research and development of onion in the country. These all efforts have led to the development of a very strong research base in India. The DOGR at Rajgurunagar (Maharashtra) coupled with AINRPOG is doing yeoman service to onion-growers.

I congratulate Dr N.K. Krishna Kumar, Dr Jai Gopal and Dr V.A. Parthasarathy for editing this great monograph on onion. The chapters have been contributed by well-known experts in the field. I congratulate the DKMA for bringing out this publication. The book has been thoughtfully organized, covering all aspects of onion. I am sure this would be of great interest to all onion-workers around the world as well as students, researchers and policy-makers in India.

(S. Ayyappan)
Secretary, DARE
and Director General, ICAR

Preface

Onion is an important component of the daily intake throughout the world, particularly in the South Asia, where no culinary preparation is complete in itself if onion is not included. Onion believed to have originated in the Central Asia (around Turkmenistan–Afghanistan) is currently cultivated all-over the world under the short-day and long-day conditions. It is the single commodity exported in large quantities from India, and is also one among the market-sensitive items that can create ripples in the trade. However, it does not mean that it is less important in the domestic market; its demand is increasing day-by-day in India too as consumers are realizing its multiple utilities—medicinal, therapeutic, etc. It is a common food item for the rich and the poor, but its price volatility often renders it beyond the reach and means of the common man. Low productivity, poor seed quality, skewed cultivation and artificial scarcity are some of the pointers, which since long are demanding attention.

Onion has been in cultivation in India for decades but formal efforts on its R&D were initiated in 1960 at Pimpalgaon, Baswant and Nashik by the State Department of Horticulture, Government of Maharashtra. Later systematic research was conducted and is still continuing at the Indian Agricultural Research Institute, New Delhi; Indian Institute of Horticultural Research, Bengaluru and the National Horticultural Research and Development Foundation, Nashik. To give further impetus to research on onions, the Indian Council of Agricultural Research established a National Research Centre for Onion and Garlic in 1994 and an All-India Network Research Project (AINRP) on Onion and Garlic was initiated in 2009 to validate stability and adoptability of different production technologies. Over the years, R&D efforts have made significant impact through development of varieties, and various production/protection and post-harvest management technologies. Innovative farmers and private sector undertakings have also contributed significantly in production and overall development of onion-crop in India. Still large gaps do exist in overall understanding of onion production, protection, post-harvest handling, marketing and value-addition.

In the National Workshop of All-India Network Research Project on Onion and Garlic at the Bidhan Chandra Krishi Vishwa Vidyalya, Kalyani, West Bengal, in April 2013, a need was felt for an Indian publication on the Onion, capturing significant research findings with comprehensive presentation. This book "*The Onion*" is the translation of that vision. This compilation is perhaps the first of its kind and covers most of the R&D on the onion in India.

This volume has been divided into 18 Chapters focussing on different aspects of topical interest—Genetic Resource Management, Genetics, Breeding, Biotechnology and Development of Varieties; Technologies on Crop Production and Protection; Post-harvest Management and Value-addition; and Marketing and Export. A highlight has been the market analysis and the factors influencing onion price stability. Relevant data in all the chapters have been suitably supplemented with tables and graphical presentations. Efforts have also been made to bring uniformity in the contents of the chapters. The information contained here is a reflection of the decades of painstaking research. The editorial board is especially indebted to all the authors who have put in their best efforts in gathering relevant information from all possible sources.

We are extremely thankful to Dr S Ayyappan, Secretary, DARE, Government of India and Director General, ICAR, for his support and encouragement. We are highly thankful to the Directorate of Knowledge Management in Agriculture, ICAR, New Delhi, for publishing this valuable tome. We acknowledge the valuable suggestions of our colleagues, Drs Ranvir Singh, B.K. Pandey and Vikramaditya Pandey at the Horticultural Science Division of the ICAR Headquarters, New Delhi. The help rendered by Dr E. Srinivas Rao, IIHR, Bengaluru; Shri Dhiraj K. Sharma, CISH, Lucknow and Mrs Shashi A. Verma, DKMA, New Delhi, was invaluable. The technical support provided by Shri Shaikh, Horticultural Science Division, in day-to-day handling of the manuscript is duly acknowledged.

Although we have tried our best to present this treasure of information in as perfect a manner as possible, it is open to improvement. As editors, we have tried to make the presentation comprehensive and error-free, but should the readers find any lacunae, we would be happy to address them in revised editions.

N. K. Krishna Kumar
Jai Gopal
V. A. Parathasarathy

Acronyms

AFLP	:	Amplified Fragment Length Polymorphism
AINRP	:	All-India Network Research Project
AINRPOG	:	All-India Network Research Project on Onion and Garlic
ANS	:	*anthocyanidin synthase*
BAC	:	Bacterial Artificial Chromosome
BBF	:	broad-based furrow
CA	:	Controlled Atmosphere
CAPS	:	Cleaved Amplified Polymorphic Sequences
CERRA	:	Centre Régional de Recherche Agronomique
CGMS	:	Cytoplasmic-genic male-sterility system
CHI	:	*Chalcone Isomerase*
CISH	:	Central Institute for Subtropical Horticulture
CMIE	:	Centre for Monitoring Indian Economy
CMS	:	Cytoplasmic Male Sterility
CNRA	:	Centre National de Recherche Agronomique
COMAV	:	Centre for the Conservation and Breeding of the Agrodiversity
CPE	:	Cumulative Pan Evaporation
CRA	:	Centre de Recherche Agronomique
CRREA	:	Centre Régional de Recherches Environnementales et Agricoles
CTD	:	Cumulative Thrips Days
CV	:	Coefficient of Variation
DARE	:	Department of Agricultural Research and Education
DAS	:	Days After Storage
DFR	:	Dihydroflavonol 4-reductase
DKMA	:	Directorate of Knowledge Management in Agriculture
DOGR	:	Directorate of Onion and Garlic Research
EST	:	Expressed Sequence Tags
FAA	:	Free Amino Acids
FOS	:	Fructo-oligosaccharides
GAP	:	Good Agricultural Practices
GBNV	:	Groundnut Bud Necrosis Virus
GC	:	*Galanthum*-Cytoplasmic
GCA	:	General Combining Abilities
GCV	:	Genotypic Coefficient of Variation
GISH	:	Genome *In-situ* Hybridization
HRI	:	Horticulture Research International
IARI	:	Indian Agricultural Research Institute

IASRI	:	Indian Agricultural Statistics Research Institute
ICAR	:	Indian Council of Agricultural Research
IDM	:	Integrated Disease Management
IIHR	:	Indian Institute of Horticultural Research
INM	:	Integrated Nutrient Management
IPGRI	:	International Plant Genetic Resources Institute
IR	:	Infrared Radiation
ISSR	:	Inter Simple Sequence Repeat
IWM	:	Integrated Weed Management
IYSV	:	Iris Yellow Spot Virus
KVK	:	Krishi Vigyan Kendra
MBC	:	Minimum Bactericidal Concentration
MH	:	Maleic Hydrazide
MIC	:	Minimum Inhibitory Concentration
MPKV	:	Mahatma Phule Krishi Vidyapeeth
NAFED	:	National Agricultural Co-operative Marketing Federation of India Ltd
NCBI	:	National Centre for Biotechnology Information
NHRDF	:	National Horticultural Research and Development Foundation
NPC	:	Nominal Protection Coefficients
NRCOG	:	National Research Centre for Onion and Garlic
NSSO	:	National Sample Survey Organization
OP	:	Open Pollinated
ORF	:	Open Reading Frames
OYDV	:	Onion Yellow Dwarf Virus
PCV	:	Phenotypic Coefficient of Variation
PEG	:	Polyethylene Glycol
PHL	:	Post-harvest Losses
PMC	:	Pollen Mother Cell
PMI	:	Phosphomannose Isomerase
PPP	:	Public Private Partnership
PSB	:	Phosphorus-solublizing Bacteria
QTL	:	Quantitative Trait Loci
RAPD	:	Random Amplified Polymorphic DNA
RFLP	:	Restriction Fragment Length Polymorphism
RILs	:	Recombinant Inbred Lines
SCA	:	Specific Combining Abilities
SCAR	:	Sequence Characterized Amplified Region
SDD	:	Stimulo-deterrent-diversion
SEM	:	Scanning Electron Microscope
SNP	:	Single Nucleotide Polymorphism
SSC	:	Soluble Solids Content
SSR	:	Simple Sequence Repeat
TNAU	:	Tamil Nadu Agricultural University
WGRU	:	Warwick Genetic Resources Unit

Contents

Origin, History and Distribution

1

K.E. Lawande

Many of the oldest cultivated plant species belong to genus *Allium*. Onion and garlic are important vegetable crops of this genus, and are used as ingredients in many of the dishes around the world since thousands of years back. World's onion production has steadily increased, and onion has become the most important horticultural crop, after tomatoes. There are several varieties of onion—red, brown, yellow, white and green, ranging from very strong smelled to mild and sweet. Onions can be eaten raw, and can be cooked, fried, dried or roasted. Besides, being used as a food item, onions are valued for their therapeutic effects. Onions were described by Charak in *Charak Samhita* (300 BC) and in *Shusruta* (AD 300) as medicine for diuretic, for good digestion and heart, and for eyes and joint problems. In Chinese medicine, onions are being used to treat angina, cough, bacterial infection and breathing problems. Early American settlers used wild onions to treat cold, cough and asthma, and also to repel insects. Modern concept of medicine also recognizes importance of onions in the following, such as lowering blood sugar, curing cardiovascular problems, improving gastrointestinal health, fighting cholera, preventing hair loss, improving bone health, curing tooth disorders and urinary disorders, and in prevention of blood-clot formation. Onions are also used as an antibacterial and aphrodisiac substance.

Historical perspective

The onion is being cultivated for the last 5,000 years the worldover. It was grown in Chinese gardens almost 5,000 years back. In Egypt, onions are traced back to 2500 BC. There is a clear evidence that the Sumerians were cultivating onions as early as 2500 BC. One Sumerian report dating back 2500 BC, indicates someone sloughing over city-governor's onion patch. Egyptians worship onions since it symbolizes eternity; they burned onions along the Pharaohs. Paintings of onions are on the inner walls of the pyramids and in tombs of both Old and New Kingdoms. Onions have been mentioned as a funeral offering, and are depicted on the banquet tables of great feast.

In the Bible, onions are mentioned to have been eaten by the Israelites. In numbers 11: 5 of the New International Version of Holy Bible, the children of Israel lament meagre desert diet enforced by the Exodus: "We remember the fish, which we eat in Egypt freely, the cucumbers, and the melons and the leeks and the onions and garlic". In ancient Greece, athletes ate large quantities of onions as it was believed to lighten balance of blood. Roman gladiators were rubbed down with onions to give firmness to their muscles.

In Bhagavad Gita, Krishna narrates foods which are too bitter, too sour, salty, hot, pungent, dry and burning are dear to those in the mode of passion (those who are Rajasic). Such food causes distress, misery and diseases. Onion and garlic are in this category. They excite baser instincts and make it difficult for one to control senses. The prohibition on onion and garlic is implicit by virtue of their characteristics. Historical and cultural significance of onions have been well documented in *Garuda Purana* (Shastri, 1995) where it is regarded as Rajasic (of aphrodisiac quality).

While describing ancient recorded history of onion in India, Swarup (2006) gave the following chronological order of events.

Period	Record
Vedic period 15,000–1,000 BC	Rigveda, Yajurveda, Atharvaveda
Apastamba 860–300 BC	Apastamba Dharma Sutra I
Charak 600 BC	Charak Samhita
Patanjali 200 BC	Patanjali
Shusruta AD 300–400	Shusrut Samhita
Gupta period AD 606–648	Chinese travelers' memoirs
Insting AD 671–695	Chinese travelers'memoirs
Mughal period AD 1556–1605	Ain-i-Akbari

An old Turkish legend says that when Satan was thrown out of heaven, garlic sprouted where he first placed his left foot, and onions grew where he placed his right foot.

Origin and distribution

The name "onion" originated from the classical period when it was given the Latin name *unio,* meaning oneness or unity, or a kind of single onion. The French called it *oignon*. Martin Elcort in his book, *"The Secret Life of Food"*, wrote, "The word onion was created by adding the onion-shaped letter O to the word union, yielding a new spelling ounion. The letter 'u' has been dropped to create modern spelling— onion" (Anonymous, 2013).

Onion is native to Central Asia of temperate region (between Turkmenistan and Afghanistan) where some of its wild relatives still grow. The closest among them are *Allium vavilovii* Popov & Vved from Turkmenistan and northern Iran and *Allium asarense* R.M. from Iran. *Allium oschaninii* O. Fedtsch, from Uzbekistan and neighbouring countries, is considered to be the ancestor of *A. cepa,* the present-day onion. From Central Asia, the supposedly onion ancestor migrated first towards Mesopotamia [onion has a mention in the Sumerian literature (2500 BC)], then to Egypt (1600 BC), India and South East Asia. From Egypt, *A. cepa* was introduced into Mediterranean area, and from there to all Roman Empire. According to Vavilov (1926), South-West Asian gene centre was proposed as the primary centre of onion domestication and variability. Vavilov and Burkinich (1929), based on ecotypes and wild forms, further confirmed that Afghanistan and adjacent countries are the genetic centre of origin of the cultivated forms of onion and garlic. More than 600 species of *Allium* are distributed in Afghanistan, Turkey, Iran and Central Asia, comprising Turkmen SSR, Uzbek SSR, Tadzhik SSR, Kirgiz SSR and Kazakh SSR, and Mongolia (Kotlinska *et al.*, 1990).

The secondary centre of its origin in Mediterranean gene centre represents the area from which onions with large bulbs were selected (Castell and Portas, 1994). Onions have since been cultivated for a long time, so their bulbs and inflorescences must have been adapted closely to temperature and photoperiod where they grow. A huge range of cultivars and landraces exist, developed over the centuries, to fit diverse climate and food preferences of the world (Brewster, 1994). The genetic material developed and being cultivated is of a long-day type, requiring longer photoperiod and moderately cool temperature for development of bulbs and a very low temperature for flowering.

In India, onions were adapted from a very early time, before Christian era. Originally, native of Central Asia of temperate region with perennial-biennial habit and a long-day character, they have established well under the tropical environment and short-day (11–11.5 hours) photoperiod (Seshadri and Chatterjee, 1996).

During acclimatization of different vegetable crops and their varieties, farmers had applied selection pressures involuntarily to meet market preferences. In case of onion, the need to produce seeds indigenously has played an important role in adaptation. Out-breeding mechanism of the onion has promoted its selection suiting to diverse environments during the process of adaptation and diversification.

At the centre of origin and between 25 and 40°N latitude, onion is biennial in seed production and requires more than 14 hours day-length for bulb production. In subtropical and tropical parts of India, between 12 and 25°N latitude, it is biennial only but produces bulbs under comparatively shorter photoperiod (11–11.5 hours) in winter. Winter-season crop accounts for 60% of the total production in India. Onion cultivation is predominant in western Maharashtra and Gujarat, where two crops, one in a rainy season (*kharif*) and the other in winter season (*rabi*) are taken regularly. Its tropicalization progressed further southwards to Bellary region of north Karnataka, and finally vegetatively propagated multiplier onions or shallot-type onions were established in Tamil Nadu at 6 to 8°N latitude. The adaptations to hardy conditions of high rainfall, high temperature and short photoperiod, typical of rainy season (*kharif*) crop of western India, could not be chronologically documented (Seshadri and Chatterjee, 1996). Export from Mumbai and Kandla ports, mainly to Gulf countries, predominantly during November to April, coincides with the harvest of rainy season and late rainy season crop. This is a unique example where largely market forces have influenced domestication and diversification of the crop. Demand for highly pungent pink-skinned bulbs from Gulf countries resulted in the selection of such types by the farmers of the western India, and even seeds could be produced under similar climatic conditions. This adaptation made onion to be an annual crop. The phenomenon led to loss of short dormancy of onion-bulbs. This aspect of onion domestication in western India was unnoticed, and was not even recorded (Seshadri and Chatterjee, 1996)

In Africa, tropical cultivars may have been introduced either from southern

Egypt, or from India *via* Sudan to Central and West Africa (Messiaen and Rouamba, 2004). Onion trade from India made it possible to select adapted types. Selection from genetically heterogeneous seeds or bulb-lots by local farmers facilitated adaptation of seed-propagated onions. *A. cepa* as bulb-onion and/or shallot is cultivated probably in all countries of tropical Africa. Mali, Senegal, Burkina Faso, Ghana, Niger, Nigeria, Chad, Sudan, Ethiopia, Kenya, Uganda, Zambia and Tanzania are chief onion-producing countries. In the lowlands, between 10° N and 10° S, shallots replace onions as temperature is too high for vernalization and seed production and climate is too humid. The short vegetative cycle of shallot (60–75 days) makes possible two crops of this in a year. The spicy taste and high dry matter content (15–18%) of shallots have made them attractive for growers further down the equator; in many areas where common onions are also produced. Red or purple onions, grown in East Africa, named Bombay Red or Red Globe, symbolize Indian origin, routed through Bombay (now Mumbai) and Kandla ports of Maharashtra and Gujarat, respectively.

There are no native *Allium* species in Latin America. They were first introduced there at the end of 14th century. The most important *Allium* species in the region are: *A. cepa*, *A. sativum*, *A. ampeloprasum*; and *A. fistulosum* to some extent (Jaramillo, 1994). Onions were taken to North America by the first settlers from European continent. The first pilgrims brought onions with them on the *Mayflower*. They found, however, that strains of wild onions were growing across North America. Native American Indians were using wild onions in a variety of ways—eating them raw or cooked, for seasoning or as a vegetable. According to diaries of colonists in 1648, bulb-onions were planted as soon as the pilgrim-farmers could clear the land.

A. fistulosum originated in Asia, probably in Siberia or China, grown predominantly in Japan as welsh onions or Japanese bunching onions, and is adapted to severe winter and moist soils. Welsh onion produces long slender white stem, which is consumed; it does not produce bulb. By the end of 18^{th} century, Japan started growing bulb-onion varieties adapted to extreme long-day conditions.

Global scenario

Production – productivity

Onion is grown over an area of 43.64 lakh ha with a total production of 863.44 lakh tonnes, and a productivity of 19.79 tonnes per ha (Anonymous, 2013). World area under onion over a decade has increased from 28.43 lakh ha to 43.64 lakh ha; an increase of 53.49%. Production has increased 72.87%, from 499.46 lakh tonnes to 863.44 lakh tonnes, and productivity from 17.57 to 19.79 with a percentage increase of 12.63 (Fig.1.1).

Among various onion-producing countries, India leads in the area (11.10 lakh ha), followed by China (10. 15 lakh ha), and in production, China produces the maximum (247.65 lakh tonnes), followed by India (159 lakh tonnes). Highest productivity of onion has been reported from Republic of Korea (66 tonnes/ha), followed by the USA (56 tonnes/ha), Spain (53 tonnes/ha), Netherlands (51 tonnes/ha), Egypt (36 tonnes/ha), Iran (35 tonnes/ha) and Turkey (32 tonnes/ha) (Figs 1.2a, 1.2b).

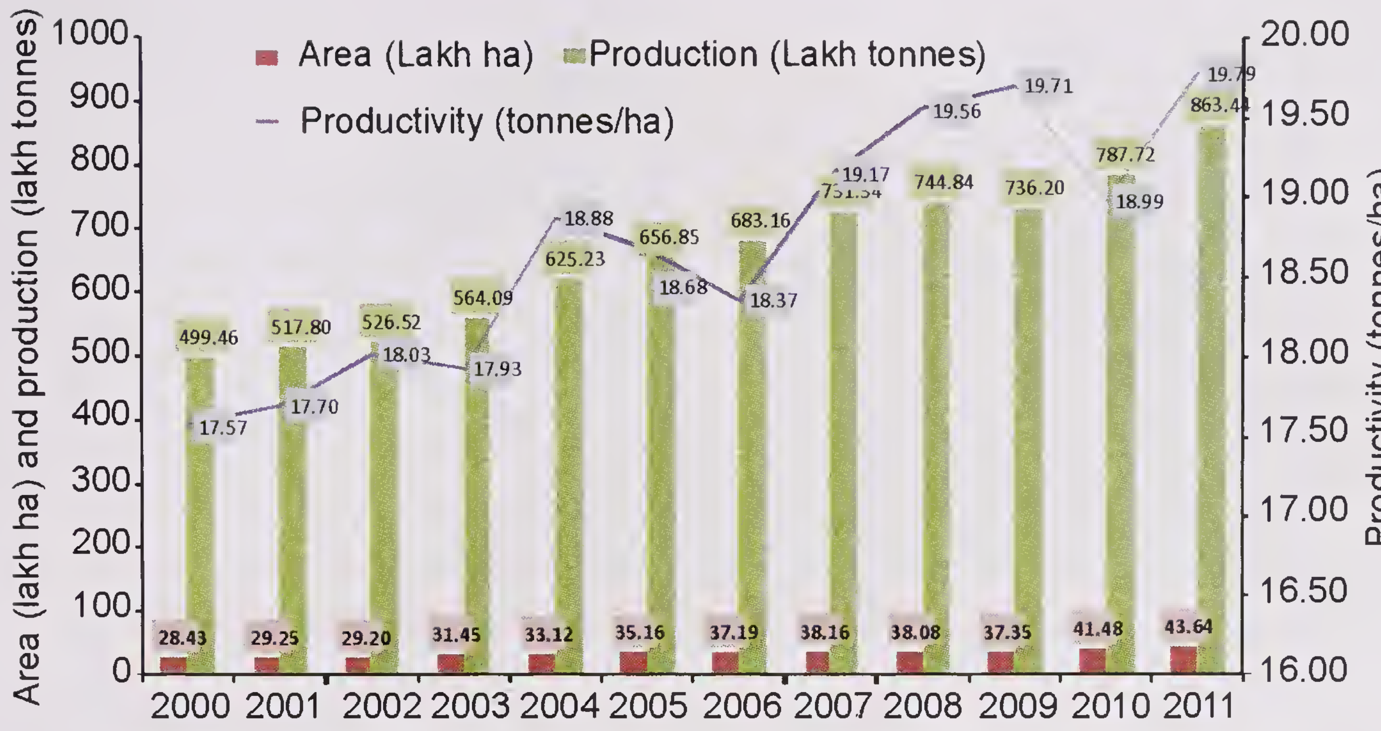

Fig.1.1 Year-wise area, production and productivity of onions in the world

The countries showing high productivity fall between 30° and 50° N latitudes where onion is a long-day crop, requiring more than 14 hours and duration of more than 180 days. Biomass development of onion is very high due to its high yield per unit area. Onion cultivation in India, contrary to above range, is predominantly between 12° and 25° N latitude, falling under subtropics to tropics. Here, varieties mature under short day (11–11.5 hrs) and short duration (90 to 120 days). These genotypes have inherently low yield potential, and this is the main reason for its low productivity in the country. However, management of proper production technologies has shown an increase in yield up to 40 tonnes per ha.

The world can be divided into four zones based on the adaptation of onion — Very long-day conditions; Long-day conditions; Intermediate long-day conditions; and Short-day conditions—distributed on both the sides of the equator (Fig.1.3). Under the first group, major onion-growing area is under short-day and long -to intermediate long-day conditions. Under long-day, onions are biennial while under short-day, they are annual. Intermediate long-day varieties can produce bulbs in short-day conditions during the winter but they do not produce seeds under short-day; they produce seeds only under long-day and cool temperature.

Trade

Global export of onion is of the tune of 6.77 million tonnes; worth 2,856 million US dollars. India has consistently been number one exporter of onion; exporting 1.11 million tonnes worth 370.73 million US dollars. Netherlands exports onions mostly to European countries. Besides India, China (0.74 million tonnes), Egypt (0.49 million tonnes), Mexico (0.37 million tonnes), USA (0.35 million tonnes), Spain (0.25 million tonnes), Argentina (0.21 million tonnes), Pakistan (0.1 7 million tonnes) and Turkey (0.12 million tonnes) also export sizable quantity of onions (Anonymous, 2013).

China can give a tough competition in future to India in onion trade in the world. Malaysia, Russian Fed, USA, Japan, UK, Saudi Arabia, Germany,

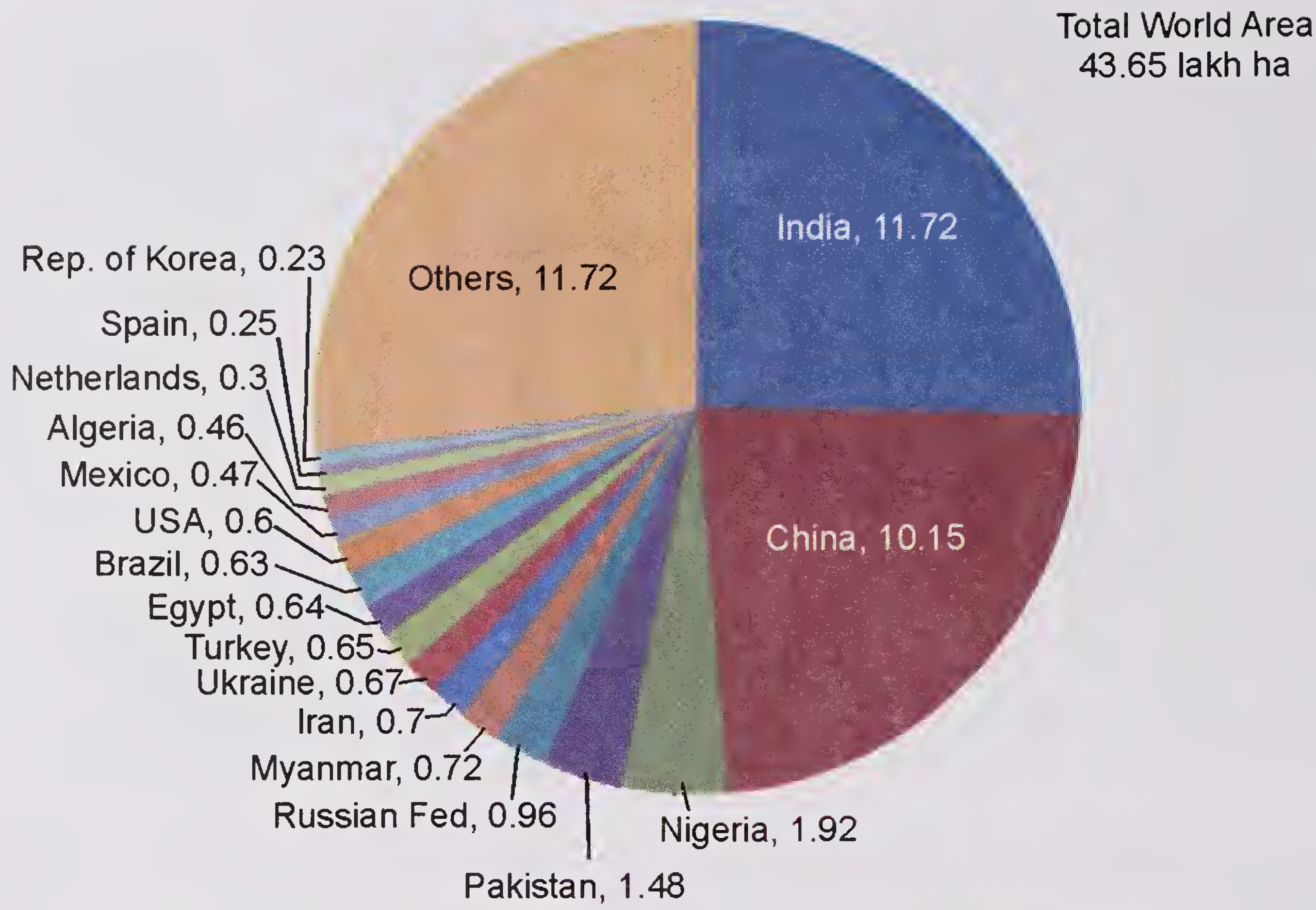

Fig.1.2a Area (lakh ha) in major onion-producing countries (2011)

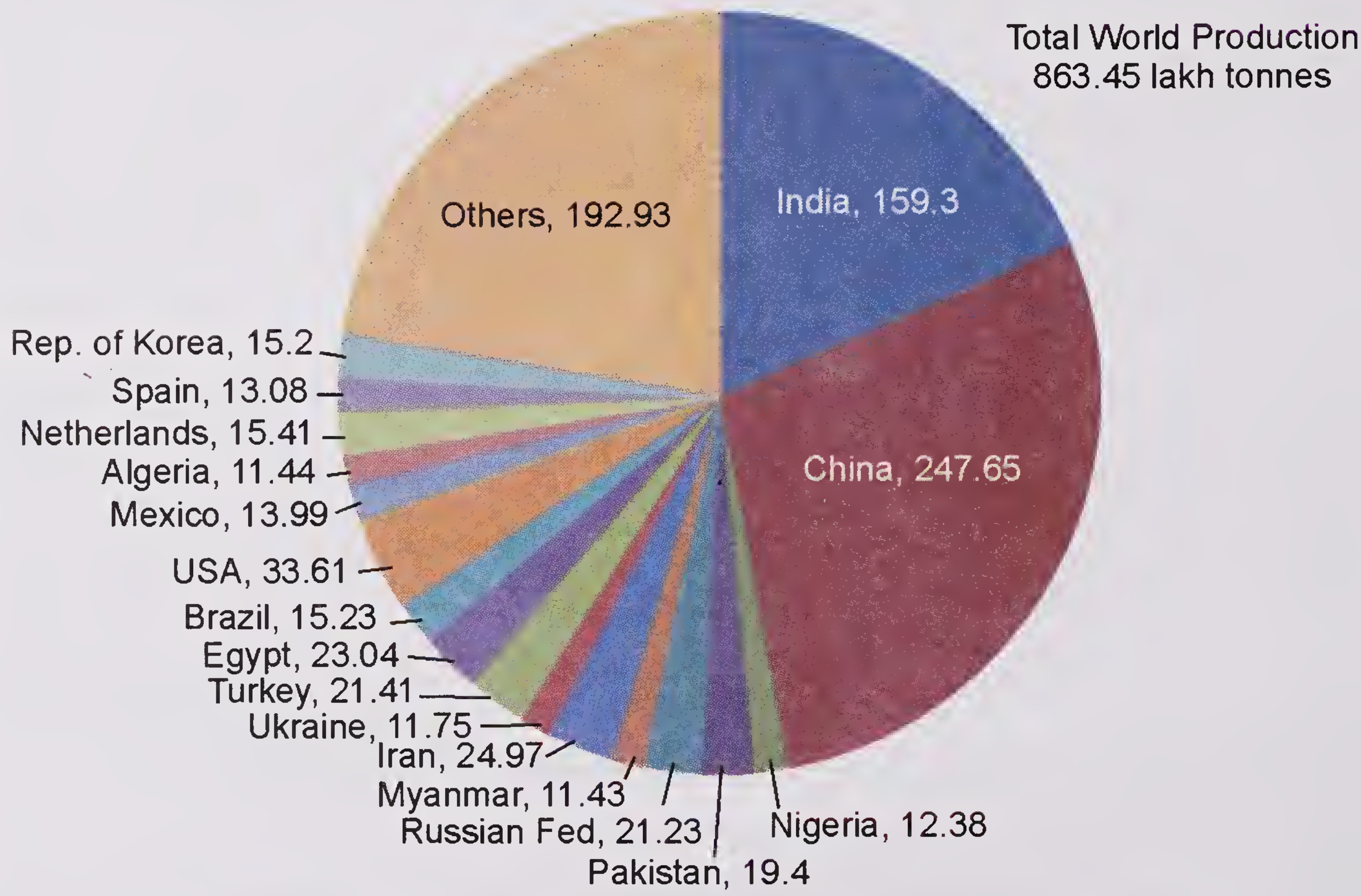

Fig.1.2b Production (lakh tonnes) in major onion-producing countries

Bangladesh, Canada, Sri Lanka, UAE, Colombia, Senegal, Belgium, France and Vietnam are the major onion-importing countries of the world. India exports 15 to 16 lakh tonnes of onion to Bangladesh, Malaysia, UAE, Sri Lanka, Indonesia, Singapore, Nepal, Oman, Kuwait, Qatar, Vietnam, Bahrain, Saudi Arabia and Mauritius. Export to European countries from India is also increasing steadily.

Pungent and tingling taste of Indian onions is famous in Middle East and South East Asian countries. Red, pink and white onions grown under short-day conditions in India are becoming popular in European countries.

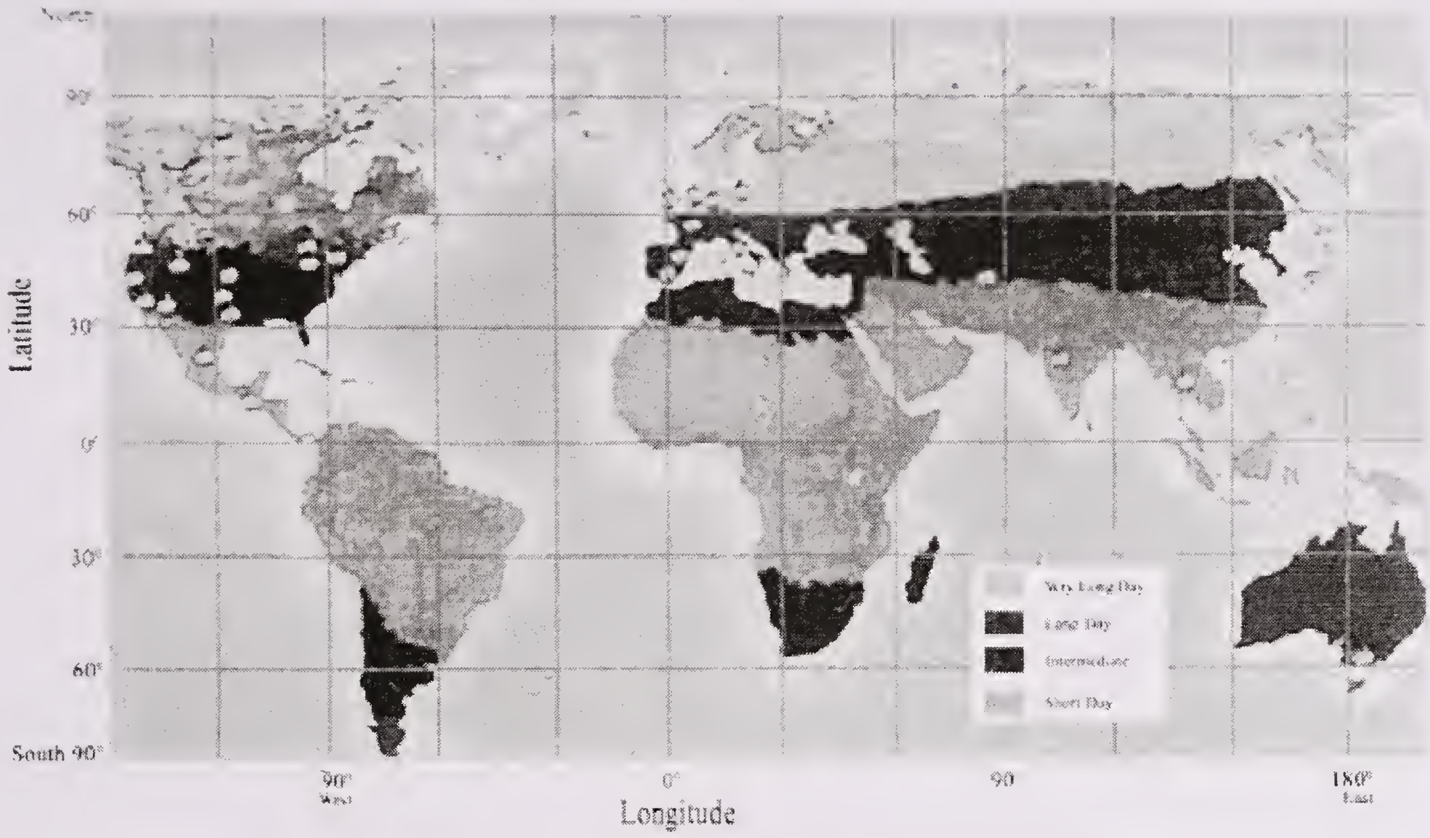

Fig.1.3 Adaption of the onion in the world

Present-day export of India can be doubled easily with systematic crop planning, infrastructure development for storage, grading, packing, transfer subsidy and strong and rigid national policy on onion export. There is a need for development of varieties exclusively for export for niche-area markets. Strengthening Agri-Export Zones for onions in potential production areas would enhance overseas trade of Indian onions.

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Onion R&D in India—Status and Prospects

2

J. Gopal and A.A. Murkute

In India, onion is grown in three crop seasons— *kharif,* late *kharif* and *rabi.* Its principal crop is in *rabi* (50–60%), and 20–25% each is in *kharif* and in late *kharif.* During 2011–12, total area under onion was over 9.92 lakh hectares with production of 166.54 lakh tonnes (Fig. 2.1) (Agricultural Statistics, 2013). Maharashtra, Karnataka, Gujarat, Bihar, Madhya Pradesh, Rajasthan, Andhra Pradesh and Tamil Nadu are the main onion-growing states. In general, barring north-eastern states and Kerala, all states grow onions. Country's 26% area and 29% production comes from Maharashtra alone (Agricultural Statistics, 2013). In addition to fulfilling domestic demand constantly, India exported 18.22 lakh tonnes of onion worth ₹ 2,294 crore in 2011–12 (NAFED, 2013). About 90% export of onion is from Maharashtra. In general, there is a critical shortage in arrival of onions in the market during November to January. From May to November stored onions are used for domestic as well as export purpose. November to December, *kharif* onions are available in the market and from January to March, late *kharif* onions from Maharashtra reach the market (Table 2.1). The productivity of late *kharif* and *rabi* crops is around 25 tonnes per hectare, and that of *kharif* crop is 8–10 tonnes per hectare. During *kharif,* cloudy weather and consistent drizzle cause diseases like anthracnose and bulb-rotting. In *rabi,* high thrips incidence aggravates the problems of purple-blotch and *Stemphylium*-blight.

R&D history of the crop

Systematic R&D in onions was started in 1960 at Pimpalgaon, Baswant, Nashik, and later at the Indian Agricultural Research Institute (IARI), New Delhi, and Indian Institute of Horticultural Research (IIHR), Bengaluru. The National Horticultural Research and Development Foundation (NHRDF), Nashik, was established by the National Agricultural Co-operative Marketing Federation of India Ltd (NAFED) and its Associate Shippers of onions on 3 November 1977 under the Society Registration Act 1860 at New Delhi, for carrying out research and development activities on export-oriented crops (NHRDF, 2011), to begin with was onion and garlic. Multiplier onion varieties were developed by the Tamil Nadu Agricultural University (TNAU), Coimbatore. Prior to this, research on collection and maintenance of landraces and standardization of agro-techniques was attempted by different State Agricultural Departments. With the concept of coordinated projects and Agricultural Universities, the work on the onion research was strengthened, in terms of varietal development for different seasons and standardization of production techniques in the early nineties. The R&D on onion

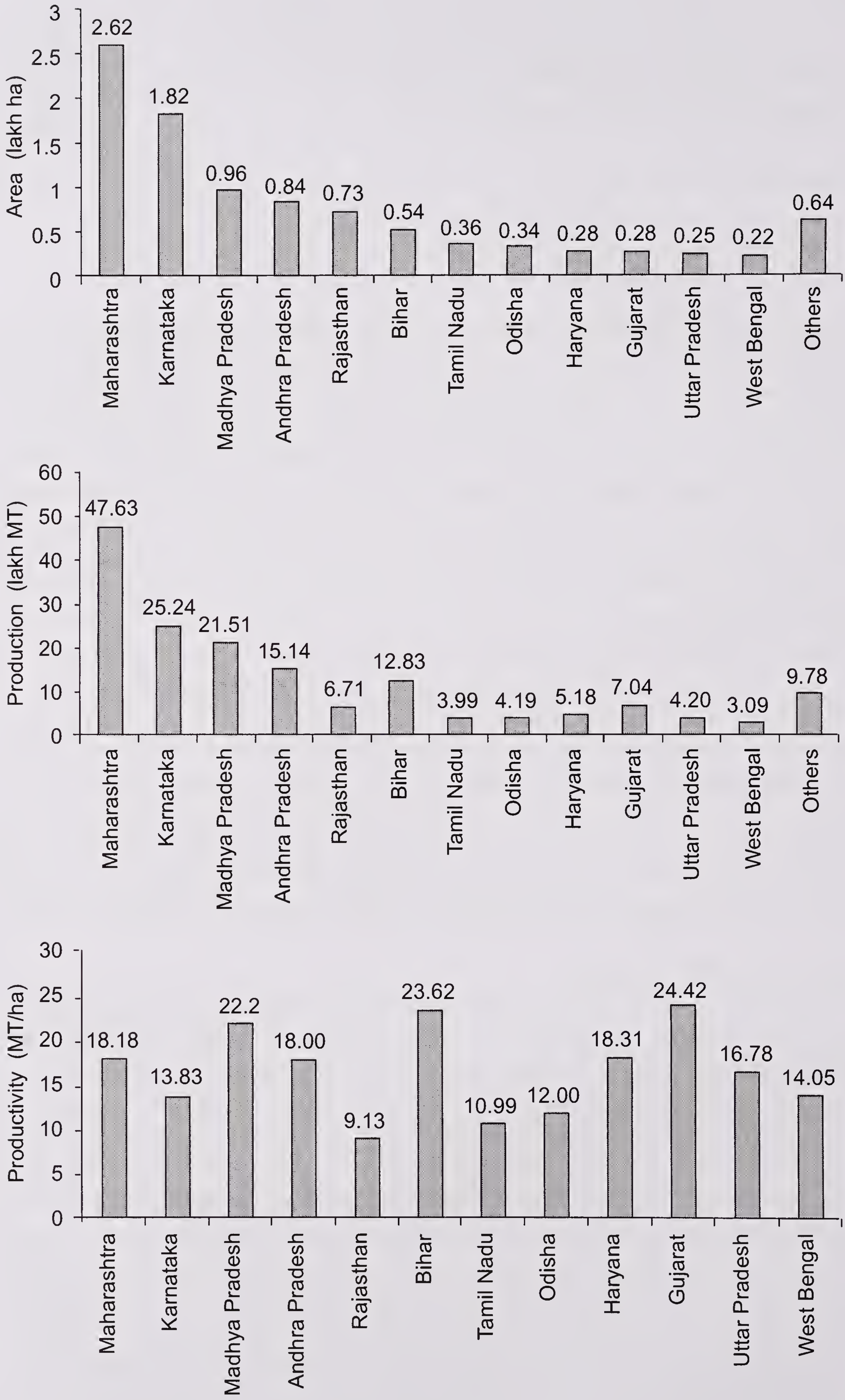

Fig. 2.1 Statewise area, production and productivity of onions in India during 2012–13 (*Source:* Agricultural Statistics, 2013)

Table 2.1 Crop calendar for onion

State	Season	Time of sowing	Time of transplanting	Harvesting calendar			
				Starting		Ending	
				Week	Month	Week	Month
Maharashtra and Gujarat	1. *Kharif*	May–June	July–August	First	October	Fourth	December
	2. Late *kharif*	August–September	September–October	Fourth	January	First	March
	3. *Rabi*	October–November	December–January	Second	April	Fourth	May
Tamil Nadu, Karnataka and Andhra Pradesh	1. Early *kharif*	March-April	April–May	Fourth	August	Fourth	September
	2. *Kharif*	May–June	July–August	First	October	Fourth	November
	3. *Rabi*	September–October	November–December	Second	March	First	April
Punjab, Haryana, Rajasthan, Uttar Pradesh and Bihar	1. *Kharif*	May–June	July–August	Third	November	First	December
	2. *Rabi*	October–November	December–January	Fourth	April	Fourth	May
West Bengal and Odisha	1. *Kharif*	June–July	August-September	First	November	Second	December
	2. Late *kharif*	August–September	October–December	Second	December	First	February
Hills	1. *Rabi*	September–October	October–November	First	July	First	August
	2. Summer (long-day type)	November–December	February–March	First	September	Fourth	October

Table 2.2 Institutions working on onion in India

Sl No.	Institutions	Major area of work
State Agricultural Universities		
1.	Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal	Crop production
2.	Chandra Shekar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh	Crop improvement
3.	ChaudharyCharan Singh Haryana Agricultural University, Hisar, Haryana	Crop improvement
4.	Dr PanjabraoDeshmukh KrishiVidyapeeth, Akola, Maharashtra	Crop improvement
5.	Junagadh Agricultural University, Junagadh, Gujarat	Crop improvement
6.	Mahatma Phule KrishiVidyapeeth, Rahuri, Maharashtra	Crop improvement
7.	Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan	Crop improvement
8.	Orissa University of Agriculture and Technology, Chiplima, Odisha	Crop improvement
9.	Punjab Agricultural University, Ludhiana, Punjab	Crop improvement
10.	Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan	Crop improvement
11.	Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu	Crop improvement
12.	University of Agricultural Sciences, Dharwad, Karnataka	Crop production
ICAR Institutes		
1.	Central Institute of Temperate Horticulture, Srinagar, Jammu and Kashmir	Crop improvement
2.	Directorate of Onion and Garlic Research, Pune, Maharashtra	Crop improvement, Crop protection, Crop production, Post-harvest management
3.	Indian Agricultural Research Institute, New Delhi	Crop improvement, Crop production
4.	Indian Institute of Horticultural Research, Bengaluru, Karnataka	Crop improvement, Crop protection, Crop production, processing
5.	National Horticultural Research and Development Foundation, Nashik, Maharashtra	Crop improvement, Crop protection, Crop production, Post-harvest management
6.	Vivekananda Parvatiya Krishi Anusandhan Shala, Almora, Uttrakahand	Crop improvement
Private Firms		
1.	BejoSheetal Seeds Pvt. Ltd, Jalna, Maharashtra	Crop improvement
2.	Jain Irrigation Systems Ltd, Jalgaon, Maharashtra	Processing
3.	Jindal Crop Science, Pvt. Ltd, Jalna, Maharashtra	Crop improvement

got impetus with the establishment of the National Research Centre on Onion and Garlic at Nashik in 1994. This was shifted to the present location at Rajgurunagar in 1998, and has been upgraded to the Directorate with the addition of an All-India Network Research Project on Onion and Garlic in 2008. Besides, concentrating on genetic improvement and biotechnology of onions, the institute's development work on several agro-technologies, including post-harvest management practices, has strengthened R&D of onions, besides supplementation of work by the NHRDF and some universities. At present, different state agricultural universities, ICAR institutes across the country and private companies (Table 2.2) are working on different R&D aspects of onions.

R&D status

Important aspects of status and prospects of R&D of onions are presented as follows.

Varietal improvement

The onion cultivation in India is continuing since time immemorial. As a result, a large numbers of landraces including some wild species are also traceable in India, particularly in the north-eastern states. This variability is being maintained at the national germplasm collection of onions at the DOGR, a National Active Germplasm site for onions (Table 2.3). Many farmers in various parts of the country are growing old onion landraces. For example, Pune Fursungi, a red coloured landrace, is cultivated in Nashik and Pune areas of Maharashtra in late *kharif* and *rabi*. Junagadh, Saurashtra and Mehsana areas of Gujarat are dominated by Pili Patti, a landrace, generally grown in *rabi*. Bellary Red, another red onion landrace, prevalent in Karnataka and Sukhsagar, is being cultivated in West Bengal. K.P. onions dominate in Andhra Pradesh and Nirmal Local occupies larger area in Madhya Pradesh. Further, multiplier type has been a unique feature in Tamil Nadu.

The varietal improvement programme began with the improvement of local varieties. Consequently, more than 50 varieties of onions, including 2 F_1 hybrids and 6 varieties of multiplier onions, have been developed and released

Table 2.3 Status of onion germplasm at NAG site (DOGR, Rajgurunagar)

Sl No.	Category	No. of accessions
1	Dark Red	274
2	Light Red	429
3	White	450
4	Yellow	50
5	Exotic onion	237
6	Wild species	12
		(i) *Allium altaicum* Pall.
		(ii) *Allium ampeloprasum* L.
		iii *Allium cepa* × *A. fistulosum*
		v *Allium cepa* × *A. cornutum* (PRAN)
		v *Allium chinense*
		vi *Allium flavum*
		vii *Allium fistulosum* L.
		viii *Allium galanthum*
		ix *Allium guttatum*
		x *Allium hookeri*
		xi *Allium schoenoprasum* var. *schoenoprasum*
		xii *Allium tuberosum*

(Table 2.4). Most of these varieties are mainly for *rabi* season. Development of some *kharif*-growing varieties was done earlier by the Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, NHRDF, Nashik and IIHR, Bengaluru, and later by the DOGR, Rajgurunagar. In 1980s work on hybrid breeding using male sterile lines was initiated by the IIHR Bengaluru. Only two onion hybrids 'Arka Kirthiman' and 'Arka Lalima' were released from the IIHR. But these were not found better than open-pollinated varieties and hence did not pick-up. Private companies have introduced some exotic hybrids in India but they are grown on a

Table 2.4 Onion varieties developed by different organizations

Organization	Variety	Bulb colour	Planting season	Year of release
Agril Dept, Maharashtra	N53	Red	*Kharif*	1975
	*N2-4-1	Red	*Rabi* and late *kharif*	1985
	*N257-9-1	White	*Rabi*	1985
MPKV, Rahuri	Baswant 780	Red	*Kharif*	1989
	Phule Safed	White	Late *kharif* and *rabi*	1994
	Phule Suvarna	Yellow	*Rabi* and late *kharif*	2001
	*Phule Samarth (S1)	Red	Late *kharif*	2006
IARI, New Delhi	Pusa White Flat	White	*Rabi*	1975
	Pusa White Round	White	*Rabi*	1975
	Early Grano (Long-day type)	Yellow	Late *kharif* and *rabi*	1975
	Brown Spanish (Long-day)	Brown	Hills	1975
	*Pusa Red	Red	Late *kharif* and *rabi*	1975
	*Pusa Ratnar	Red	*Rabi*	1975
	*Pusa Madhavi (Line 120)	Red	*Rabi*	1987
	*Selection 126	Brown	*Rabi*	2012
IIHR, Bengaluru	Arka Pragati	Red	*Kharif* and *rabi*	1984
	*Arka Niketan	Red	*Rabi* and late *kharif*	1987
	*Arka Kalyan	Red	*Kharif*	1987
	Arka Lalima (F_1 hybrid)	Red	*Rabi*	1993
	Arka Kirtiman (F_1 hybrid)	Red	*Rabi*	1993
	Arka Pitamber	Yellow	*Rabi*	2006
	Arka Bindu	Red	*Kharif,* late *kharif* and *Rabi*	2006
	Arka Ujjwal (multiplier onion)	Red	*Rabi*	2010
	Arka Swadista	White	*Rabi*	2010
	Arka Vishwas	Dark red	*Kharif* and *rabi*	2011
	Arka Sona	Yellow	*Rabi*	2011
	Arka Bheem (tri-parental synthetic)	Red	*Rabi*	2011
	Arka Akshay (tri-parental synthetic)	Dark Red	*Rabi*	2011

(Contd...)

(. . . Table 2.4)

Organization	Variety	Bulb colour	Planting season	Year of release
HAU, Hisar	Hissar 2	Red	*Rabi*	1976
	*HOS1	Red	*Rabi*	2006
NHRDF, Nashik	Agrifound Rose	Red	*Rabi*	1987
	Agrifound Red (Multiplier)	Red	*Kharif* and *rabi*	1987
	*Agrifound Light Red	Red	*Rabi* and late *kharif*	1988
	Agrifound White	White	*Rabi*	1994
	*Agrifound Dark Red	Red	*Kharif*	1996
	*NHRDF Red (L 28)	Red	*Rabi*	2006
	*NHRDF Red (L 355)	Red	*Rabi*	2012
VPKAS, Almora	VL 67 (Long-day)	Red	Hills	1973
	*VL 3 (Long-day)	Red	Hills	1990
RAU, Rajasthan	Udaipur 101	Red	*Rabi*	
	Udaipur 102	White	*Rabi*	
	Udaipur 103	Red	*Rabi*	
PDKV, Akola	*PKV White	White	*Rabi*	2009
GAU, Junagadh	Gujarat White Onion (GWO) 1	White	*Rabi*	2000
CSAUAT, Kanpur	Kalyanpur Red Round	Red	*Rabi*	1983
PAU, Ludhiana	Punjab Selection	Red	*Rabi*	1973
	*Punjab Red Round	Red	*Rabi*	1993
	Punjab 48 (S 48)	White	*Rabi*	1978
	Punjab White	White	*Rabi*	1998
	*Punjab Naroya (PBR 5)	Red	*Rabi*	1997
TNAU, Coimbatore	Co1 (Multiplier)	Red	*Kharif* and *rabi*	
	Co 2	Red	*Kharif* and *rabi*	1978
	Co 3	Red	*Kharif* and *rabi*	1982
	Co 4	Red	*Kharif* and *rabi*	1984
	Co 5		*Kharif* and *rabi*	
	MDU	Red	*Rabi*	1982
RARS, Durgapura	Rajasthan Onion1	Red	*Rabi*	2004
	Arpita (RO59)	Red	*Rabi*	2005
	RO 252	Red	*Rabi*	2010
DOGR, Rajgurunagar	*Bhima Super	Red	*Kharif*, late *kharif* and *rabi*	2006
	*Bhima Raj	Red	*Kharif* and *rabi*	2007
	*Bhima Red	Red	*Kharif* and late *kharif*	2009
	*Bhima Shakti	Red	Late *kharif* and *rabi*	2010
	*Bhima Kiran	Red	*Rabi*	2010
	*Bhima Shweta	White	*Kharif* and *rabi*	2010
	*Bhima Shubhra	White	*Kharif* and late *kharif*	2010
	*Bhima Dark Red	Red	*Kharif*	2012

*These varieties were released through All-India Coordinated Research Project on Vegetables or All-India Network Research Project on Onion and Garlic. Others were released by the institutes.

very limited scale, due to high seed cost, poor storability under Indian conditions and not much advantage in terms of yield and uniformity in bulb characters. Some new hybrids, developed in the country, are under evaluation.

Biotechnology

For crop improvement, biotechnological approaches are used as contemporary tools. For onions in India, however, these approaches are still in their nascent stage. The Directorate of Onion and Garlic Research has taken lead, and has been successful in standardizing protocols for direct and indirect *in-vitro* regeneration of onions. A preliminary understanding of development of onion haploid through *in-vitro* gynogenesis has been achieved (DOGR, 2012). Molecular markers (RAPD, ISSR and SSR) have been identified to estimate genetic diversity in onion and related wild Alliums.

Production technologies

Technologies and practices have been developed for various stages of onion-crop, from sowing to harvesting. Interventions in R&D for production technologies are dynamic. The DOGR and other institutions have standardized cultural practices for onion cultivation. Some important practices are outlined as follows.

Seed priming and nursery management

Being a biennial crop, onion-seeds need to be stored at least for a season. The seeds are known for poor storability, which sometimes results in poor germination. Solid matrix priming and halo priming with 0.3% KNO_3 or coating with Royalflo enhanced field emergence with more than 75% germination in seeds stored for nine months (IARI, 2010). Treatment of seeds with glycine betaine (2.5, 5%) increased yield by 14–19%; and its foliar spray by 12–18% (IIHR, 2010). Seed treatment with vermiwash was recommended at the University of Agricultural Sciences, Dharwad, Karnataka (Jawadagi *et al.*, 2008), as the freshly harvested onion-seeds treated with vermiwash recorded significantly higher germination (80.6%), numerically high growth rate index (19.3), shoot length (8.5 cm) and seedling drymatter accumulation (22.3 mg). Coating per kg of onion-seed with DAP (30 g) + Borax (0.1 g) + Carbendazim (3 g) was found suitable for 40% higher bulb yield. During *kharif*, karanj leaf powder (500 g/kg of seeds) gave higher seed germination (NHRDF, 2011). Gypsum in combination with cow-dung or clay or neem or vermi-compost powder (1 : 1 v/v) was used for pelleting onion-seeds; but germination of pelleted seeds was noticed to be at a par with non-pelleted seeds (IIHR, 2010).

During harvest and post-harvest operations, onion-seeds may be infected with storage fungi, *Penicillium, Aspergillus,* etc. Anthracnose, caused by *Colletotrichum gleosporiodes,* has also been reported to be seed-borne (DOGR, 2012). Umbels treated with systemic fungicide (Iprodione + Bavistin @ 0.2% before harvesting) yielded disease-free seeds. Their germination test showed seedling vigour more than other treatments, i.e. Mancozeb, neem oil etc. and control (DOGR, 2012). Seed treatment with *Trichoderma viride* @ 4 g/kg of seeds, followed by soil application of *T. viride* @ 1,250 g/ha mixed with 50 kg FYM was useful in reducing damping-off disease in the nursery. Soil application of copper oxychloride @ 0.25% was adjudged as an alternative treatment to Bavistin (NHRDF, 2011).

To raise a nursery for sowing onion by transplanting in a hectare, 0.05 hectare would be sufficient. Depending on the variety, 6–8 kg of seeds would be sufficient to cultivate 1 ha by traditional transplanting method. Beds used for raising seedlings should be 10–15 cm high with 1 m width and length as per convenience. The distance between the two beds is kept at 30 cm to facilitate intercultural operations. Seeds are sown in rows manually at 10–15 cm distance and are irrigated preferably by drip or sprinklers. Pendimethalin 30 EC, a pre-emergence herbicide, @ 2 ml/litre at the time of sowing seeds in the onion nursery controlled weed population effectively compared to other herbicidal sprays (DOGR, 2012).

Seedling transplanting and crop geometry

About 45–50 days old nursery becomes ready for transplanting in *rabi* and in 35–40 days in *kharif*. Uprooted seedlings are cut one-third from the top. Seedlings are dipped in a solution of Carbosulfan (2 ml/litre) and Carbendazim (1.5 g/litre) for two hours and then gently pressed in the soil. For proper growth of the seedlings, ample nutrition is indispensable. Thus, crop geometry is vital for ensuring optimum crop density in the field. In *rabi,* transplanting in flat beds (2m × 3 m) at 10-cm plant-to-plant spacing with 15-cm row-to-row spacing is recommended. In *kharif,* crop geometry of 12 rows at 10 cm distance on broad raised beds of 15 cm height and 120 cm width is recommended (Lawande, 2011). At the University of Agricultural Sciences, Dharwad, Karnataka, maximum plant height and leaf length in cv. Bellary Red was recorded with 15 cm × 7.5 cm spacing, followed by 15 cm ×10 cm spacing (Jawadagi *et al.*, 2012). Bulb yield, net returns and benefit: cost ratio were maximum when crop at 15 cm × 10 cm spacing was given 12.50 tonnes of FYM/ha + 2 tonnes of vermi-compost/ha + 5 kg of biofertilizers/ha.

Cropping sequence and intercropping

Intercropping assures profit even if one crop fails due to natural vagaries, and cropping sequence maximizes utilization of soil fertility with optimum productivity. Sugarcane-based intercropping with onion has been suggested (NRCOG, 2004). Soybean in *kharif,* followed by onion in *rabi*, groundnut in summer, followed by onion in late *kharif* or *rabi* has been recommended (NRCOG, 2006). Soybean in *kharif,* followed by onion in *rabi* has been found more remunerative and cost-effective than other sequences — groundnut-onion and maize-onion (DOGR, 2012).

Integrated nutrient management

Removal of nutrients by the onion-crop depends mainly on the variety, soil condition, quantity of fertilizers applied, season and bulb yield. Integrated nutrient management is an approach for fulfilling nutrient requirements of the crop at an appropriate time in an optimum quantity with a proper mode of application. It is an integration of many practices. An onion-crop with a bulb yield of 35 tonnes/ha approximately removes 120 kg nitrogen, 50 kg phosphorus and 160 kg potash (Tandon, 1987). However, experiments conducted at Rajgurunagar showed that onion-crop removed 90–95 kg N, 30–35 kg of P_2O_5 and 50–55 kg of K_2O to yield 40 tonnes of onion-bulbs/ha (DOGR, 2012). FYM @ 20 tonnes/ha + neem-cake @ 1 tonne/ha + S @ 20 kg/ha + NPK @ 50: 50: 50 kg/ha as basal application and spray of polyfeed @ 1% at 30 and 45 DAP and multi K @ 1% at 60 and 70 DAP enhanced bulb yield (NHRDF, 2011). Application of 75% of the recommended fertilizer dose (RDF), FYM (5 tonnes), poultry-manure (2.5 tonnes) and vermicompost (2.5 tonnes)/ha gave marketable bulb yield with nutrient content and uptake equal to 100% RDF (150: 50: 80: 50 kg NPKS/ha) + 20 tonnes FYM/ha or 100% RDF alone (DOGR, 2012). Nitrogen 110 kg/ha in three splits — at the time of planting and 30 and 45 DAP —with basal application of phosphorus (40 kg/ha), potash (60kg/ha) and sulphur (40 kg/ha) has also been recommended (AINRPOG, 2013). Use of cytozyme @ 0.2% as a root-dip before transplanting, followed by foliar sprays (0.2%) at 15, 45 and 75 days after transplanting led to higher onion yields (NHRDF, 2011).

Supplementation of chemical fertilizers with biofertilizers proved to be beneficial for onion-crop (Yogita and Ram, 2012). Maximum plant height, number of leaves, neck thickness, bulb diameter, bulb weight, number of scales and yield and minimum number of days required for bulb formation and number of days taken to maturity were recorded with 100 kg N + 50 kg P + 70 kg K/ha + 2 kg/ha *Azotobacter* + 1.9 kg/ha VAM. Biofertilizers, *Azospirillum* and *Azotobacter,* increased growth and yield compared to control (Sharma *et al.*, 2010).

Application of plant hormones to enhance quality of onion-bulbs was evaluated at the Anand Agricultural University, Gujarat (Patel *et al.*, 2010). GA_3 50 mg/litre as root-dip, followed by foliar spray significantly increased bulb volume, equatorial and polar diameters of bulbs as well as yield. Dipping roots in NAA 100 mg/litre was found effective to reduce physiological weight loss, spoilage loss, and finally total loss.

Subbarao *et al.* (2011) advocated green manuring with sesbania, cowpea, berseem, wild indigo, greengram, blackgram and *dhaincha*. Under organic production system, foliar application of Panchgavya (5%) at 30, 45 and 60 days after planting improved marketable onion-bulb yield (20.2 tonnes/ha) (DOGR, 2011b, 2012). This was the best among various organic growth stimulants—Panchgavya, Dashparni, Amrutparni, Vermiwash, Seeweed extract, EM Solution, Humic acid, Bio-Potash and microbial extract.

Irrigation and fertigation

Irrigation requirement of the crop depends on the season, soil type, method of irrigation and crop age. Onion being a shallow-rooted crop needs light irrigation frequently to maintain optimum soil moisture for proper growth and development. Water deficit at the crucial growth stages reduces crop productivity. Excess irrigation decreases yield, besides enhancing post-harvest losses. At the Bidhan Chandra Krishi Viswavidyalaya, Mohanpur (West Bengal), irrigation at 0.55 atmospheric tension at 6–8 day intervals to cv. Sukhsagar gave highest yield (19.90 tonnes/ha) (Deb *et al.*, 2009). In cv. Telagi Red, bulb yield (54.91 tonnes/ha), number of leaves, leaf area, leaf area index and neck girth per plant and equatorial diameter, polar diameter and bulb weight were significantly higher when field was irrigated at a day's interval at 100% pan evaporation (PE) at the University of Agricultural Sciences, Dharwad (Karnataka) (Bagali *et al.*, 2012).

Onion fields need to be irrigated 8 hr before transplanting for proper establishment of the crop (NHRDF, 2011). With drip irrigation significantly higher marketable bulbs were produced compared to other irrigation methods. And there was around 30% saving in water with drip system than the surface system. Highest water-use efficiency (770 kg/ha cm) and minimum storage losses were recorded in drip system, followed by sprinkler (386.5 kg/ha cm), and the lowest efficiency was with surface irrigation (252.5 kg/ha-cm). B: C ratio was highest in drip irrigation (1.98), followed by surface irrigation (1.35) (Tripathi *et al.*, 2010). To maximize fertilizer-use efficiency in onions, drip fertigation with organic manures (FYM@7 tonnes/ha, poultry-manure @ 3.5 tonnes/ha and vermi-compost @ 3.5 tonnes/ha) and 80% recommended dose of water-soluble fertilizers was recommended (DOGR, 2012).

Weed management

Frequent application of irrigation and fertilizer to the onion-crop favours severe crop-weed competition. The crop exhibits greater susceptibility to weeds in comparison to most other crops, mainly due to slow growth of the crop at the initial growth stages and also owing to its inherent characteristics such as short stature, non-branching, sparse foliage and shallow-root system. At Navsari Agricultural University, Gujarat, major weed flora was recorded in onion (Vashi *et al.*, 2010) —Monocot weeds were *Cynadon dactylon* (L.) Pers., *Echinochloa crusgalli* L., *Sorghum halpense* L., *Echinochloa colonum* Link and *Digitaria obsendens* Scop, and dicot were *Phyllanthus maderaspatiensis*, *Ephorbia hirta* L. *Amaranthus viridis* L., *Digera arvensis* Fork., *Trianthem aportulacastrum* L., *Convolvulus arvensis* L. and *Physalis minima* L.

Chemical weed control along with cultural methods is inevitable because of labour scarcity. At the Bidhan Chandra Krishi Viswavidyalaya, West Bengal, hand-weeding at 40 days after transplanting along with the application of quizalofop-ethyl 5% EC at 2.5 ml/litre of water at 20 DAP significantly reduced weed density (25.5) and dry weight (55.3 g). It also resulted in highest bulb diameter (4.09 cm), bulb weight (13.42 kg) and bulb yield (335.64 q/ha) in cv. Arka Kalyan (Yumnam *et al.*, 2009).

Spray of Oxyflurofen 23.5% EC @1.5ml/litre before planting of bulbs and one hand-weeding at 55 days after transplanting showed good weed-control efficiency (73.6%), higher marketable bulb yield (36.1 tonnes/ha) and highest B: C ratio (2.54) (DOGR, 2011b). Pendimethalin @ 0.75 kg/ha at pre-emergence stage and at 30 days after transplanting was promising for weed control (IARI, 2010). Rice-straw mulch + Pendimethalin @ 3.5 litre/ha at 3DAP was found better weed control measure and gave higher bulb yield during *rabi,* and alternatively, wheat-straw mulch + Oxyfluorfen @ 0.15 kg a.i./ha proved effective (NHRDF, 2011).

Pest and disease management

Insect-pests and diseases are biotic stresses, which are a major hurdle in reaping bumper onion-crop. An Integrated Pest Management (IPM) module for controlling pests and diseases has been recommended for the crop (DOGR, 2011a). It consists of seed treatment with Thiram + Carbendazim (2: 1) @ 3g/kg of seeds or *Trichoderma* @ 4–6 g/kg of seeds. Multiplying 2 kg of *Trichoderma* in one quintal of FYM and applying in one hectare is also recommended for controlling soil-borne pathogens. Dipping seedlings in 0.025% Carbosulfan + 0.1% Carbendazim solution for 2 hours before transplanting in the main field is suggested to control insect-pests in the nursery. Spray of Mancozeb @ 0.25% or Chlorthalonil @ 0.25% or Iprodione @ 0.2% or Propiconazole @ 0.1% has been recommended to control purple-blotch and *Stemphylium* blight in the standing crop (DOGR, 2011b).

Onion thrips (*Thrips tabaci* L.) is a potential pest of onion, and almost 100% fields have been known to be infested with it worldwide (Krishnakumar *et al.*, 2011). In Maharashtra, the state with the largest onion-growing area in India, yield losses were reported up to 50% in *rabi* if thrips were not controlled. Thrips infestation predisposes onion-crop to purple-blotch (*Alternaria porri*). According to a study at the DOGR, two population peaks —first one in the month of August and the other in January-February—occur in Maharashtra. Crop barriers with outer two rows of maize or an inner row of wheat with an outer row of maize (Fig.2.2) were found to block 80% infestation, as thrips are weak flier (Srinivas and Lawande, 2006). In *rabi,* estimated threshold level for thrips was 30 thrips/plant, and the highest B : C ratio of chemical control was achieved when thrips were controlled between 45 and 75 days of planting (Srinivas and Lawande, 2008). Minimum thrips population (0.28/ plant) and almost 99% reduction in their incidence was recorded over control with foliar spray of Imidacloprid at the Rajasthan Agricultural University, Rajasthan (Bhargava, 2010). The maximum bulb yield (32.89 tonnes/ha) was recorded in treatment with foliar sprays of Imidacloprid (Confidor 200SL) at 20 g a.i./ha, which was at a par with seedling root-dip in Imidacloprid, followed by foliar spray of Imidacloprid (315.46 q/ha). Maximum cost: benefit (1: 39.97) ratio was in treatment with Imidacloprid. Considering Imidacloprid spray as a protective treatment (avoidable loss: 0%), control proved non-protective with 54.08% of avoidable losses.

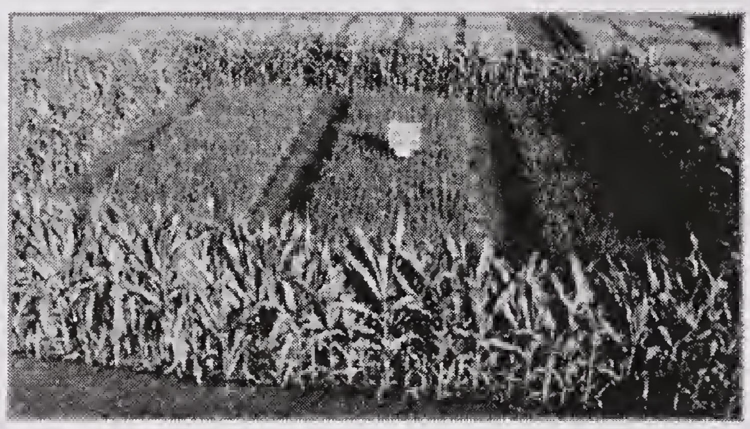

Fig. 2.2 Barrier cropping with maize

Six sprays of Spinosad @ 1ml/litre at a weekly interval or three sprays of Fipronil @ 1.5 ml/litre at 15 days interval were effective in managing thrips population and giving 25% more marketable yield than control during *rabi* (NHRDF, 2011). Insecticidal spray of Dimethoate @ 0.06% or Monocrotophos @ 0.05% or Profenofos @ 0.05% or Carbosulfan @ 0.05% or Cypermethrin @ 60 g a.i./ha or Methomyl @ 0.05% or Spinosad @ 56 g a.i./ha was recommended to control thrips. Spraying at bulbing stage (45–75 DAS) was found crucial for minimizing losses (DOGR, 2011b).

Interventions for kharif *onion production*

Kharif onion productivity is very low (10 to 12 tonnes/ha) owing to high incidence of foliar as well as soil-borne diseases and weed population. A technology has been standardized for enhancing its productivity. It includes nursery-raising in summer on broad-bed furrows (BBF) with drip or sprinkler under shade-nets with seedlings ready for transplanting in the first week of June; transplanting of seedlings on the BBF; application of FYM or vermi-compost pre-mixed with *Trichoderma viride* before bed preparation; and application of pre-emergence weedicides. Fertigation through drip help avoid nutrient losses through leaching, which is common in high rainfall areas. This technology ensures 25 tonnes/ha without affecting quality of bulbs (DOGR, 2011a). Fortnightly schedule of Mancozeb was effective for managing foliar diseases of onion during *kharif*; recorded disease incidence of 35% and yield of 30 tonnes/ha as against disease incidence of 45% and yield of 16.67 tonnes/ha in control (IIHR, 2010).

Sets technology

Onion production through sets is practised in *kharif* when planting coincides with heavy showers and nursery-raising is difficult due to hot-and-humid weather in May. Onion-sets (small bulblets) being much larger than seeds have higher vigour than transplanted seedlings and result in early establishment, thus crop grows successfully even in less favourable conditions. Sets have a shorter growing season than plants from seeds and transplants, and therefore can be exploited when a rapid or early season production is required.

Seeds are sown in the last week of January on the raised beds @ 15 g/m^2 to harvest onion-sets in the third week of May. Sets are graded and stored at room temperature in a ventilated storage structure till their field planting. Different groups of sets are planted in mid-July on the raised beds. Sets of 2 to 2.5 cm size planted at 30-cm spacing in the last week of August on ridges gave highest yield and net returns (NHRDF, 2011). Closer distance planting (15 cm ×10 cm) was found more beneficial regarding marketable bulb yield, net income, cost: benefit ratio and cost of cultivation (Singh and Singh, 2002). Planting sets on sandy-loam soil by flat system and ridge- and- furrow system resulted in an average bulb yield of 13.2 and 12.0 tonnes/ha, respectively, compared to 9.6 tonnes/ha in broad-bed system (Sharma *et al.*, 2003). The bulb-crop from the sets during *kharif* recorded highest yield and better bulb development with potash@ 50 kg/ha as basal + foliar application of sulphate of potash @ 1% at 30 to 40 days after planting (DAP) along with nitrogen @ 150 kg/ha and phosphorus @ 50 kg/ha (NHRDF, 2011).

Farm mechanization

Shortage of labour at a crucial time and also increased labour cost make farm mechanization inevitable for the crop. Mechanization is mainly required for sowing, transplanting and harvesting. Direct seed sowing during *kharif* as well as *rabi* with local machine and pneumatic seed-drill (imported by the CIAE, Bhopal, from Italy) (DOGR, 2013) was compared with manual sowing (broadcasting) and seedling transplanting methods (Fig. 2.3). Among various direct sowing

Fig. 2.3 Different sowing methods for onion
(a) Broadcasting; (b) Poona seed-drill; (c) Pneumatic seed-drill

methods, bigger bulbs, more A grade bulbs percentage and less double bulbs were observed with pneumatic seed-drill. Transplanting recorded highest marketable yield; was significantly higher over pneumatic seed-drill. Low seed rate, easy sowing, saving in time and early maturity of onions were observed with pneumatic seed-drill. The lowest marketable bulbs were observed with Poona seed-drill, followed by manual sowing (broadcasting).

A six-row tractor-operated onion transplanter for flat-bed was designed and fabricated (IIHR, 2010). The six-roller wheels pressed roots of the seedlings in the soil and shovels covered them with soil. The row spacing in the prototype was 15 cm and seedling spacing was 10 cm. Its expected working speed was 1 km/hr and field capacity was 0.8 ha/day.

Manual onion harvesting is drudgery, and thus mechanized harvesting is of utmost importance. Prototype of onion digger, with length 1.2 m, speed ratio 1.25: 1 and slope of elevator 15 degrees, performed with digging efficiency of 97.7% and separation index of 79.1%, and showed minimal bulb damage of 3.5%, and low fuel consumption of 4.1 litres/ha and draft of 10.78 kN (Khura *et al.*, 2011). Onion detopper was designed and developed at the Haryana Agricultural University, Hisar, to facilitate digging and top removal (Rani and Srivastava, 2012). Onion-bulbs were fed through a chute-type feeding unit to belt conveyor moving at a speed of 0.53 m/s which ensured uniform transport of bulbs to an conveyor. The cutter was provided at the downward side of the conveyor. The speed of the cutter could be varied and output capacity was 300 kg/hr with the detopping efficiency 79%. The belt conveyor had two rollers and an endless conveyor belt.

To mechanically extract onion-seeds, experiments were conducted with spike-tooth extraction mechanism in a laboratory test set-up (IARI, 2010). The mechanism gave extraction efficiency of 98.93% and cleaning efficiency of 97.07%. The seed loss ranged between 2.15% and 3.08% at cylinder speeds of 3–5 m/s. Seed extraction cost by mechanical seed extractor and manual/conventional method was ₹ 1,800 and ₹ 9,000 per tonne of onion-umbel, respectively. Break-even point for seed extractor was 78.77 hr (31.51% of annual utility), and it's payback period was 2.4 years.

Post-harvest handling and storage

Although, pre-harvest cultural practices such as fertilizer application, irrigation, etc. have profound role on storage life of bulbs, these factors cannot be managed easily. So, proper post-harvest management practices become imperative. Comprehensive studies indicated that post-harvest losses can be to the tune of 45–50% if the proper care of the harvested produce is not taken. In storage, *kharif* onions are more prone to losses than late *kharif* and *rabi* produce. Total losses, which include physiological loss of weight, rotting and sprouting, reached almost 70% in *kharif* after three months of storage (DOGR, 2013). Light red varieties have more storability than dark red and white bulb varieties (Tripathi and Lawande, 2010). Besides, varietal difference, losses in storage were also found related to bulb size, neck thickness and neck length. Curing is an important post-harvest management operation that impacts storage. Windrow method of field curing for 3–5 days, followed by shade curing for 7–10 days has been recommended. Curing bulbs under poly-tunnel in *kharif* and pits in *rabi* was effective in reducing losses. Artificial curing in curing chamber with a full load at 35°C temperature and airflow velocity of 3.2 m/s cured bulbs efficiently. These bulbs were superior in storage as compared to curing under ambient conditions during *kharif* (NHRDF, 2011).

Grading of bulbs improves marketability of the produce; hand-grading is an expensive operation. To reduce grading cost and increase precision, two onion graders—manually operated and motorized graders (Fig. 2.4)—were designed and evaluated (Tripathi and Lawande, 2009). They increased efficiency by 5 and 20 times, respectively, over hand-grading. Grading precision achieved by graders is 98% as against 50% in hand-grading. Capacity of manual grader is 5 quintals per person per hour with 90% accuracy, and that of motorized grader is two tonnes per hour with 90% accuracy.

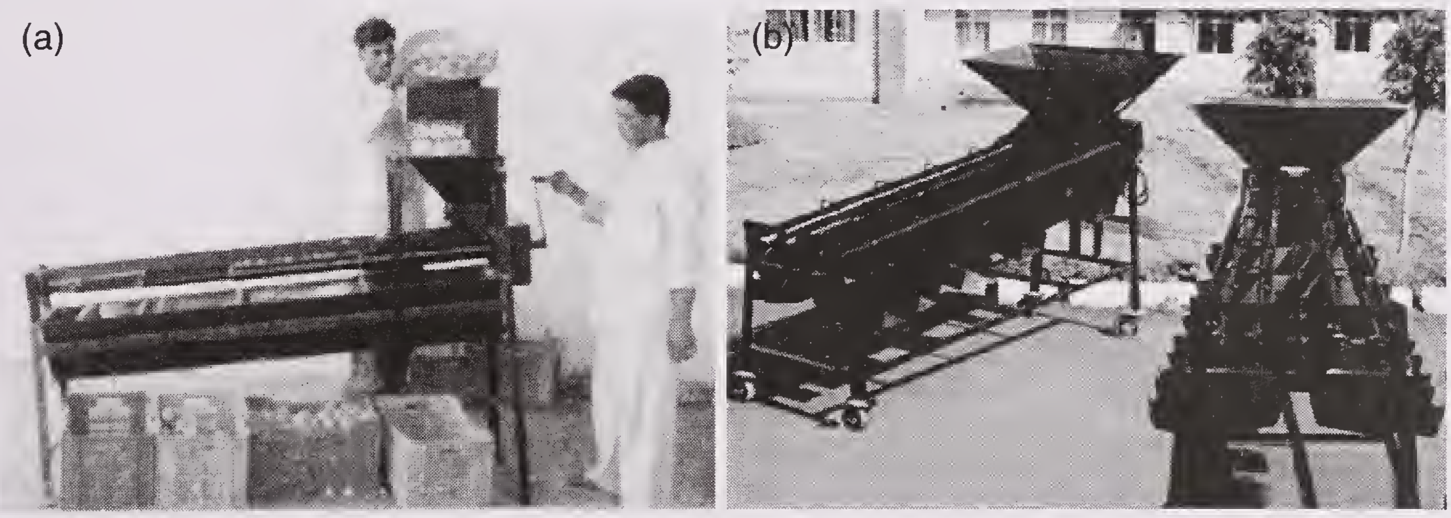

Fig. 2.4 Hand-and motor-operated grading machines developed by the DOGR (a) Hand-operated onion-grader; (b) Motorized onion-grader

A trial was conducted to assess the effect of different storage structures — traditional, bottom-ventilated, mud-plastered and chain-linked structures (Fig. 2.5). And packing materials—stakes, hessain cloth bags, netlon bags and plastic crates—were compared for packaging. Mud-plastered top and bottom ventilated storage structures were superior in reduction of losses (weight loss, rotting and sprouting) over other structures irrespective of the packing materials. Among single-row structures, low-cost bottom-ventilated structure was found the best in curtailing losses and increasing net profit. Low-cost storage model of 5 to 10 tonnes capacity

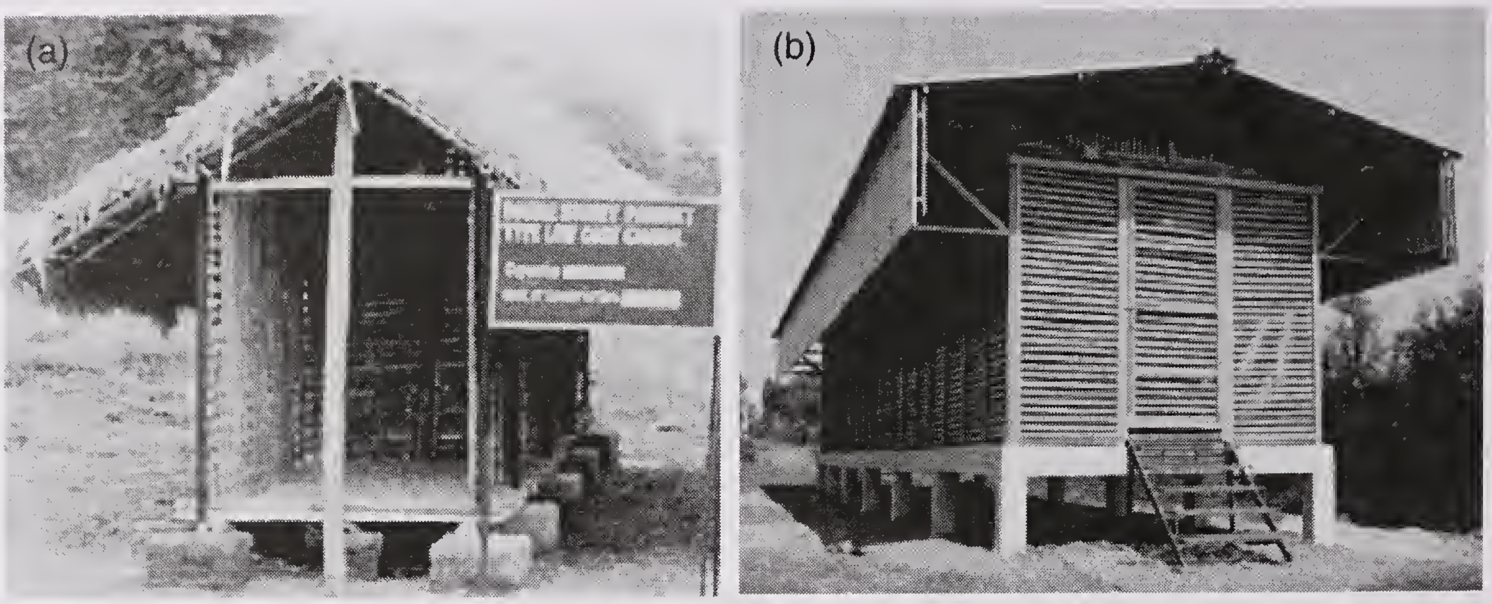

Fig. 2.5 Onion storage structures
(a) Low-volume, low-cost structure; (b) High-volume bottom and side-ventilated structure

and high cost model of 25 to 50 tonnes capacity with bottom and side ventilation recommended by the DOGR have become quite popular among farmers (Murkute and Gopal, 2013). Considering minimal storage losses, subsidy is being advanced for these models by different state governments. Cold storage is most efficient to restrict physiological weight loss, but its conduciveness for sprouting restricts its use. To restrict sprouting, use of gamma irradiation has been advocated in cold storage (Tripathi and Lawande, 2011).

Processing

Processing increases shelf-life without compromising freshness and quality of the produce. It adds value to the finished product and increases consumers' preference. Based on the recovery and quality of red and white onion flakes, cabinet-drying method has been recommended (DOGR, 2011b). White onions gave higher recovery (11.17%) than red onions (10.12%). While sun-drying of onions in open results in scorching and it turns them brownish in colour. Time required is maximum for sun-drying in open, followed by solar-drying in glass cabinet and is minimum in electrical cabinet-drying. Cabinet-dried onion flakes showed overall acceptability score for colour on the Hedonic scale, followed by solar-and sun-dried flakes. Cabinet-dried onion flakes are with superior shelf-life of flakes and also in rehydration ratio. Bulk trial on white onion dehydration using 50 kg lot indicated that dried onion yield of 9.9% on the fresh weight basis could be obtained. Sensory evaluation studies using 9-point Hedonic scale revealed that curry prepared with dehydrated onions was acceptable in colour, taste/ pungency and texture compared to fresh and rehydrated samples. Dried white onions in three different packages at the end of 6 months storage period— PET jar (100g), 150-gauge polyethylene pouch and plastic pallet— at room temperature showed that samples in PET jar and plastic pallet retained original colour, while samples packed in polythene pouch turned brown (IIHR, 2010).

Peeling of onions is essential to prepare dehydrated onions, onion powder, onion flavouring, onion salt, onion rings, and pickled and canned onions. The Central Institute of Agricultural Engineering, Bhopal, has developed a batch-type multiplier onion peeler (Naik *et al.*, 2007). Multiplier onion needs to have ends cut with a sharp knife and soaked in clean water for 10 minutes to facilitate loosening of peel, followed by 1–2 minutes air-drying to remove surface water. With 92% peeling, and unpeeled and damaged percentage being 6% and 2%, respectively, the capacity of the peeler has been found 50–60 kg/h.

Growth and projections

Onion production increased from 40.4 lakh tonnes in 1994–95 to 166.4 lakh tonnes in 2012–13 (Agricultural Statistics, 2013). The increase has mainly been from increased cultivated area under onion that stood at 10.6 million hectares in 2010–11. Although second in production after China at the world level, India is far behind in onion productivity in comparison to many countries. In India, average onion productivity is only 14.21 tonnes/ha, which is lower than the world average of 19.47 tonnes/ha. The highest onion productivity has been reported of 67.33 tonnes/ha from Ireland. There is a need to analyze factors responsible for lower productivity in India to come out with a workable plan to meet domestic requirement as well as for increasing export of this important crop; which India has been traditionally exporting.

To cater to the requirement of the ever-increasing population, keeping per capita consumption, export, processing and losses at existing rate (consumption, i.e. 6.7 kg/person/year, export 9%, processing 6.75% and losses 30%; base year 2010–2011), our country would require 21.12 million tonnes of onion by 2050 as against 14.82 million tonnes in 2010–11. This demands an increase in average productivity from 14.53 to 20.7 tonnes/ha— 42.5% higher than 2010–11. Efforts can be made to reduce losses up to 20%, increase export up to 25% and processing up to 15% by 2050. With these targets, we have to increase production from 14.82 million tonness to 28.57 million tonnes with productivity of 28.01 tonnes/ha.

Reasons for low productivity

1. Shortage of quality seed of improved varieties.
2. Low yield potential of onions under short days in India.
3. Predominance of open pollinated (OP) varieties due to non-availability of suitable F_1 hybrids.
4. Non-availability of disease and pest resistant varieties.
5. Sub-optimal cultivation standards adopted by farmers.
6. Shortage of irrigation at critical stages.
7. High storage losses due to poor storage conditions.
8. Price instability leading to suboptimal use of inputs.

Prospects and strategies

Keeping in view the inherent problems of the onion-crop and changing ecological, environmental, and socio-economic scenario, technological initiatives required for meeting domestic and export market requirements are presented as follows.

Seed: Old local genotypes still predominate, and seeds are produced by the farmers without undertaking proper measures such as required isolation distance etc. There is no organized system for production and distribution of quality onion-seeds. Seeds produced by a few research organizations are sold to farmers in limited quantity. Need is that good quality/breeder seeds from research organizations should be procured by the state and national seed certification agencies for multiplication and distribution to farmers at the reasonable rate.

Storage: In India, storage of onions is required from May to November. For domestic supply, export as well as of bulbs, about 40 lakh tonnes of onions are to be stored. Storage of onion-bulbs for longer periods is problematic. *Kharif* onion-crop is rainfed, and is harvested while physiologically still immature. This cannot be stored even for a month. There is a need to develop genotypes having good storage life. Refinement of cultural practices to minimize storage losses and designing of bottom and side ventilated storage structures by which storage losses can be reduced by 10–20% have been done. There is an urgent need for popularization of such storage structures and for providing financial assistance to onion-growers in different states.

Cold storage of onions with back-up of irradiation for suppression of sprouts would be new area for research. Cold-storage technology is now picking up, particularly with the private sector. These cold storages are ventilated types with controlled atmosphere, wherein gases, particularly carbon dioxide, product of bulb respiration, is monitored and regularly controlled. The storage losses in such stores are not more than 5%. The technology is, however, expensive, and is not reaching small and marginal farmers. The development of technology package for pre-cooling and establishment of cool chain for overseas trans-shipment is imperative to augment exports. Innovations in design of refrigerated containers would be crucial to reduce transit losses. Development of these facilities in strategic production areas would reduce post-harvest losses. There is a need to develop and standardize technology for storing onions in controlled atmosphere cold storages, where there is scope to reduce storages losses drastically.

Onion hybrids: At present in India, only open-pollinated varieties are in cultivation. Some exotic hybrid varieties with higher seed cost are being promoted by some private seed companies, but they are not much adapted to short-duration conditions of India and thus have a little advantage over commercial open-pollinated varieties. Thus development of hybrid onion varieties adapted to Indian conditions is urgently needed. Non-availability of inbred lines and durable male sterile lines are hampering hybrid production.

Disease and pest resistance: All onion varieties in cultivation in India are susceptible to various diseases and pests. Thus, breeding for disease and pest resistance is an area which needs to be prioritized. There is a need to screen all available germplasm systematically including wild *Allium* species for various diseases and pests. Resistant or the tolerant types so identified need to be adopted and used in breeding for developing disease and pest resistant varieties. Marker-assisted selection and cloning of resistant genes can also be made use of for accelerating development of resistant varieties.

Processing and value-addition: Onion processing industries are emerging at a faster rate and would be demanding more raw material. The processing units are facing problems of year-round supply of high TSS white onion (>18%) varieties. Varieties with low reducing sugars, high pyruvic acid and allicin content are required to develop value-added nutritionally rich products. However, development of onion and garlic varieties rich in medicinal and functional food value is still a challenge.

***Kharif* production technology:** Production of successful onion-crop during *kharif* is still a challenge as the crop is mainly rainfed and severely attacked by many diseases and pests. *Kharif* production technology thus needs to be refined.

Mechanization: There is demand for the development of machines and tools for small and medium farmers to minimize labour requirement. Direct seeding can substantially reduce the labour cost involved in traditional transplanting. Available seed-drills lack precision in terms of maintanence of plant population and interspaces between plants. They need to be upgraded by using pneumatic seed-drill technology available in advanced countries, which at present is expensive, and is used in large farms only. Similarly, work on transplanters, harvesters, etc. also needs to be undertaken.

Future Thrusts

Considering natural resource degradation, climate change and associated stresses, following strategies would help carry forward technological initiatives for meeting domestic and export requirements of onions.

- Combine conventional breeding with biotechnological approaches for introgression of genes from wild species for resistance/tolerance to biotic and abiotic stresses, male sterility, high TSS, and for creation of variability.
- An organized system for production of quality seeds in sufficient quantity and their distribution at reasonable rates need to be developed by involving research organization, state and national seed certification agencies and also private sector.
- Development of low-cost cold storage technology is needed to minimize storage losses.
- Robust recommendations need to be given based on long-term multilocational trials on the Integrated Nutrient Management (INM), Integrated Pest Management (IPM) and Integrated Disease Management (IDM) for enhancing and for sustenance of productivity.
- A more flexible public private partnership (PPP) needs to be developed wherein basic and strategic research should be undertaken by research organizations, and applied aspects like variety/hybrid development, agronomic recommendations and extension activities should be undertaken through PPP mode.
- Government has to do crop planning for effective supply chain management and price control. A firm policy on promotion of exports is needed. Facilities for quick transport, provision of ventilated containers and cargo clearance through agri-export zones are to be strengthened.

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3

Biosystematics, Botany and Genetic Resources

Vijay Mahajan, K.S. Negi and A.J. Gupta

Genus *Allium* includes bulbous biennial or perennial herbs. A few of them like onion or garlic emit a distinctive and pungent odour when tissues are crushed; while others lack volatile compounds. Some species belonging to the genus have very long sheathing leaf-bases used for consumption and some have storage organs as rhizomes or as storage roots used for medicinal purposes.

Taxonomy

The taxonomic position of Alliums is still unclear. The genus *Allium* as a whole was assigned to family "Liliaceae" by some taxonomists (Polunin, 1969) on account of its superior ovary, and to Amryllidaceae by others (Traub, 1968) because of umbellate inflorescence. Because of superior ovary (characteristic of Liliaceae), scapose umbellate inflorescence (flowers borne in a bracted umbel on the top of a scape) and with membranous bracts (characteristic of Amaryllidaceae), Alliums were placed in family Alliaceae by Purseglove (1972). Others opted for a subfamily – Allioideae of Liliaceae (McCollum, 1976). Fay and Chase (1996), Friesen *et al.*, (2000) and Chase *et al.,* (2009) considered *Allium* (including *Caloscordum* Herb., *Milula* Prain and *Nectaroscordum* Lindl.) as the only genus in tribe Allieae. The following hierarchy regarding its classification has been adopted (Rabinowitch and Brewster, 1990).

Kingdom: Plantae
Class: Monocotyledon
Super Order: Liliflorae
Order: Asparagales
Family: Alliaceae
Tribe: Allieae
Genus: *Allium*

A. cepa is considered as divisible into two large cultivar groups—Common Onion Group, with a large, normally solitary bulb, reproduced from seed or from seed-grown bulblets ('sets'), and an Aggregatum Group, with smaller, several bulbs, forming an aggregated cluster, originating from a single mother-bulb. A cultivar of *A. cepa* will be considered as 'shallot' (belonging to Aggregatum Group) if more than 200 buds are present in one kg of mother-bulbs and if under the suitable climate, most of them produce new bulbs (Messiaen and Rouamba, 2004). Shinde and Sontakke (1993) described edible Alliums (Tables 3.1, 3.2).

Table 3.1 Details of edible Alliums

Species	Chromosome No.	Other information
Allium cepa L.	2n=2x=16	Closely related to wild diploids of Central Asia (*A. vavilovii, A. oschaninii, A. pskemense, A. galanthum*)
A.cepa var.*ascalonicum* Backer	2n=2x=16	Commonly known as shallot, perpetuated by bulbs, which form in clusters on the soil surface
A.cepa var.*aggregatum* G. Don	2n=2x=16	Commonly known as potato -onion/ underground onion/multiplier onion/ Egyptian ground onion. It grows underground as closely packed clusters of bulbs rather than on the surface, like shallot
A.cepa var.*viviparum*(Metz) Mansf. /*proliferum*	2n=2x=16	Commonly known as tree/Egyptian tree onion. It is A.*cepa*×*fistulosum* interspecific hybrid (Bozzini, 1964).It grows as a perennial underground bulb, is reported to be resistant to pests and diseases
A. sativum L.	2n=2x=16	Species producing bulbs consisting of several cloves, is a sterile diploid.Some authors consider *A.longicuspis* to be its wild ancestor
A.fistulosum L.	2n=2x=16	Commonly known as Welsh onion or Japanese bunching onion.It is perennial bunching type, common in China and Japanese garden
A.porrum L.	2n=4x=32	Commonly known as leek, considered as cultivated wild of *A.ampeloprasum,* which is common in Mediterranean and South-West Asia
A.kurrat Sfth. & Krause	2n=4x=32	Commonly known as kurrat, another cultivated form of *A.ampeloprasum,* grown for green leaves, common in Egypt and Near East
A.ampeloprasum L.	2n=4x=32, 6x=48	Also known as great headed garlic, used as substitute for garlic in cooking, its bulbs are larger than garlic, leaves are like leek, produces inflorescence
A.schoenoprasum L.	2n=2x=3x=4x2	Also known as chive. It is propagated by root division,is tolerant to extreme cold and drought
A.tuberosum Rottl. ex Spreng.	2n=4x=32	Also known as Chinese chive of Eastern Asia, is grown for green leaves
A.chinense G. Don	2n=2x=16,4x=32	Also known as rakkyo.It is a pickling type of China, South Asia and Japan

Morphology

Roots

They are produced from the base plate.The new roots form an irregular ring above and around the older ones and emerge through corky outer tissue. Each successive ring has more roots than the previous one, and this continues till there is active vegetative growth.

Leaf

Each leaf consists of a hollow green photosynthetic blade and a cylindrical sheath which connects blade to the base plate of the onion-plant. Each leaf arises inside encircling leaf-sheaths of the older leaves, and grows up through them, so to form a pseudostem from the concentric leaf-sheaths. The hollow, tapering leaf-blades are arranged in two rows opposite to each other. Leaves shape vary from fistular, flat, elliptic filiform to linear.

Table 3.2 *Allium* species in subsect. *cepa* (Mill.) Stearn

Allium species
A. cepa L.
A. cepa L.(Aggregatum Group)
A. asarense R.M. Fritsch & Matin
A. vavilovii M. Pop. Et Vved.
A. fistulosum L.
A. altaicum Pall-Latvia
A. galanthum Kar. et Kir
A. pskemense B. Fedt.
A. oschaninii O. Fedt.
A. cornutum Clementi
A. fedschenkoanum Regel
A. ledebourianum Roem. et Schult
A. schoenoprasum L.
A. roylei Stearn

Source: Hanelt *et al.* (1992)

Flower

During the period of apparent external dormancy, main and usually several lateral growing points on the upper surface of the base-plate continue to grow slowly and form shoot initials consisting of bladed leaves and flower-stalk primordia (Abdalla and Mann, 1963). Individual plants may produce several scapes varying from 1 to 20 or more, depending upon the cultivar. Flower stalk may vary in height from 0.9–1.2 m. The scape is a stoutly formed green, hollow structure which becomes rather inflated at about one-third of the way up; it carries flower buds at its tip. At first buds are enclosed in a thin papery outer spathe or sheath, consisting of 2–3 bracts, which split open by pressure of the developing flowering buds, which are in a more or less spherical inflorescence known as umbel. Umbels are aggregate of cymes of 5–10 flowers each, and flowers open in definite sequence. Flowers are white to bluish in colour. Each flower has a perianth of six white tepals with a central green vein, six stamens with green or yellow anthers, and an ovary of three locules each containing two rather large ovules. The style is only 1–2 mm long when the flower opens, and reaches its full length of 4–7 mm over next 3–6 days. The stigma is simple or slightly trilobed knob which only develops when the style reaches its full length; at the time, the stigmatic surface exudes a sticky liquid to which pollen can adhere (Currah and Ockendon, 1978). The number of flowers may vary from 50 to 2,000 depending upon the species and cultivar, time of planting, size and storage conditions of mother-bulbs. The flowers are protandrous in nature and are generally cross-pollinated. The anthers of inner whorl dehisce first, and it usually occurs between 9 AM and 5 pm. The style becomes receptive when it attains the length of 5 mm. This happens in a day or two after the anthers have dehisced. An inflorescence may continue opening for two weeks or more and the plant may be in bloom for more than 30 days.

Bulb

The leafy plant eventually ceases to form leaf-blades, and instead apex begins to initiate a number of bladeless, concentric, thickened leaf-sheaths, which form bulb-scales. Together with the swollen lower leaf-sheaths of the older leaves, they make up the fleshy part of the onion-bulb.

Biosystematics

Many *Allium* species were found earlier in Himalayas. In the recent decades, some of them have apparently become rare, endemic or extinct. Since the work of Hooker (1892, 1947), who compiled for the first time information on *Allium* species and mentioned its 27 species in the *Flora of British India*, no other reports are available on this genus. At present, information in some regional floras is available, but are seemingly incomplete. From the Indian Himalaya and adjoining regions, some workers have depicted *Allium* species as follows— (i) Duthie (1906)-11 species; (ii) Blatter (1927-29)-12 species; (iii) Hooker revised and supplemented by Stearn (1947)-32 species; (iv) Nasir (1975)-41 species; (v) Naithani (1984)-07 species; (vi) Polunin and Stainton (1984)-12 species; and (vii) Karthikeyan *et al.*, (1989)-36 species.

The species close to cultivated *Allium cepa* L. are *A. vavilovii* Popov.&Vved. from southern Turkmenistan and northern Iran, with which it gives 100% fertile hybrids, and *A. asarense* R.M. Fritsch & Matin, from Iran. *A.oschaninii* O. Fedtsch. (from Uzbekistan and neighbouring countries), which was considered its ancestor, didnot produce fertile hybrids with the cultivated species. Onion species have been cultivated since long, and so their bulbs and inflorescences development must have adapted closely to varied temperature and photoperiod ranges, thus, there exists a wide range of cultivars and landraces, developed over the centuries, to fit in with the diverse climates and food preferences of the world (Brewster, 1994). Most of the 600 species of *Allium* are distributed in Afghanistan, Turkey, Iran and Central Asia; in Turkmen SSR, Uzbek SSR, Tadzhik SSR, Kirgiz SSR and Kazakh SSR; and in Mongolia, the Tien-Shan Mountains and the Himalayas (Kotlinska *et al.*, 1990).

The history of infrageneric classification in *Allium* dates back to Linnaeus (1753), who accepted 30 species in three alliances. Later authors recognized an increasing number of infrageneric groups—six sections and 285 species (Regel, 1875, 1887); nine sections and 228 species for the former USSR (Vvedensky, 1935) alone; three subgenera, 36 sections and subsections, and about 600 species (Traub, 1968); six subgenera and 44 sections and subsections (Kamelin, 1973); three subgenera and 12 sections (Stearn, 1980); and five subgenera and 16 sections (Hanelt, 1990). Later, Hanelt *et al.*, (1992) have revised classification that includes six subgenera, 50 sections and subsections for 600–700 species based on the multidisciplinary approach including morphological, anatomical, karyological, serological and numerical investigations as well as studies of life-cycle, distribution, ecology and isozyme data. A first approach to structuring the genus by molecular markers was published by Linne von Berg *et al.*, (1996). The resulting phenogram confirms mostly with the subgeneric classification based on the integration of morphological and other methods. Friesen *et al.*, (2006) presented a new classification of the genus consisting of 15 subgenera and 72 sections for about 780 species based on the phylogenetic study. Recently, molecular approaches using plastid DNA and nuclear ribosomal DNA (nrDNA) sequences have been applied to understand evolutionary processes and taxonomic relations within the species.

The number of the species in the genus varied from as low as thirty-one, described by Linnaeus in 1753 (Traub, 1968), to as high as 1,100 (Stearn, 1944). Traub (1968) grouped American species under 4 sections to put them on the same basis of classification as the old world species, which were later revised into subgenera, sections and subsections. About 35–40 species occur in temperate and Alpine regions of Himalaya (Hooker, 1892; Stearn; 1947; Kachroo *et al.*, 1977; Polunin and Stainton, 1984; Karthikeyan *et al.,* 1989) in India. Some of the species are distributed in the neighbouring regions also (Hara, 1966; Nasir, 1975; Stewart *et al.*, 1979; Xu *et al.,* 1990; Xu and Kamelin, 2000). Hanelt *et al.* (1992) and Fritsch *et al.* (2010) have reported that genus includes more than 700 species, which grow wildly in temperate, semi-arid and arid regions of the northern hemisphere, hence, results in a remarkable polymorphism .This is one of the largest monocotyledonous genera.

Onion adaptation in India has been carried out from a very early time; before the Christian era. Originally, native to Central Asia of temperate region with perennial/biennial habit and a long-day bulbing character, it has established well in the country under the tropical and short-day (11–11.5 h) conditions. During acclimatization of different kinds of vegetable crops and their varieties, farmers involuntarily applied selection pressure to meet market preferences. In the case of onion, ability to produce seeds indigenously has played an important role in adaptation. In the course of adaptation and diversification, out-breeding mechanisms in onion have promoted selections suitable for different environments. Among the cultivated species of *Allium*, onion (*A. cepa* L.), leek (*A. porrum* L.), shallot (*A. ascalonicum* L.) and chives (*A. schoenoprasum* L.) are well-known vegetable crops grown in different parts of India (Wealth of India, 1985; Pandey *et al.,* 2005a). Several lesser-known wild species of *Allium* (Table 3.3) were

Table 3.3 Distribution of wild *Allium* species in Indian gene centres

Species	Distribution and status of occurrence	Wild/occasionally cultivated
Allium ampeloprasum L. var. *ampeloprasum* L.	Western Himalaya; C	Wild; Occasionally cultivated (vegetable, pickle, condiment)
Allium atropurpureum Waldst.et Kit.	Western Himalaya; C	Wild

(Contd...)

(. . . Table 3.3)

Species	Distribution and status of occurrence	Wild/occasionally cultivated
Allium atrosanguineum Schrenk	Western Himalaya (Kashmir); C	Wild
Allium auriculatum Kunth*	Western Himalaya (Kumaon); LC	Wild; Occasionally cultivated (condiment)
Allium caesium Schrenk	Lahaul, Himachal Pradesh; LC	Wild
Allium carolinianum DC.* (*A. thomsonii* Baker)	Western Himalaya; C	Wild; Occasionally cultivated (condiment)
Allium chinense G. Don*	North-eastern Himalayan region (Khasi hills); C	Wild; Occasionally cultivated (vegetable, pickle, condiment) (high seed sterility)
Allium clarkei Hk. f.*	Uttarakhand (Kashmir) Himalaya; rare species	Wild
Allium consanguineum Kunth*	Western (Kashmir) and central Himalaya; C	Wild; Occasionally cultivated (minor cultivated species grown for vegetables and condiment in eastern Himalaya)
Allium fasciculatum Rendle	Indian Himalaya, Tibet, Nepal; LC	Wild
Allium fedschenkoanum Regel	Western Himalaya (Kashmir); rare species	Wild
Allium griffithianum Boiss.*	Western Himalaya; C	Wild; Occasionally cultivated (condiment)
Allium hookeri Thw.*	North-eastern Himalaya (Khasi hills); sporadic in upper Gangetic plains; C	Wild
Allium humile Kunth*	Western Himalaya; C; endemic species	Wild; Occasionally cultivated (condiment)
Allium longistylum Baker	Western Himalaya; LC	Wild
Allium loratum Baker	Western Himalaya, Tibet; rare species	Wild
Allium macranthum Baker	Bhutan and adjoining region; LC	Wild
Allium odorum L.	Western Nepal, West Tibet; LC	Wild
Allium oreoprasum Schrenk	Ladakh Himalaya; LC	Wild
Allium platyspathum Schrenk	Western Tibet; LC	Wild
Allium prattii Wight	West Nepal and adjoining Himalaya; rare species/ sporadic in distribution	Wild

(Contd...)

(. . . Table 3.3)

Species	Distribution and status of occurrence	Wild/occasionally cultivated
Allium przewalskianum Regel*	Western Himalaya; C	Wild; Occasionally cultivated (vegetable, condiment)
Allium roylei Stearn* (*A. lilacinum* Royle)	Western Himalaya; rare species	Wild; OC (condiment)
Allium schoenoprasum L.	Western Himalaya (Kashmir, Drass); C	W; Occasionally cultivated (vegetable, salad, condiment)
Allium schrenkii Regel	Himalayan mountains to Siberia; LC	Wild
Allium semenovii Regel	Western Himalaya, Kashmir to Uttarakhand, Himachal Pradesh, Zanskar; C	Wild
Allium sikkimense Baker	Ladakh, Sikkim Himalaya, Tibet; C	Wild
Allium stracheyi Baker*	Western Himalaya (Kashmir-Kumaon); narrow endemic species, rare/threatened species	Wild; Occasionally cultivated (vegetable, condiment; recorded in the Red Data Book of Indian Plants)
Allium tuberosum Rottl.ex Spreng.	Widely distributed in Himalaya; C	Wild; Occasionally cultivated (vegetable, condiment)
Allium victorialis L.	Temperate Himalaya; C	Wild
Allium wallichii Kunth	Eastern part of Western Himalaya; C; endemic species	Wild; Occasionally cultivated (vegetable, condiment)

*Commercially important species; C, common; LC, less common; SGB, seed genebank; FGB, field genebank; IV, *in -vitro* repository

Sources: Gohil, 1992; Negi and Pant, 1992; Sharma *et al.*, 1996; and Pandey *et al.*, 2008

reported from the north-western Himalayan region of India (Gohil, 1992; Negi and Pant, 1992; Sharma *et al.*, 1996).

Genetic Resources

Despite global culinary and economic significance, genetic research on onion has lagged behind to a great extent compared to other major vegetable crops (McCallum *et al.*, 2008). Important onion temperate germplasm collections are maintained in United Kingdom, Netherlands, Hungary, United States and Japan, and tropical cultivars are maintained in India, Brazil and Colombia and at the AVRDC (Taiwan). An analysis of the data from the European collections indicated 2,800 accessions of *A. cepa* originating from 104 countries [the maximum was from the Netherlands (9%), followed by the USA (7.4%) and United Kingdom

(7.4%)]; overall, 1,394 accessions have been recorded as landraces, 2,519 as advanced cultivars and 1,555 as wild species. Specifically, 433 *A. cepa* landraces originated from 64 countries (14% from Portugal, 13% from Russian Federation, etc.). The oldest sample was collected in 1909 (*A. hissaricum* from Tajikistan), while 6% of the samples, for which acquisition date was known,entered in genebanks before 1960 and more than 70% were acquired after 1980 (Maggioni, 2004). About 83,*A. cepa* (basal) germplasm have been conserved in a small genebank at the Horticultural Research Section of the ARC at Wad Medani (east-central Sudan) (Mirghani and Mohammad, 1997). The largest number of national onion accessions in Africa have been kept at the Centre Régional de Recherche Agronomique (CERRA), Maradi (Niger), and the largest regional collection has been stored at the Centre Régional de Recherches Environnementales et Agricoles (CRREA) and Farako-Bâ (Burkina Faso,Africa). There are several shallot collection centres—one at Centre de Recherche Agronomique (CRA), Bareng (Guinea) and another at the Centre National de Recherche Agronomique (CNRA), Bouaké (Côte d'Ivoire). In Indonesia, shallot collection has mainly been preserved at Lembang. Kotlinska *et al.*, (1990) collected 122 samples of 27 different *Allium* species from the Central Asia.

At the global level, efforts of the International Board for Plant Genetic Resources (IBPGR, now IPGRI) to conserve vegetable crops germplasm began in 1980 (Sloten, 1980). The Vegetables Network of the European Cooperative Programme for Crop Genetic Resources Networks (ECP/GR), initiated in 1980, is self-funded by the European member-countries and is coordinated by the International Plant Genetic Resources Institute (IPGRI) (Maggioni, 2004). The adoption in 1996 of the FAO/IPGRI list of Multi-crop passport descriptors for data exchange was a landmark in standardization throughout the European region (Lipman *et al.*, 1997). At present, online vegetable databases (www.ecpgr.cgiar.org/Databases/Databases.htm) offer mainly passport data, and additional data can be taken from the database managers.

A study on the genetic resources of *Allium* spp., prepared by Astley *et al.*, (1982), traced about 9,400 accessions of cultivated and wild *Allium* in the major world collections. According to the online FAO-WIEWS, this figure after 20 years has almost reached three times higher. The total number of *Allium* accessions in European genebanks, distributed in 27 European countries, can be estimated at around 18, 000; representing over 60% of the world's *Allium* accessions.

Cooperative Programme consists of one collection of seed-*Allium* species at the Genetic Resources Unit, Horticulture Research International (HRI), Wellesbourne, United Kingdom—the material conserved includes 131 advanced European leek cultivars and 124 onion landraces (mainly from Spain and Portugal) and 850 advanced onion cultivars from Europe and the rest of the world (Australia, Brazil, India, Japan, Pakistan, New Zealand, USA, etc.) (Maggioni, 2004). The second collection is at the European field of long-day *Allium* species, Vegetable Section, Genebank Department, Research Institute of Crop Production, Olomouc, Czech Republic—this comprises 641 garlic accessions from more than 15 countries and 119 shallot accessions, mainly from Finland and Norway (Staveliková, 2002), and the third is at the European field collection of short-day *Allium* species, Faculty of Agricultural, Food and Environmental Quality Sciences, Rehovot, Israel—this collection, supported by the Israeli Gene Bank, includes garlic, shallot, elephant garlic and *A. tuberosum* from short-day zone, and also from South-East Asia and South America (Rabinowitch, 2002).

The taxonomic *Allium* Reference Collection and *in-vitro Allium* collection are available at the Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben, Germany. Live collection of nearly 400 wild *Allium* species is a unique reference for taxonomic investigation of all the *Allium* species (Fritsch, 2002), while *in-vitro* collection includes 372 accessions of vegetatively propagated *Allium* species, including 98 virus-free garlic accessions (Keller and Senula, 2002). And the decorative *Allium* species collection is maintained by the Department of Floriculture, Volcani Centre, Bet Dagan, Israel. This includes about 200 entries, and is used to study floral induction and florogenesis besides understanding potential of some species as ornamental crops (Maggioni, 2004). The Centre for Genetic Resources at Wageningen (Netherlands) has 300 *A. cepa* and *A. ampeloprasum* accessions (Groot and Boukema, 1986). Plant Research International, Wageningen, the Netherlands, collected *Allium* mainly from Greek Islands (Bothmer, 1974) and contains 73 different clones of species from the so-called *ampeloprasum* complex (Kik, 2002). It was found of potential value for finding male-sterility sources to be introduced in leek (Kik *et al.*, 1997).Warwick Genetic Resources Unit (WGRU) was developed from the Vegetable Gene Bank (VGB), built in 1980, at the National Vegetable Research Station at Wellesbourne, UK. The WGRU has a unit for collection, conservation, characterization, documentation and research study of a range of vegetable crops and their wild relatives. The collection at the WGRU includes: *Allium*: onion, leek and wild taxa, besides current/obsolute cultivars and landraces of small-seeded outbreeding vegetables of other genus.

The Vegetable Germplasm Bank of Zaragoza (BGHZ) and the Centre for the Conservation and Breeding of the Agrodiversity (COMAV), both in Spain, have important *A. cepa* L. collections representing most of the Spanish onion variability (Castell and Díez, 2000; Carravedo and Mallor, 2007). Eighty-six Spanish onion accessions are local onion landraces, collected as seeds from farmers in the main growing regions of Spain between 1981 and 2006 (Mallor *et al.*, 2011).

Kim *et al.* (2012) cryopreserved 1,158 accessions of garlic as well as some *Allium* species during 2005-2010 using droplet-vitrification technique with a mean regeneration of 65.95% after cryostorage at the genebank of the National Agrobiodiversity Centre, Republic of Korea.

International agencies, including Bioversity International, have recognized global centres of *Allium* germplasm in many countries—Czechoslovakia, Hungary, Israel, Japan, UK and USA (Astley *et al.*, 1982; Simon, 2005). In European *Allium* database (EADB, 2010), at present 10,473 accessions are from 32 countries for distribution under the Standard Material Transfer Agreement (SMTA). Many other small and medium sized collections are distributed around the world, totalling to 137 collections in 66 countries (Maggioni, 2004) (Table 3.4).

According to Fan-Zhi Cheng (2004) in China, there were 151 accessions of *A. fistulosum* in the Chinese national germplasm resources bank, and breeding was

Table 3.4 *Allium* species diversity conserved in the international germplasm repositories

Allium species	No. of countries holding *Allium* accessions	European countries (ISO codes) with large collection (no.of accessions)	AVRDC (AVGRIS)	NPGS (USA)
A. cepa L.	27	GBR (999); RUS (944); FRA (793);POL (408)	483	903
A. sativum L.	18	ESP (713); CZE (641); DEU (486)	505	302
A. fistulosum L.	9	RUS (191); DEU (84); GBR (56)	30	115
A. ampeloprasum L./ *A.porrum* L.	16	RUS (390); FRA (307) ; GBR (151)	14	207
A. schoenoprasum L.	12	DEU (54); BGR (16); GBR (11)	-	31
A. chinense G. Don	1	DEU (5)	5	-
A. tuberosum Rottl. ex Spreng.	4	DEU (40)	5	12
Wild species	12	DEU (4300); GBR (769); ISR (420); POL (240)	87	-
Total *Allium* spp.	27	17,431	1,129	1,570

GBR = Great Britain; RUS = Russia; FRA = France; POL = Poland; ESP = Spain; CZE = Czechoslovakia; DEU = Holland; BGR = Bulgaria; ISR = Israel; AVRDC = Asian Vegetable Research and Development Centre ; AVGRIS = AVRDC Vegetable Genetic Resources Information System; NPGS = National Plant Germplasm System

Sources: European *Allium* database-versions 2001 and 1999; FAO: WIEWS 2002; Maggioni *et al.*, 1999; Maggioni *et al.*, 2002

mainly focused on the colony variety selection, male-sterile line selection and virus resistance selection.A total of 184 samples of Chinese chive (*A. tuberosum*) (native to country) and 43 samples of onion (*A. cepa*) are stored in the national gene bank. Among, *Allium* species in the USSR, *A. inderiense, A. delicatulum, A. caeruleum* and *A. savranicum,* require protection in Volgograd region, as *A. regelianum* in any part of the USSR. *A. regelianum* flowered during late June, and in the preliminary trials was successfully cultivated and produced seeds (Sagalaev, 1987). In Leningrad (USSR), Kazakova and Semenov (1985) reported about 300 wild species of *Allium*, which have been classified into 9 sections.

As part of the biodiversity assessment and germplasm conservation project, Adair *et al.*, (2006), collected 55 populations of taper-tip onion (*A. acuminatum*)from throughout the Great Basin region of the USA (Idaho, Oregon, Nevada). Keller and Senula (2003) reported a large collection of *Allium* and its wild species maintained at Gatersleben, Germany. In addition to the field maintenance, *in-vitro* culture and cryopreservation are used to increase maintenance safety and plant quality. One-third of the 3,500 *Allium* accessions are maintained vegetatively. *Allium* germplasm maintained at the National Gene Bank of Ukraine consists of *A. cepa, A. odorum* [syn. *A. ramosum*], *A. porrum* and *A. fistulosum* (Shabetia *et al.,* 2006).

Germplasm resources in India

The genetic resource of *Allium* in India is the potential source of genes for widening crop genetic base. Despite high economic value, limited number of germplasm accessions of the wild onion species have been collected and conserved mainly owing to difficulty in access to areas of occurrence. The National Bureau of Plant Genetic Resources has undertaken plant exploration activities in different regions of India has and collected wide diversity in cultivated (*A. cepa* L.) and wild *Allium* species. These have been established, multiplied and conserved after characterization at different locations (Singh and Rana, 1994; Pandey *et al.*, 2005). Search for the potential of wild species in the Indian gene centre has intensified after successful interspecific crosses between *A. cepa* L. and *A. roylei* Stearn (a wild species and an accession of Indian origin). Transfer of genes resistant to powdery mildew and leaf blight from the latter species to the former has opened new avenues in utilization of Indian species for crop improvement (Kofoet and Zinkernagel, 1990; de Vries *et al.*, 1992). Realizing importance of germplasm in buildingup resources for future commercial exploitation, Kale *et al.* (1994) undertook a detailed survey of traditional and non-traditional onion-growing areas of Maharashtra, and of India in general, and collected 148 red-skin and 33 white-skin types of onions, evaluated the tropical germplasm and identified some lines on the basis of maximum average bulb weight, high TSS and for single centreness at the Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri.

Singh and Rana (1994) reported that the National Bureau of Plant Genetic Resources had conducted extensive plant explorations in different *Allium*-growing states/regions in India and collected over 2,200 accessions of onion (*A. cepa* L.) and garlic (*A. sativum* L.), including landraces, farmers' traditional cultivars, and wild relatives (*A. ampeloprasum*, *A. auriculatum*, *A. ascalonicum*, *A. carolinianum*, *A. chinensis*, *A. wallachi*, *A. tuberosum* and *A. rubellum*). The Institute has also introduced over 1,100 accessions of *Allium* germplasm, which include improved cultivars, germplasm collections, and related species from over 40 countries. Some of them have been identified to be tolerant/resistant to diseases such as purple-blotch (*Alternaria* sp.), *Stemphylium*-blight and garlic mosaic virus (GMV). Since 1990 up to 2008, the NBPGR imported 1,316 *Allium* spp. (Table 3.5), comprising 47 species, excluding *A. sativum* (garlic), from various countries like USA, UK, Slovakia, Holland, Netherlands, Israel, Mongolia, South Africa, Taiwan, Hungary, Russia, Mexico, Germany, Denmark and Niger (Singh *et al.*, 2006; Anitha *et al.*, 2011).

During 1986–2006, a total of 46 accessions of wild *Allium* species were collected from high hills of Uttarakhand, Himachal Pradesh, Jammu and Kashmir of Western Himalaya and the north-eastern region (Chaurasia and Singh, 1996–2001; Negi, 2006a). Native as well as exotic wild species (37 species) have been maintained, characterized/evaluated at the field genebank (Table 3.6) at Bhowali, Uttarakhand (Negi, 2006a).

Onion germplasm diversity was also collected from three northern Telangana districts of Adilabad, Karimnagar and Nizamabad by Kamala *et al.,* (2011). Seventy-four samples (bulbs-66; seeds-8) were collected from 33 villages and 23 mandals. The DOGR is the National Active Germplasm Site (NAGS) for onion and garlic germplasm. Its present collection exceeds 1,500 accessions of red, white and yellow Alliums from different parts of the country, including exotic

Table 3.5 *Allium* species introduced from abroad by the NBPGR, New Delhi

Allium species	Number of accessions	*Allium* species	Number of accessions
A. albidum Fisch. ex M.Bieb.	3	*A. narcissifolium* Lam.	1
A. altaicum Pall.	21	*A. obliquum* L.	3
A. ampeloprasum L.	124	*A. odorum* L.	1
A. ampeloprasum var. *porrum* L.	9	*A. oreoprasum* Schrenk	3
A. angulosum Lour. nom. illeg.	8	*A. oschaninii* O. Fedt.	4
A. cepa L.	882	*A. porrum* L.	4
A. cepa L.var. *cepa*	2	*A. pseudoampeloprasum* Miscz. ex Grossh	1
A. cernuum Rorh	3	*A. pseudocepa* Schrenk	10
A. christophii Trautv.	1	*A. pskemense* B. Fedtsch.	3
A. dictyoprasum C. A. Mayer Ex Kunth	5	*A. pulchellum* G. Don	1
A. drobovi Vved.	2	*A. pyrenaicum* Costa & Vayr.	1
A. fallax Schult. & Schult.f., nom. illegit.	1	*A. ramosum* L.	5
A. fistulosum L.	66	*A. ratavienee*	1
A. flavum L.	2	*A. roylei* Stearn	1
A. fuscoviolaceum Fomin	3	*A. schergianum* Boiss.	1
A. galanthum Kar. et Kir.	2	*A. schoenoprasum* L.	23
A. giganteum Flickr	1	*A. senescens* L.	5
A. glaciale Vved.	1	*A. thunbergii* G. Don	2
A. guttatum Sardoum	1	*A. tuberosum* Rottl. ex Spreng.	10
A. ledebourianum Roem. et Schult	4	*A. ursinum* L.	1
A. lineare L.	3	*A. vavilovii* Popov. & Vved.	9
A. longicuspis Rgl.	7	*A. vineale* L.	1
A. moly L.	1	Other *Allium* spp.	82
A. montanum F.W. Schmidt, non Schrank	1		
Total			1,316

Sources: Singh *et al.* (2006); Anitha *et al.* (2011)

Table 3.6 *Ex-situ* conservation of wild *Allium* species at the NBPGR, New Delhi

Species maintained (No. of accessions)	*Ex -situ* conservation method	Species maintained (No. of accessions)	*Ex-situ* conservation method
A. ampeloprasum L. var. *ampeloprasum* (4)	FGB, IV	*A. hookeri* Thw. (2)	FGB, IV
A. auriculatum Kunth (2)	SGB, FGB	*A. humile* Kunth. (1)	FGB
A. carolinianum DC (5)	FGB	*A. roylei* Stearn (4)	FGB
A. clarkei Hook.f. (1)	FGB	*A. wallichii* Kunth (2)	FGB
A. consanguineum Kunth, Enum. (2)	FGB	*A. oreoprasum* Schrenk (1)	SGB, FGB
A. stracheyi Baker (2)	SGB, FGB	*A. auriculatum* Kunth (1)	SGB, FGB
A. griffithianum Boiss. (3)	SGB, FGB, IV	*A. chinense* G. Don (2)	FGB, IV

SGB, seed genebank; FGB, field genebank: IV, *in-vitro* repository
Source: Negi (2006a)

introductions (Table 3.7). Underutilized and wild *Allium* species (*A. ampeloprasum, A. tuberosum, A. chinense, A. ascalonicum, A. hookeri* and *A. cepa.* var. *aggregatum*) are being multiplied and characterized for utilization in the breeding programmes (Gopal *et al.*, 2013).

Table 3.7 Landraces of onion and garlic in India

Name of farmer's variety/landrace	State
Onion	
Fursungi Local	Maharashtra
Bellary Red	Karnataka
Nasik Red (Nasik)	Maharashtra
Telgi Local (Vijapur)	Karnataka
Sukhsagar (West Bengal)	West Bengal
K P Onion (Andhra Pradesh)	Andhra Pradesh
Pillipatti Junagadh (Gujarat)	Gujarat
Nirmal Local (Madhya Pradesh)	Madhya Pradesh
Bhavnagar Local (Gujarat)	Gujarat
Garlic	
Ooty Local	Tamil Nadu
Sikkim Local	Sikkim
Rani Bennur Local	Karnataka
Gadwa	Karnataka
Rajeli Gaddi	Karnataka
Jamnagar Local	Gujarat
Jeur Local	Maharashtra

Source: Gupta and Mahajan (2013)

Utilization of genetic resources

Modern varieties sold by the international seed companies, particularly F_1 hybrids, which have a narrow genetic base, are replacing old varieties. Thus, there is every likelihood that old landraces with potentially valuable and adaptive genes may be lost. The risk of genetic erosion due to introduction of a single new cultivar was especially considered high by Crisp and Astley (1985) for the vegetables that are built on a narrow geneticbase. On a global level, efforts of the International Board for Plant Genetic Resources (IBPGR, now IPGRI) began in 1980 to conserve vegetable crops germplasm, including *Allium* and related species according to their importance for rural development and their economic value for farmers in tropics (Sloten 1980).

There is a need for collection, characterization, preservation and regeneration of seeds and clones of old varieties and landraces (Astley 1990). Besides conservation of genetic variability for future, the actual utilization of available accessions is another important goal. However, low utilization of germplasm banks is a rule worldwide (Nass and Paterniani, 2000). The main factors responsible for low utilization of plant genetic resources are lack of evaluation, documentation and adequate description of collections, lack of desired information by breeders, accessions with restricted adaptability, and insufficient number of plant breeders, particularly in developing countries (Mallor *et al.*, 2011).

For processing

Traditional tropical African cultivars, 'Violet de Galmi', 'Blanc de Soumarana' (Niger), 'Violet de Garango' (eastern Burkina Faso), 'Bawku' (northern Ghana), 'Red Kano' (northern Nigeria), 'Violet d'Abéché' (eastern Chad), 'Malanville' (Benin), 'Rouge de Tana' (West Africa) and 'Tana' (adaptation from 'Rouge de Tana' in Madagascar);and selections like 'Yaakar', 'IRAT 19' and 'Noflaye'

(Senegal) have bulbs with high dry matter content and they store well under natural conditions (Messiaen and Rouamba, 2004). When introduced varieties of onion were not suitable for processing in Sudan, an improved white variety (Nasi), suitable for dehydration, was selected from the local material. Three other varieties (Kamlin yellow, Hilu and Saggai improved) were developed and released for farmers of Sudan (Mirghani and Mohammad, 1997). Abd El-Hafez *et al.,* (1976) tested 12 cultivars in Egypt—Beharry showed the highest value for total soluble solids in two growing seasons, followed by Giza 6 Mohassan, followed by American cultivar and hybrids "Texas Yellow Grano and New Mexico Early Grano". In Niger, Blanc de Galmi [Galmi White] (IRAT2) and Blanc de Soumarana [Soumarana White] (IRAT3) were intended for dehydration and had high dry-matter content (Nabos, 1976).

Valdivia and Holle (1971) found Dehydrator 8 in Brazil, as the best variety for dehydration with TSS 25.11%. Maeso and Villamil (1980) evaluated 10 long-day cultivars and reported that Dehydrator14, Southport White Globe and Dehydrator 8 yielded up to 52.0, 38.8 and 26.0 tonnes/ha, respectively, with dry matter content of 16.3, 14.0 and 17.51%, respectively, and they were recommended for processing in Southern Uruguay. Roger (1983) compared 13 cultivars for dehydration; none gave higher TSS than the standard variety Dehyso (22.3%). Hysol and the breeding line No. 79019 were best with 18.8 and 18.3% TSS, respectively, in NewZealand. Rogers and Henderson (1989) tested 36 cultivars of onion for dehydration. Southport White Globe, Hysol and F_1 Dehydrator 8 were found suitable for dehydration with TSS more than 15%. In Venezuela, short-day onions, White Creoso, White Dehydrator No.3 and White Dehydrator No.2 were best for drying (Flores, 1994).

Bajaj *et al.,* (1979) identified cv. Punjab 48 as most suitable for dehydration on account of its high TSS (14.6%).Roopali was better suited both for storage and dehydration (Maini *et al.*, 1984). Kalra *et al.,* (1986) found S 74 most suitable for dehydration, followed by Punjab 48, with TSS 14.3 and 13%, respectively. Raina *et al.,* (1988) recorded maximum (15.8%) TSS in Texas Yellow, followed by Punjab Selection (13.3%), Udaipur 102 (13.5%) and Punjab 48 (13.4%). Saimbhi and Bal (1996) observed TSS ranging from 14.0 to 16.2% and cultivar PWO 1 suitable for processing. After assessing Indian varieties and landraces which did not offer TSS range more than 12%, Jain Food Park Industries, Jalgaon, introduced White Creole, which was subjected to further selection for high TSS and developed V 12 with TSS range of 15-18% (Mahajan, 2011). Verma *et al.*, (1999) evaluated 5 red and 3 white onion varieties for dehydration and Punjab 48 was found superior, followed by Pusa White Flat. Since the establishment of the NRC for Onion and Garlic in 1998 at Rajgurunagar, a special programme for development of high TSS white onion variety has been launched. In 2000, about 7,199 bulbs were examined for TSS. Only 2.72% bulbs recorded TSS more than 14%. In all, 109 bulbs with TSS from 15 to 23% were selfed, and population improvement for high TSS is in progress (Mahajan, 2011).

For other characters

Tropical African cultivars 'Noflaye' was selected for resistance to bolting.

Mediterranean cultivars, either under their original name, 'Babosa', 'Valenciana Temprana' ('Jaune Hâtif de Valence'), from Spain, or after breeding for increased earliness and selection in South Africa, resulted in open-pollinated cultivar 'Pyramid'. The earliest of these cultivars, 'Texas Early Grano 502', could form bulbs at the latitude 0°, but no seed production occurred in tropical Africa. Cultivars of the Creole group of onions may have been developed in Louisiana from African onions brought to the New World at the time of the slave trade. American catalogues offer traditionally Red Creole, and more recently Yellow Creole and White Creole with relatively high dry matter content, but poor seed production in tropical conditions. Creole onions store better than Grano/Granex types, but not so well as the West African lines. Their bolting resistance is higher than onion cultivars imported from India, hence are suitable for high altitude growing areas, e.g. in Kenya. Several seed companies worldwide have undertaken breeding work to improve tropical short-day onions, including Technisem in West Africa and East West Seed Company in Zimbabwe and Asia. Improved cultivars resulting from this breeding work are commercially available. These include 'Noflaye' (Technisem—later bolting selection from 'Rouge de Châteauvieux') and 'Red Pinoy' (East West Seed Company—a long storage and late bolting red onion derived from a red polycross). The islands Réunion, Mauritius and Rodrigues, have an onion-growing tradition too e.g. 'Rouge de Châteauvieux', a red/pink onion was bred more than 100 years ago from a fortuitous cross between French 'Rouge Pâle de Niort' and an Indian cultivar. In Mauritius and Rodrigues, smaller, very pungent 'Local Red' onions are also grown and locally maintained (Messiaen and Rouamba, 2004). The storage quality of bulbs of onion cultivars, RHR White, PBR5, PW 1, Arka Niketan, IIHR Yellow and Hisar 2 under room temperature, was evaluated for 4 months. The lowest sprouting percentage was in IIHR Yellow, followed by RHR White (Batra *et al.,* 2000). Sagalaev (1987) reported *A. angulosum* (*A. tuberosum*) to be tolerant to slight soil salinity. It was used locally as a food plant.

Hanelt (1985) reported that wild species located in the central Asian mountains of Turkestan had winter hardiness and high vitamin C content (*A. altaicum*) and heat and drought resistance (*A. vavilovii, A. oschaninii* and *A. pskemense*)

Sweet onions first became a force in the market largely due to the efforts of and the publicity generated by the Vidalia onion industry in Georgia. In the early 1930s, Mose Coleman, an onion grower in Vidalia County, Georgia, recognized that sweet onions did not have the characteristic pungent bite normally found in onions (Boyhan and Torrance, 2002). Approximately 10% of the onions grown in New Mexico were marketed as 'sweet' (Johnson, 2005). New Mexico competes with several other growing areas, which produce their own branded sweet onions. Other brands grown in the US include 'Walla Walla' from Washington, 'Maui' from Hawaii, and 'Texas Sweets' and California's 'Sweet Imperials'. 'Nu-Mex Sweet' and 'Carzalia' are trademarks for sweet onions grown in New Mexico.

The performance of seven onion (*A. cepa*) genotypes 'Pusa White Flat', 'Agrifound Dark Red', 'PBR 5', 'Amrawati', 'Pusa White Round', 'Phule Safed' and 'Agrifound Light Red' was evaluated during *rabi,* both under alkaline (*p*H 9.20, 9.45 and 9.70) and salinity (EC 3.5 and 5.2 dS/m) stresses besides a non-stress control. Highest mean bulb yield obtained under salinity was with 'Pusa White Flat', followed by 'Amrawati' among different tested genotypes (Sharma *et al.,* 2000). Earlier studies in India on the influence of salinity on seed germination, growth, flavour, and yield attributes showed its adverse effect on these traits (Joshi and Sawant, 2012). A field experiment at Karnal has shown that onion and garlic can be grown in soils with salinity level up 4 dS/m (Chauhan *et al.*, 2007).

During late *kharif* in Maharashtra, out of 198 germplasm, Selection Nos 175, 151, 176, 186 and 168 recorded significantly minimum storage losses of 28.0, 30.0, 32.0, 32.0 and 33.0%, respectively, after 120 days of storage compared with other selections and Baswant 780 (35.0%) (Ranpise *et al.,* 2004). Out of 44 onion-germplasm lines, NRCOG 888, 910, 922, 944 and 946 from a gene pool were identified as stable genotypes with high yield and suitable for cultivation in all three seasons (*kharif,* late *kharif* and *rabi*); indicating their stability in unfavourable environments in western India (Prasad *et al.*, 2006). Out of 220 white onion germplasm, W 234, W 353, W 340, W 172, W 361, W 462 and W 079 recorded less storage losses during *rabi* (Mahajan *et al.,* 2005). Three hundred eighteen germplasm were evaluated for all the three seasons, 90 were found to give more than 40 tonnes/ha during *rabi*. Ninteen lines performed well giving higher total yield in *rabi*. Seventy-six lines yielded better than check PKV White, and 188 lines better than Phule Safed during late *kharif*. Under different environments, W 404 and W 398 were stable for marketable yield; giving higher mean values than population mean (Mahajan *et al.*, 2005a). One hundred ninety-two white-onion germplasm were evaluated for three or more years during *kharif* at the DOGR. Marketable yield higher than 21 tonnes/ha was recorded in lines W160, W 082, W 448, W 021, W 366, W 302, W 314, W 043, W 075 and W 397 (Mahajan *et al.,* 2011a). Germplasm lines W 48, W 009, W 355, W 404, W 367, W 172, W 418, and W 056 recorded more than 25 tonnes/ha during *kharif,* late *kharif* and *rabi*. One hundred fifty-one red onion germplasm were evaluated during *rabi* season. Genotypes 670, 1044, 720 and 1015 had good storability. Thirty-three genotypes were found suitable for *rabi* cultivation with more than 30 tonnes marketable yield /ha with good storability and other desirable characters (Gupta *et al.*, 2011).

As food Alliums

Field surveys and exploratory studies have confirmed utilization for edible purposes of wild *Allium* species in Garhwal and Kumaon regions of Himalaya (Negi and Gaur, 1991). Generally, all plant parts are edible and are consumed raw or as cooked vegetable. Young leaves of many wild species are preferred over mature as vegetable, in soups or for raw consumption. Freshly harvested leaves or bulbs are occasionally sold in village markets. Onion leaves and tuberous/fibrous roots are rich in carbohydrates, vitamins and minerals. Bulbs/pseudostems of *A. clarkei, A. griffithianum, A. pratii* and *A. victorialis* are consumed raw, cooked or pickled. Cloves or bulbs of *A. ampeloprasum* and *A. chinense* are pickled. In Pithoragarh region of Uttarakhand Himalaya (India), young leaves of *A. stracheyi* are used as potherb or are cooked mixed with potato. Fleshy fibrous roots of *A. hookeri* are consumed as vegetable in the north-eastern hill region of India or in soups and pickles in the same way as *A. stracheyi* in the north-western Himalaya. In Bhutan, *A. fasciculatum* is generally used as a vegetable (leaves and scape), as salad and in soups (young inflorescence).

As condiment/for flavour

Although all *Allium* species have different aroma (strongly pungent to mildly aromatic) and flavour (onion- or garlic-like odour) but the selective use of the species/plant part is based on the utilization and preference by local communities. Young leaves and bulbs of *A. humile*, *A. carolinianum* and *A. loratum* have garlic flavour and are used to garnish different food preparations. Similarly, *A. stracheyi*, *A. roylei* and *A. tuberosum* have mild onion flavour, and are widely used as flavouring agent and for garnishing. For routine domestic use, fresh leaves and bulbs are commonly used and for off-season requirement, leaves are generally dried and processed for long-term storage. In Kumaon region of Uttarakhand (Western Himalaya), dried leaves of *A. stracheyi* (jumbo) are primarily used for garnishing or seasoning vegetable/curries (Negi and Gaur, 1991). Bhotia tribals collect and process (dry) and bring marketable produce for sale from areas of abundant availability of these species to lower elevations (Chaurasia and Singh, 1996–2001; Sanyal *et al.,* 2000). Bulbs of *A. consanguineum* and leaves and flowers of *A. chinense* are commonly used as flavours in soups, curries, etc.

For medicinal use

Some wild *Allium* as *A. humile*, *A. carolinianum* and *A. przewalskianum* are traded for drug and trade industries in Himachal Pradesh in India (Chauhan, 1999). Dried scales of *A. wallichii* are used locally for pectoral complaints; cloves of *A. ampeloprasum* are utilized after dipping in mustard oil for paralytic limb, ear-pain and arthritis; bulbs of *A. wallichii* are used for anti-flatulence and digestive disorders; and leaves of *A. griffithianum* and *A. tuberosum* are used as carminative. Keusgen *et al.,* (2006) collected information about the current medical applications of sixteen wild species, nine of which belong to different sections of *Allium* subgenus *Melanocrommyum* from Tajikistan and Uzbekistan region. These plants are used against headache, cold and stomach problems, and are mostly applied fresh or after boiling. Three wild *Allium* species growing in Tajikistan and Uzbekistan (*A. oschaninii*, *A. pskemense*, *A. praemixtum*) are closely related to common onion, and are used as spice like it, but *A. oschaninii* and *A. pskemense* are used for medicinal purpose also. Special dishes, which are much esteemed for strong tonic properties, are prepared from leaves of three following species of subgenus *Melanocrommyum: A. motor*, *A. rosenbachianum* and *A. rosenorum.*

Commercial wild species

Many wild species of *Allium* (11 species) are of commercial value for food, flavour and medicine. These exist as natural populations or are grown on a small scale in home-gardens. Processed products in the form of dried bulbs, leaves, buds and flowers of some wild species of *Allium* (*A. auriculatum*, *A. carolinianum*, *A. griffithianum*, *A. humile*, *A. roylei* and *A. wallichii*) are in great demand and because of that these species are occasionally grown in home-gardens. Sun dried/

furnaces dried leaf powder of the above mentioned species has good shelf-life for off-season consumption (Negi, 2006a, b) and for sale in the market. Market products are also available in refined forms as processed bricks/cakes or balls; sold in border areas of Himachal Pradesh, Uttarakhand and adjoining regions. Crushed foliage of *A. przewalskianum* prepared as balls and put in a string were reportedly sold in the market in the cold desert region of India (Baker, 1874). The dried leaves of different species are sold at the rate of ₹ 1,500–2,500 per kg (approximately 25–45 US Dollars) (Negi, 2006a). Ornamental value of wild species in India is yet to be explored for the Indian market.

Future strategies

The genetic resource is the base for any crop improvement programme. Genetic erosion is a threat owing to human intervention. Deterioriation is fast in advanced countries that disturbs natural balance. In such a situation, there is an urgent need to conserve genetic resources, and undertake their documentation and utilization. So many wild species are restricted to gene banks only, which should be evaluated in different agroecological conditions in the world for their possible utilization in terms of food, medicine, nutrition or other economic value. In Alliums so many wild resources are available and are unexploited or underexploited. Many of the species have medicinal properties and need to be analyzed properly and utilized. Foliage or roots of some of the *Allium* species are consumed but need systematic studies for their proper utilization, and can be used as a substitute to onion and garlic. There is a need for the systematic evaluation of available *Allium* species for various horticultural characters besides resistance to pests and diseases for their proper exploitation. Crossability of wild species with the cultivated one is not exploited like in other crops due to certain crossability barriers. These need to be overcome systematically among various species with biotechnological tools. Use of desirable traits in the development of hybrids and varieties according to demand of the consumers is necessary.

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Genetics and Breeding of Open-pollinated Varieties

4

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Onions ranging in colour from purple, red, pink, white, yellow to brown are cultivated worldwide. In India, red to pinkish-red onions with medium to strong pungency are preferred, and white onions are the next popular group. Varied choices necessitate breeding onions for a number of agronomically useful traits and market preferences. Cultivation of open-pollinated varieties predominate in India due to their easier seed-production system in comparison to hybrids.

Cytology

Allium cepa is a diploid (2n=2x=16) with eight pairs of chromosomes (Stack and Coming, 1979) and is considered an excellent cytological model system because of its relatively large chromosomes which are easily observed under the microscope. Karyotype and chromosome behaviour in Alliums was described by Jones (1990). The eight basic chromosomes can be distinguished based on their lengths, ratio of two arms and staining intensity. Chromosome symmetry was observed to be highly conserved within *A. cepa*.

Kalkman (1984) proposed the first detailed and accurate account of onion karyotype for relative chromosome length, centromeric position and intercalary C-band pattern. These results were confirmed by several works (Peffley and Currah, 1988; de Vries and Jongerius, 1988), and have been adopted as the standard system of nomenclature for the species (Fig. 4.1).

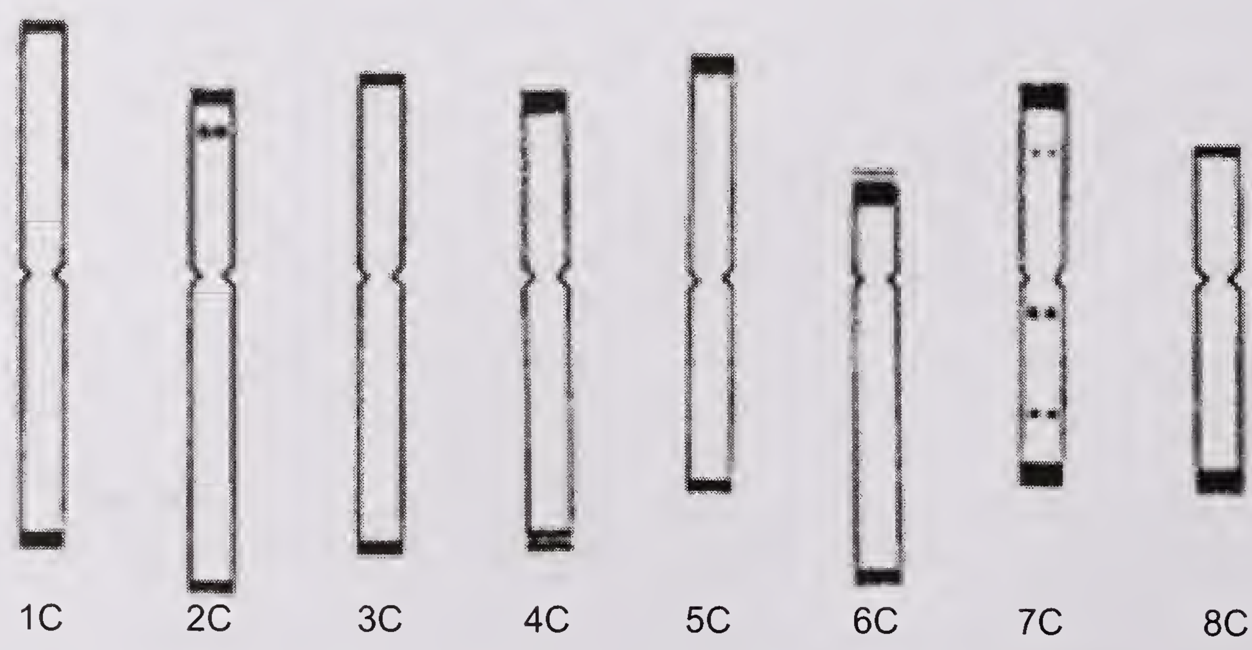

Fig. 4.1 Idiogram of *Allium cepa* (adapted from de Vries 1996)

The onion nuclear genome is notable for its great size, 15 Gbp per 1C (Ricroch *et al.*, 2005); one of the largest among cultivated plants. The 2C value for the species is 33.5 pg (Jones and Rees, 1963). King *et al.* (1998) reasoned this extremely large diploid genome as the result of tandem duplication in the process of evolution.

Genetics of Agronomic Traits

Genetic analysis in onion is time consuming because of its biennial nature and severe inbreeding depression. Thus it is difficult to produce and maintain a large, near homozygous inbred populations for genetic linkage analysis. Therefore, compared to many other vegetable crops, only a few qualitative genes with easily visible effects have been described in onion (Table 4.1). Just 17 morphological or disease resistance genes were described (King *et al.*, 1998), including bulb, foliage, anthers and seed coat colour, male sterility, restoration of CMS, pink-root resistance, ozone damage resistance, dwarf seed stalk and chlorophyll deficient mutants (Sl no. 1–12 in Table 4.1). Apart from these, Bacher *et al.* (1989) reported two partially dominant genes, *Foc1* and *Foc2,* for basal-rot resistance and Molenaar (1984) reported *gls1 and gls2* for glossy scape, epistatic to glossy foliage (*gl*).

A number of studies reported inheritance of yield, quality and resistance traits (Havey, 1993). Highly significant general combining ability (GCA) and relatively smaller significant specific combining ability (SCA) effects for yield and maturity were also reported (Hosfield *et al.*, 1975; Hosfield *et al.*, 1977a, b). Additive gene effects, governing dry matter content, bulb size (Padda *et al.*, 1973) and maturity (Pandian and Muthukrishnan, 1974), and additive and non-additive gene effects

Table 4.1 Genetics of agronomic traits in onion (Adapted from Pike 1986)

Agronomic trait	Genetic condition
Albino seedling	*a/a*
Yellow seedling linked with glossy	*y1/y1*
Yellow seedling not linked with glossy	*y2/y2*
Pale green seedling	*pg/pg*
Virescent seedling	*v/v*
Glossy foliage	*gl/gl*
Exposed anther	*ea /ea*
Yellow anther	*ya/ya*
Pink-root resistance	*pr/pr*
Male-sterility nuclear gene (Interaction between nuclear gene and plasma gene, S)	*ms/ms*
Brown seed colour	*b/b*
Bulb colour	Five major genes (*ICGLR*) dominant white (*I-*), recessive white (*cc*), yellow (*iiC-llR-*, *iiC-L-rr*, and *iiC-llrr*), and light-red to red (*iiC-L-R-*) *L2: Another locus governing red colour*
Basal-rot resistance partially dominant genes	*Foc1* , *Foc2*
Glossy scape	*gls1* , *gls2*

for bulb yield and number of leaves per plant were found to play an important role (Aghora, 1985). Available evidences suggest that bulb shape, single centre and bolting resistance during bulbing are governed by additive gene action. High heritability was reported for bulb yield, bolting percentage, bulb diameter and sprouting percentage (Patil *et al.*, 1986); indicating better scope of improvement through selection. Traits like seed yield and 1,000 seed weight had low heritability (Dadlani and Bhagchandani, 1978). Storability has been correlated directly with soluble solids content.

Genetic analyses using molecular markers of several traits have been studied. The first public genetic linkage map was published in 1998 (King *et al.*, 1998) and since then several mapping populations have been developed for genetic and molecular analysis of yield and quality traits in onion. A few of them include the following.

1. BYG15-23 × AC43
2. B2246 ×B11159
3. W202A ×Texas Grano 438
4. Interspecific *A. cepa* × *A.roylei*
5. CUD H2150 × Nasik Red
6. Doubled haploid population between DH 5225 (red, doubled-haploid onion) × OH 1 (yellow inbred that shows high frequency of gynogenic haploid production)

Onion mapping populations are generally based on the inbred lines that have typically been subjected to only one generation of self-pollination. In onion, high levels of residual heterozygosity have greatly complicated marker development and sequence analysis. Development of highly fecund doubled-haploid (DH) lines provides an opportunity to use homozygous, distributable reference lines for onion genetics and genomics. Notable among them and relevant to breeding programmes is the population based on Nasik Red and a homozygous doubled-haploid bulb onion line CUDH 2150 (Baldwin *et al.,* 2012).

The details are available in "*Allium* Map-a comparative genomics resource for cultivated *Allium* vegetables" (http://alliumgenetics.org).

Breeding Methods

Onion is a highly cross-pollinated crop, and selfing beyond second generation results in inbreeding depression. The average bulb yield was only 64% in selfed generation compared to the open pollination. The mean maturity was delayed by 12 days with increase of thick-necked bulbs from 2 to 12% in the inbred populations (Dowker and Fennel, 1981). After 3 generations of selfing, survival rate was down to 50% and seed-set was only 70% (Jones and Mann, 1963). Khan *et al.*, (2001), however, reported that degree of inbreeding depression depended on the genetic background. Therefore, breeding methods based on continuous selfing are less efficient in onion.

Onion, being cross-pollinated, has an excellent possibility for population

Table 4.2 Onion varieties released worldwide using various population improvement methods

Variety released	Method used	Reference institute involved and year of release
Improvement of ancient Russian variety 'Spasskii'	Mass Selection and Intravarietal Recurrent Hybridization	Efimochkina 1970
Yalova 1, Yalova 3 and Yalova 12	Mass Selection and Single plant selection in Thrace population	Akgun 1970
N 53	Mass Selection (Collection from Nashik, Maharashtra)	MPKV, Rahuri, 1975
Punjab Selection	Mass Selection (Collection from Punjab)	PAU, Ludhiana, 1975
Pusa White Flat	Mass Selection	IARI, New Delhi, 1975
Pusa White Round	Mass Selection (Local collection 106)	IARI, New Delhi, 1975
Co 2	Mass Selection (Collection from Tamil Nadu)	TNAU, Coimbatore, 1978
Punjab 48	Mass Selection (Collection from Punjab)	PAU, Ludhiana, 1978
Pusa Ratnar	Mass Selection (Selection from Red Granex)	IARI, New Delhi, 1978
Pusa Red	Mass Selection (Local Collection)	IARI, New Delhi, 1978
Co 3	Mass Selection (Collection from Tamil Nadu)	TNAU, Coimbatore, 1982
Kalyanpur Red Round	Mass Selection (Collection from Uttar Pradesh)	CSUAT, Kanpur, 1983
Arka Pragati	Mass Selection (Collection from Nashik, Maharashtra)	IIHR, Bengaluru, 1984
N 2 – 4 – 1	Mass Selection (Collection from Pune, Maharashtra)	MPKV, Rahuri, 1985
Arka Niketan	Mass Selection (Mass Selection from a local collection IIHR 153)	IIHR, Bengaluru, 1987
Agrifound Dark Red	Mass Selection (Collection from Nashik, Maharashtra)	NHRDF, Nashik, 1987
Pusa Madhavi	Mass Selection (Collection from Muzaffarnagar, Uttar Pradesh)	IARI, New Delhi, 1987
Dorata di Parma resistant for *Fusarium oxysporum* f. sp. cepae Snyd. et Hans.	Combination of Mass and Recurrent Selection	Fantino and Schiavi 1987
Arka Kalyan (Sel 14)	Mass Selection (Mass selection from a local collection IIHR 145)	IIHR, Bengaluru, 1987
Baswant 780	Mass Selection (Collection from Pimpalgaon, Maharashtra)	MPKV, Rahuri, 1989

(Contd...)

(. . . Table 4.2)

Variety released	Method used	Reference institute involved and year of release
VL Piaz 3	3 cycles of Mass Selection after F_2 of cross 'In-13 x L-43'	Mani *et al.* (1999)
Screening and analysis of components of white shaft weight	Maternal pedigree selection in male-sterile plants and male-fertile plants (MPSMS and MPSMF)	Zhaoshui *et al.* (1995)
Composto IPA 6 and Belem IPA 9	Mass Selection for tolerance to *C. gloeosporioides, T. tabaci* and good post-harvesting conservation qualities	De Franca *et al.* (1997)
Cobriza INTA	Mass Selection from Valenciana type onions	Galmarini *et al.* (2001)
Navideña INTA	Mass Selection from Torrentina local population	Galmarini *et al.* (2001)
Antártica INTA	Mass Selection from Valenciana type onions	Galmarini *et al.* (2001)
NuMex Chaco onion	Recurrent Selection	Cramer and Corgan (2001a)
NuMex Snowball' onion	Recurrent Selection	Cramer and Corgan (2001b)
NuMex Arthur onion	Recurrent Selection	Wall and Corgan (2002)
Gholy	Mass Selection (Ghesseh Local Onion)	Javad *et al.* (2004)
Purifying the popular land variety Abu Ferewa	Phenotypic Recurrent Mass Selection and Inbreeding followed by Bulking	Bakheet (2008)
Arka Pitambhar	Pedigree selection from the cross, U.D. 102 x IIHR-396	IIHR, Bengaluru http:/www.iihr.res.in frmVarieties.aspx
Bhima Super	Rigorous Mass Selection for single centeredness and bulb shape	Lawande *et al.* (2007)
Bhima Red & Bhima Raj	Single Bulb Selection up to three generations, followed by Mass Selection	Lawande *et al.* (2009)
Bhima Shakti and Bhima Kiran	Mass Selection for good keeping quality	Lawande *et al.* (2010a & b)
Bhima Shweta	Selection of elite lines from germplasm, followed by random mating and Mass Selection for *rabi* season white onion	Mahajan *et al.* (2010, 2011)
Bhima Shubra	Selection of white segregating bulb from red germplasm, followed by Mass Selection for *kharif* and late *kharif* season	Mahajan *et al.* (2010, 2011)

improvement methods, as natural variability is created constantly. Information on the nature and extent of the genetic variability and degree of transmission of traits and knowledge of correlations among various characters is of paramount importance in enhancing selection efficiency (Table 4.2).

A major contribution to onion breeding has been the development of new open-pollinated (OP) varieties through a range of population improvement methods. OP varieties are defined as genetically variable populations, which are maintained and multiplied by mass pollination in isolation. The most appropriate technique depends on how well-developed existing cultivars are, besides the expertise and resources available for breeding.

Mass selection

This has been the most preferred method for onion improvement throughout the world. In this, around 1-5% individual plants are selected from one population based on the phenotypic performance, and seeds are composited to raise the next generation (Fig.4.2). Several cycles of mass selection are usually employed before larger-scale multiplication of new improved variety. It takes 5–6 such cycles to attain the final uniformity and superiority required in a variety for commercial cultivation. This method is effective where populations have a wide genetic-base and for the characters, which are highly heritable and governed by additive gene action. Selection intensity and population size need to be balanced to reduce any inbreeding depression due to selection of a fewer plants and for avoiding losing superior genotypes due to higher selection intensity. The main drawback in this method is that there is no control over pollen parent; and selection is purely based on the performance of the female parent. It is a simple method, and requires no specialized knowledge and is suitable where industry is just emerging.

A refinement to mass selection is the stratified mass selection, where field plots of bulbs grown for selection are subdivided equally, and the same proportion

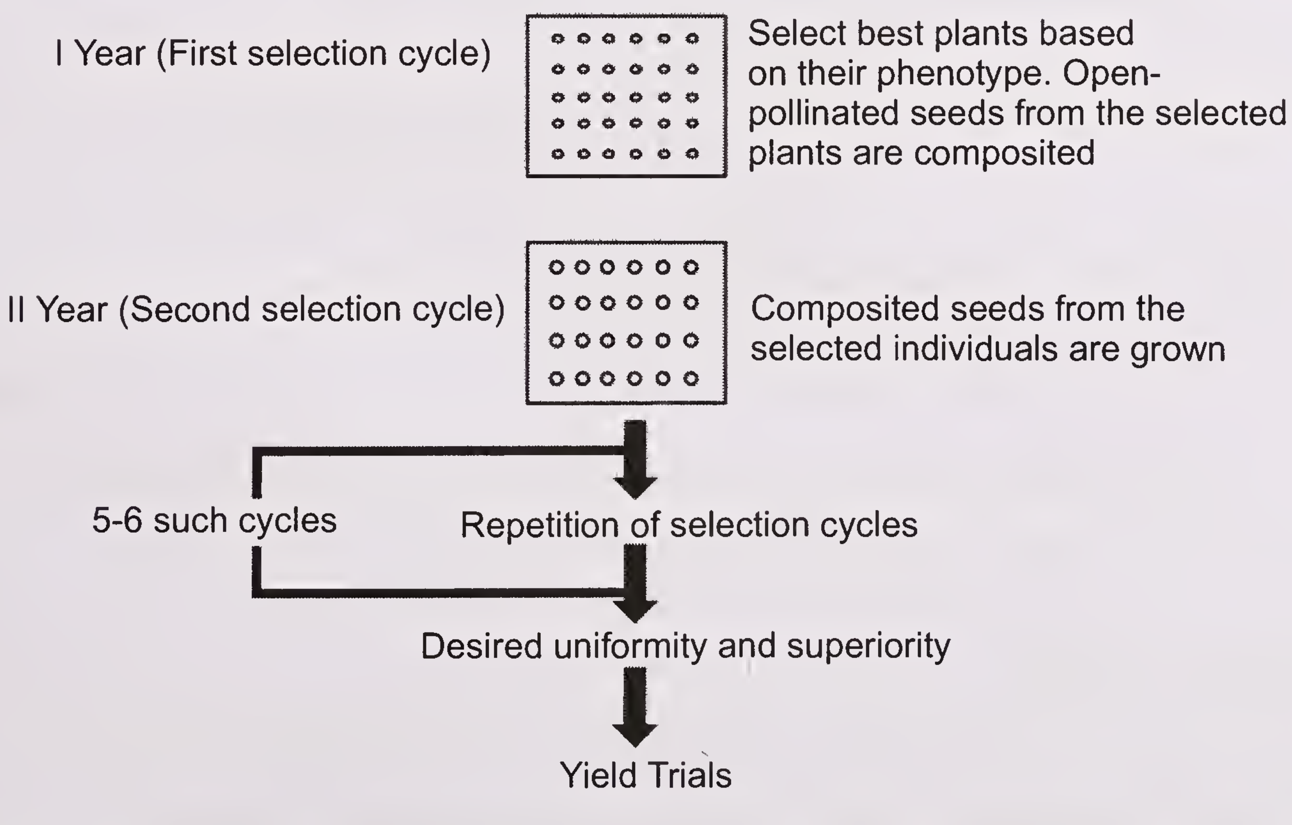

Fig. 4.2 A schematic representation of mass selection (adapted from Singh 1983)

of selected bulbs of desired types is chosen from each area. It helps make allowance for the effect of variable growing conditions within the field plot on appearance of the mother-bulbs, and correspondingly increase chances of picking out heritable variations during the selection process (Rabinowitch and Brewster, 1990).

Selfing and massing technique

This method was suggested by Jones and Mann (1963) for onions to overcome inbreeding depression. Each breeding cycle consists of the following steps.

1. The parent population may be an open-pollinated variety or the segregating progeny of a cross between two parental lines. Selected bulbs are selfed in the first generation.
2. Selfed seed are harvested and grown separately, and poor progenies are discarded.
3. Total of 15–20 bulbs in 5–10% of the best lines are selected and open-pollinated in isolation.
4. The massed seed is harvested together.

Steps 1–4 are repeated till uniformity and superiority is attained (Fig.4.3). This breeding method is open-ended, meaning number of cycles of selection can vary and promising new lines can be brought into the sequence at any stage depending upon the requirement. Pusa Madhavi is one such variety developed through this at the IARI, New Delhi.

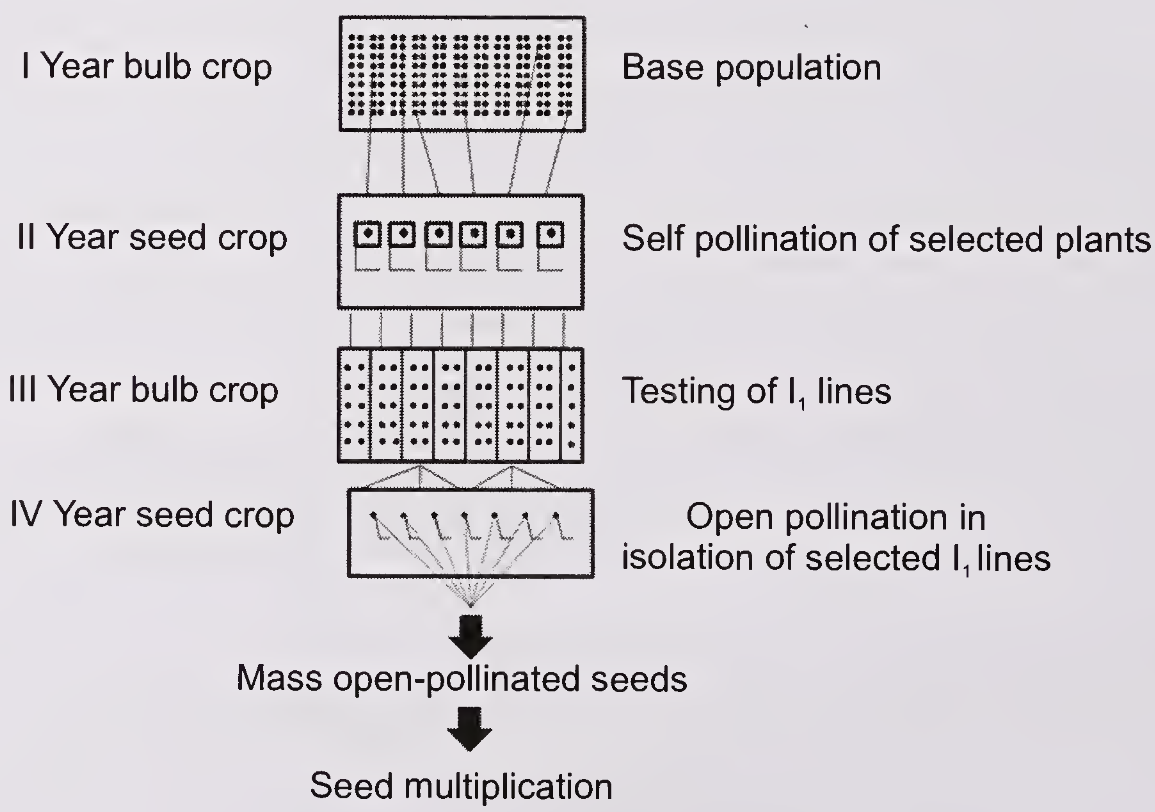

Fig. 4.3 Selfing and massing technique for genetic improvement of onion (adapted from Kalloo1988)

Synthetic varieties

This is a breeding method recommended for cross-pollinated crops like onion where floral morphology does not permit manual commercial production of F_1 hybrids. This system is valuable where commercial seed industry is not well developed to handle complex male-sterility systems for hybrid-seed production.

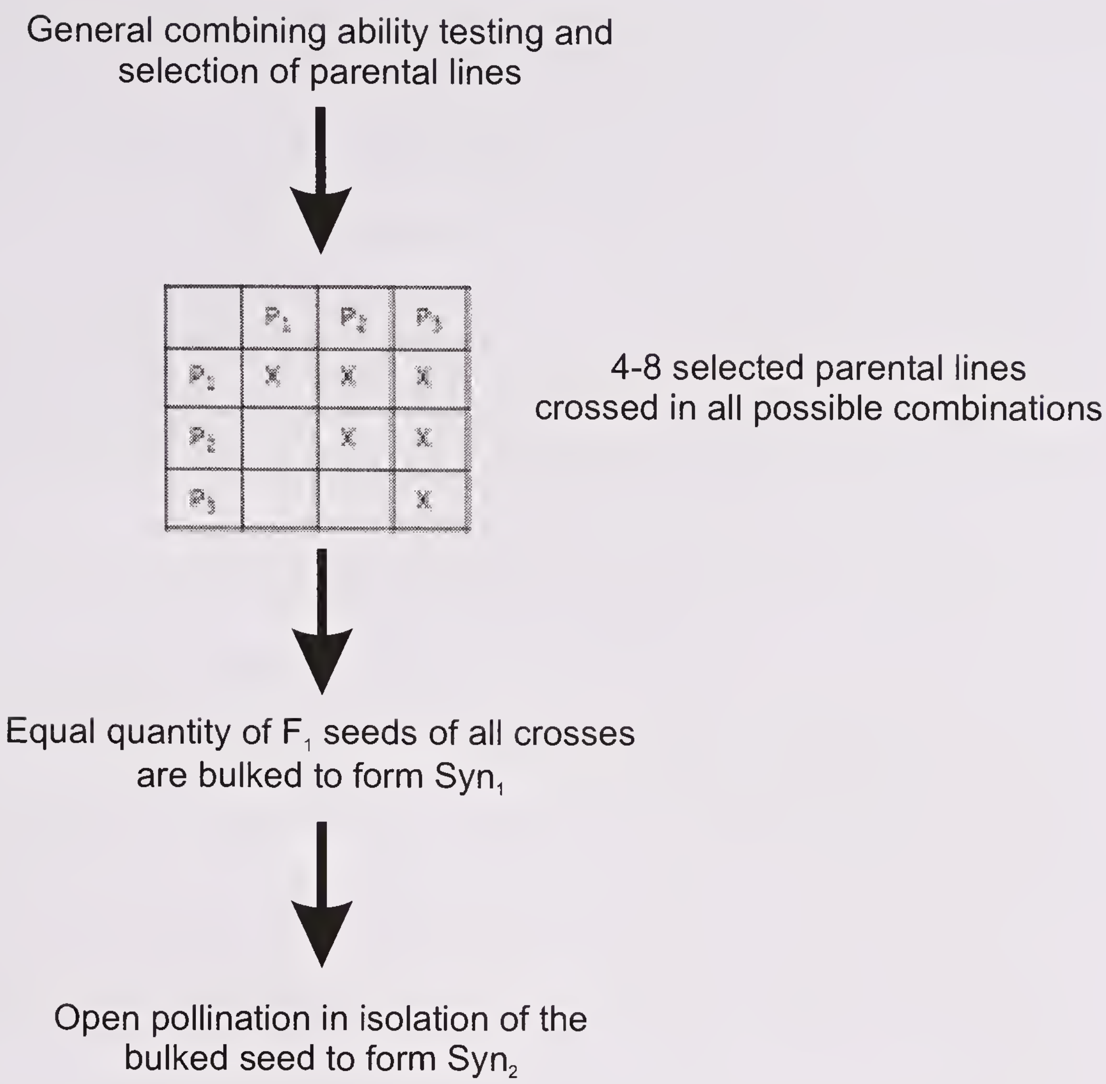

Fig.4.4 Steps involved in onion synthetic variety development

In this, cost of seeds is expected to be lower than hybrid varieties, and farmers also benefit from multiplying their own seeds for the next season.

Parental lines for a synthetic variety, which can be an inbred line or a variety developed by the mass selection or recurrent selection, are chosen based on their general combining ability and hence would be exploiting additive genetic variance. Synthetic variety is produced by crossing a number of lines that combine well in all combinations with one another, and is maintained by open pollination in isolation for a limited number of generations (Fig.4.4). Hence, the variety needs to be regularly reconstructed. Arka Bheem is one such variety developed at the IIHR, Bengaluru.

Not much information is available on the prospects of synthetic varieties in onion. Hence, efforts need to be made to generate basic evidences, especially on the issues like appropriate number of parents, choice of parents, consequent level of inbreeding, and parameters for yield prediction (Rao, 2014).

Family selection

More sophisticated open-pollination breeding methods are based on the family selection. Many desirable agronomic characters are quantitative in nature with low heritability. In such circumstances, using the family mean performance, rather than the individual bulb as an unit of selection is more appropriate. Commonly, half-sib families or 1–2 generation selfed families are used. The method operates as an alternative to field evaluation of bulbs and involves controlled pollination of selected families in consecutive seasons. New promising lines may be brought

Table 4.3 Season-wise schematic plan to breed open- pollinated onion cultivars as proposed by Pike (1986)

Season	Procedure
1	Grow source lines and select 100 bulbs, store bulbs
2	Plant selected bulbs and self
3	Plant S_1 seed in progeny rows, select best bulbs from best progeny rows, discard poor progenies completely, store bulbs
4	Plant S_1 bulbs and self 5-10 selected bulbs from each progeny, also make a few 3-5 plant masses from same progeny rows
5	Plant S_2 seed and three bulb mass seed obtained in the fourth year, select lines that look similar, select same good 3-5 bulb masses, which look uniform, store bulbs
6	Plant S_2 bulbs and mass 10-15 S_2 bulbs from selected progeny rows
7	Plant seed to have observation trials for early evaluation of bulbs, select superior progenies and discard others
8	Mass 100 bulbs and plant in a 9 feet × 10 feet cage for small seed increase of selected lines
9	Plant seed for yield trials at multilocations, select best stock bulbs for further seed increase
10	Plant bulb to make a 12 feet × 24 feet cage for seed increase, observe seed yield
11	Plant several commercial plantings to evaluate for all requirements such as shipping, storage and processing which were not possible during earlier testing
12	Release superior liner as a new cultivar

into at any stage of selection. Both the 'intermediate improved population' and 'final variety' created by the intercrossing of selected bulbs from selected families by open pollination in isolation are suitable. The final variety may be maintained by mass selection in subsequent generations. Wall *et al.* (1996) used half-sib family selection and proved its efficacy for improving pungency and single centeredness in onion breeding populations. Two methods of family selection were proposed in onion by Pike (1986) (Table 4.3) and Dowker (1990) (Fig.4.5).

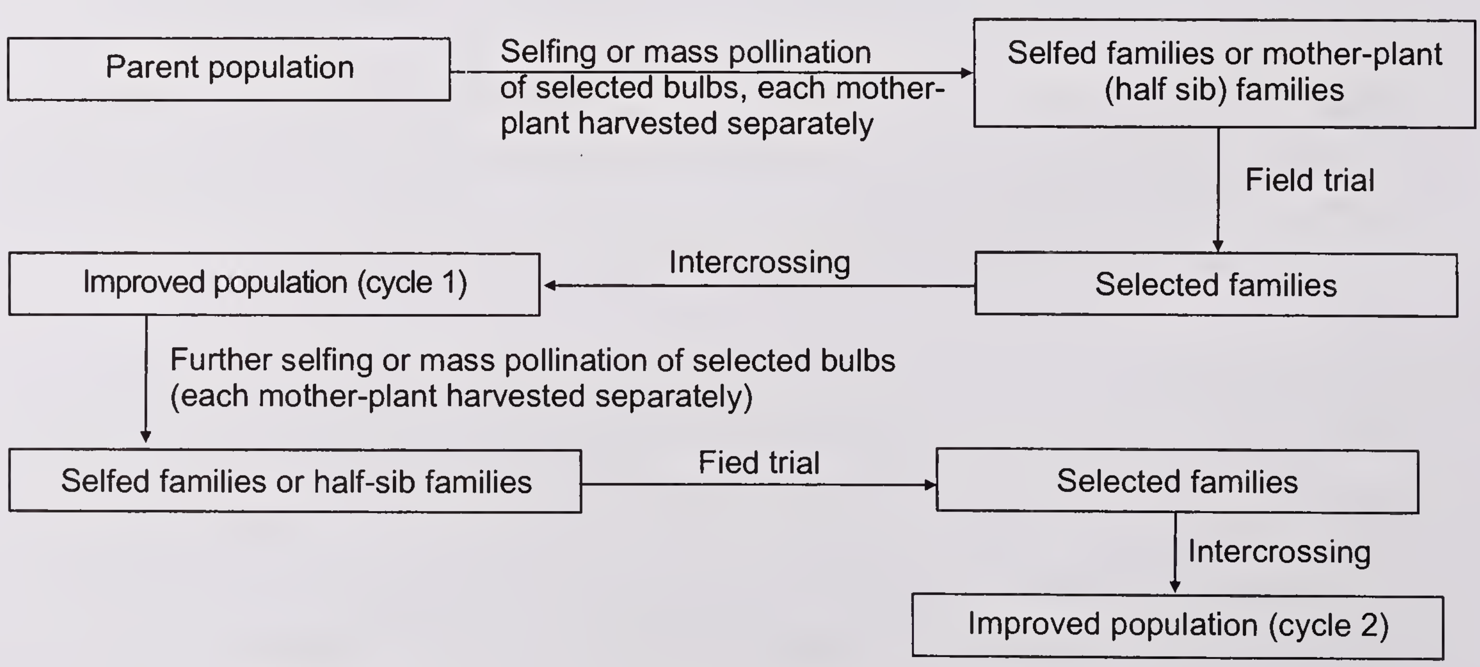

Fig. 4.5 An open- pollinated family breeding scheme in onion (adapted from Dowker 1990)

Recurrent selection

A population having a broad genetic-base, i.e. a segregating population or a multiple hybrid or any improved population with greater genetic variability can constitute a base population. A few superior plants within the base population are selected and selfed followed by inter-mating in all possible combinations under isolation of selected selfed seeds from the previous generations to complete original selection cycle. Composited intercross seeds are planted and the repetition of the original selection cycle constitutes the first recurrent selection cycle. The cycle can be repeated until there is an increased frequency of desirable genes (Fig 4.6).

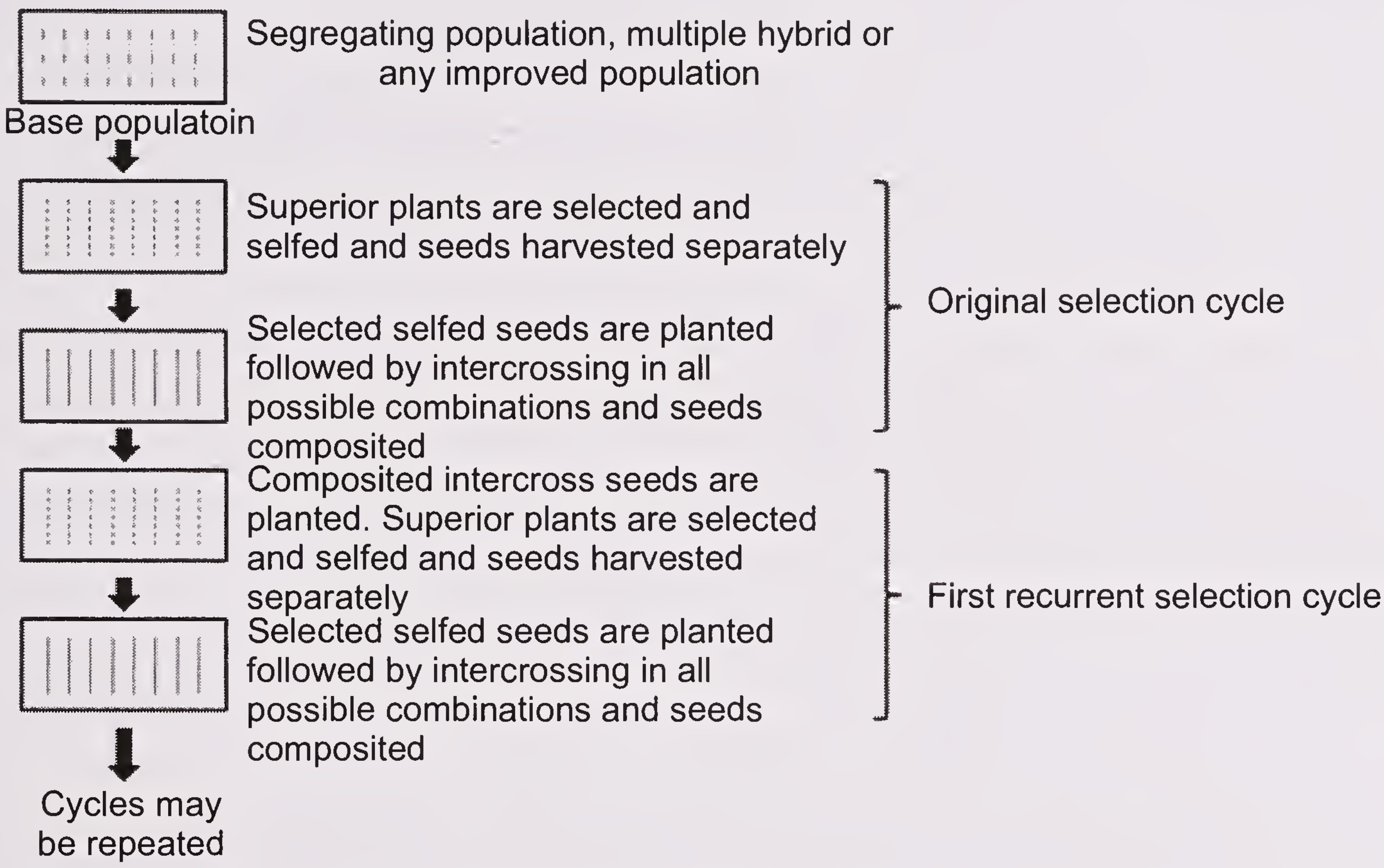

Fig. 4.6 Recurrent selection for onion population improvement (adapted from Singh 1983)

Populations based on the recurrent selections for improved yield, bulb quality and storage performance (Dowker *et al.*, 1984) were developed. Cramer (2001a, 2001b) and Wall and Corgan (2002) developed cultivars NuMex Arthur, NuMex Chaco and NuMex Snowball using recurrent selection method. "NuMex Starlite", a yellow-onion variety developed by Corgan and Holland (1993), was obtained by 5 recurrent selections from Texas Grano 502 PRR.

Pedigree selection

Considering prevalence of inbreeding depression, pedigree selection is not a preferred method. Near inbred lines are used for hybridization, followed by selfing over generations. The Indian Institute of Horticultural Research(IIHR), Bengaluru, developed a yellow onion variety, Arka Pitambar, through pedigree selection from U.D. 102 × IIHR 396. This variety produces bulbs of medium size (5.2–6.0 cm) in globe shape with thin neck, and it possesses mild pungency with 11% TSS and 9.81% total sugar.

Breeding Objectives

Since preferences vary from market to market, it is not possible to characterize fully an ideal onion. Breeding goals depend on preference of the market for colour, shape and utility.

Major goals include—High yield, intact attractive skin, uniformity for bulb shape, size and maturity, thin neck, free from splits, better storage with less sprouting and rotting, high dry matter content and disease resistance.

Though it is a biennial crop, its each seed-to-seed breeding cycle in Maharashtra and Karnataka can be accomplished within a year where *kharif* crop is taken as compared to northern India, where it takes 2 years for each cycle.

Bulb development in onion is related to climate, and hence its breeding and selections are to be made in the region where it is to be cultivated (Brewster 2008). Usually, positive selection at a time is confined to a few major traits coupled with appropriate ways of measuring characters selected to attain breeding objectives. Many objectives for breeding like shape, colour, skin retention, splits can be assessed visually and are qualified by a simple scoring system. Maturity dates can be assessed based on 50% neck fall. Selection pressure against premature bolting may be imposed by appropriate dates of *rabi* sowing. TSS is an indirect measurement of dry matter content. Many special tests have been devised for pest and disease resistance to supplement gross field observations. It should be kept in mind that bulb size, shape, maturity date, percentage thickness of neck and split bulbs all are influenced by population density (Rabinowitch and Brewster, 1990).

In the absence of continuous selection, quality of open-pollinated cultivars may degenerate. Unless constant selection pressure is applied, population drifts towards flat bulbs with multiple centres and premature bolting. Hence, selection is necessary to maintain resistance for premature bolting, single centred bulbs, bulb shape and increased dry matter. The proportion of plants with any feature that tends to increase seed yield would increase with repeated seed multiplication in the absence of selection against it (Brewster, 1994).

Breeding for production

Onion has been bred to adapt to a variety of climates. Many factors affect onion development, bulb formation and maturity; environmental conditions and plant genotype are the two main components. The onion-crop that can bulb at a day length of 11.5 hr, belongs to a short-day group and that requires 14 hr or more to bulb is a long-day type. The terms "long", "intermediate" and "short-day" are used largely by onion breeders to describe photoperiod requirements for bulb formation of different cultivars, which are misnomers (Cardoso and Cyro da Costa, 2003). "Short-day cultivars" actually from a physiological point of view are long-day cultivars, since they produce bulbs with a photoperiod above a particular critical value, which is smaller only when compared to cultivars referred to as "long-day cultivars" (Jones and Mann, 1963; Brewster, 1990).

Increasing day-length enhances speed of bulb formation and decreases time between beginning of bulb formation and bulb maturation (Steer, 1980). The minimum photoperiodic requirement can also be reduced with increased temperature (Heath, 1943). Photoperiod and temperature relation is so important that minimum photoperiod for a cultivar should never be specified without the corresponding temperature specification (Jones and Mann, 1963). In general, higher temperature accelerates, and lower delays bulb development.

High productivity in higher latitudes is favoured by long maturity season and long-day photoperiodic condition, resulting in high TSS and very compact bulbs. In contrast, Indian onions maturing under short-day condition with short-growing season yield less. Hence, average yield in India is only 12–16 tonnes/ha against 30 tonnes/ha in countries located between 25 and 30°N latitude (Sheshadri and Chatterjee, 1996). Onion in India is grown commercially between 12 and 25°N latitude during the three major seasons (Mahajan and Lawande, 2008). In Indian plains, short-day types are planted in *kharif* and *rabi* with an intermediate *rangda* season. Through centuries of selection, types, which respond to warm and humid days and around 11–11.5 hr photoperiod, have been identified and maintained by farmers. Several such local types which are very well adapted to specific regions are being cultivated on a wide area. Some of them are: Patna White, Bombay Red, Patna Red, Poorna Red, Nasik Red, Bellary Red, Gujarat White, Bengaluru Rose, Krishna Puram Rose etc. From this material, superior genotypes like N 53, Agrifound Dark Red, Basawant 780, Bhima Super, Bhima Shubra and Arka Kalyan have been developed. Experience shows that long-day types developed in cooler countries, do not perform well in Indian plains.

Lee *et al.* (2013) studied molecular mechanism of photoperiodic influence over bulbing and flowering. They observed that different *Flowering Locus T* (*FT*) genes regulated these traits. Flowering is promoted by vernalization and it correlates with up-regulation of the gene *AcFT2*, and bulb formation is regulated by two antagonistic *FT*-like genes. *AcFT1* promotes bulb formation, while *AcFT4* prevents *AcFT1* up-regulation and inhibits bulb formation in transgenic onions. Long-day photoperiod leads to down-regulation of *AcFT4* and up-regulation of *AcFT1*, and this promotes bulb formation. Thus interplay of these genes regulated by photoperiod decides transition from juvenile to reproductive phase. A greater understanding of this mechanism would help breeding varieties for different climates and would narrow down genetic isolation between long-day and short-day cultivars.

Breeding for quality

Important quality traits of the bulb are size, shape, colour, pungency, firmness, dormancy and amount of soluble solids. Bulbs of various shapes and colours are preferred by consumers in different parts of the world. Most bulb quality traits have a genetic basis, and can be manipulated by breeding. Nakamura (1959), McCollum (1968, 1966, 1971) and Dowker and Fennell (1974) estimated heritabilities of bulb size and shape in different onion populations. Bulb height and bulb shape index (bulb height/diameter) showed relatively larger heritabilities compared to bulb diameter and weight. Hence, breeders can expect response to selection for bulb height, but not for bulb diameter. Environment has a greater influence over bulb diameter. If bulb diameter grows in a shorter time-frame, bulbs will be pyriform and if more time for growth, bulb diameter will be more.

Bulb colour is an economically important trait in onion, and is conditioned by interactions of at least five major loci (Clarke *et al.*, 1944; El-Shafie and Davis, 1967; Reiman, 1931). White bulbs result from a dominant allele at *I* locus or recessive alleles at *C* locus. Coloured bulbs (chartreuse, light red, red, or yellow) are due to homozygous recessive genotype at *I* locus and a dominant allele at *C* locus. In plants that are *iiC-*, a dominant allele at *G* locus produces golden-yellow bulbs, and homozygous recessive genotype (*iiC-gg*) results chartreuse bulbs. Light-red bulbs are produced when the plant is *iiC-G-* and has dominant allele at both *L* and *R* loci; bulbs with deeper red colour are produced when both *L* and *R* loci are homozygous dominant (El-Shafie and Davis, 1967). If either *L* or *R* locus is homozygous recessive, yellow bulbs are produced. El-Shafie and Davis (1967) stated that light-red bulb colour would be produced when two yellow onions are crossed [termed complementary light-red by Jones and Peterson (1952)] of genotypes *iiCCGGLLrr* and *iiCCGGllRR*.

Among these five loci, no candidate genes were identified for *I*, *C*, or *G* loci. Kim *et al.* (2004a, 2005b) identified a differential expression of *dihydroflavonol 4-reductase* (*DFR*) gene between yellow and red coloured bulbs, and developed functional markers for different alleles of this gene (Kim *et al.*, 2009; Park *et al.*, 2013). This gene was assigned to *R* locus by Khar *et al.* (2008). The *L* locus appears to be a highly variable and has been assigned to *anthocyanidin synthase* (*ANS*) gene, reported to possess several alleles. Kim *et al.* (2005a) and Kim *et al.* (2006) reported four alleles at *L* locus [*ANS-p* for recessive pink, *ANS-l* and *ANS-L* for Brazilian and North American alleles of complementary light-red system, respectively, and *ANS-h1* for dark red]. Khar *et al.* (2008) reported a new locus (*L2*) linked at 6.3 cM to *ANS* that is for red bulb colour of onion. Additionally, Kim *et al.* (2004b) reported occurrence of a golden coloured onion owing to a natural mutation at *chalcone isomerase* gene; resulting in a pre-mature termination codon.

Carbohydrate (fructose) and sulphur metabolisms are important pathways contributing to quality of onions. Carbohydrate metabolism relates to stabilizing dry matter content, and the sulphur metabolism relates to pungency. Some of the long-day varieties are with high TSS, ranging from 15% to 24%; TSS is a function of the genotype, cultural practices and environment. Non-structural dry matter content of onion-bulbs principally consists of fructose, glucose, sucrose and fructans. Quality trait loci(QTLs) related to carbohydrate and flavour metabolism have been identified on the basis of Alien Monosomic Addition Lines (AMALs) of Japanese bunching onion (*A. fistulosum*) with extra chromosomes from shallot (*A. cepa*) (Shigyo *et al.*, 1996). Another SSR marker, ACM235, identified on chromosome 8, exhibited strong linkage with bulb fructan content in F(2:3) families from 'W202A' × 'Texas Grano 438' mapping population (McCallum *et al.*, 2006).

In Indian plains, varieties mature in high temperature, which facilitates high sulphur accumulation. Amount of s-alkyl cysteine sulphoxide precursors and enzyme allinase contribute to pungency of onion-bulbs. Candidate genes for sulphur assimilation were used to identify genomic regions affecting pungency in the cross 'W202A' × 'Texas Grano 438' (McCallum *et al.*, 2007). Linkage mapping has indicated that genes encoding *plastidic ferredoxin-sulfite reductase* (*SiR*) and *plastidic ATP sulfurylase* (*ATPS*) are closely linked (1–2 cM) on chromosome 3. QTL analysis revealed significant association between pungency and TSS with marker intervals on chromosomes 3 and 5, which were previously reported for pleiotropic effects on bulb carbohydrate composition. These markers may be used as a practical tool to break linkage between pungency and TSS.

Onion populations showed marked differences in storability (Magruder *et al.*, 1941) and firmness (Fennell, 1978). Phenotypic correlations between large size, softness, low pungency and poor storability were recognized (Bedford, 1984; Foskett, 1949; Hosfield *et al.*, 1976). These correlations have been countered for a firm, well storing and less pungent large size bulbs (Peterson *et al.*, 1986). Selective genotyping in a large 'Nasik Red × CUDH2150' F_2 family revealed a major QTL on chromosome 1 associated with bolting, and named it as AcBlt1 (Baldwin *et al.*, 2014).

Breeding for processing quality

Dehydrated products such as flakes, rings, granules, powder etc., and processed products, like onion in vinegar and brine, are being prepared and marketed worldwide. Ideotype for dehydration includes pure white bulbs, with globe shape, thin neck, high pungency and high TSS (>15–18%). In India, several attempts were made for development of white onion varieties by different research institutes (Table 4.4) (Mahajan and Lawande, 2011).

Table 4.4 Charateristics of white onion varieties developed in India (Mahajan and Lawande, 2011)

Variety	Source	TSS (%)	Average yield q/ha
Pusa White Round	IARI, New Delhi	11.13	300–325
Pusa White Flat	IARI, New Delhi	10.00	325–350
Udaipur 102	RAU, Udaipur	10.06	300–350
Agrifound White	NHRDF, Nashik	10.76	200–250
Phule Safed	MPKV, Rahuri	10.13	250–300
PKV White	PDKV, Akola	9.55	250–300
Gujarat White	JAU, Junagadh	–	300–325
N 257-9-1	Agril. Deptt, Maharashtra	10.00	250–300
Punjab 48	PAU, Ludhiana	11.00	300–325
Arka Swadista	IIHR, Bengaluru	18.00	160–180
V 12	Jain Food Park	15.00	350–400
Nimar Local	Land Race, Madhya Pradesh	12.50	250–300
Talaja Local	Land Race Bhavnagar	12.00	250–300

Breeding for export

India is the leading exporter of onions, followed by Netherlands. India's export is mostly to South-East Asia and Gulf countries; red to light-red onions with globe shape are mostly preferred in various sizes. Since, grading is a major requirement for export, any breeding programme for export should aim at uniformity in shape, size and colour. European markets require yellow or brown varieties with big size (>60 mm diameter) and less pungency. Three such varieties developed in India are Arka Pitambar and Arka Sona from the IIHR, Bengaluru, and Phule Swarna from the MPKV, Rahuri.

Apart from the above two segments, the other specific export segment includes rose onion, grown in Bengaluru and Kolar districts of Karnataka and Kadapa district of Andhra Pradesh. These are small (2.5–3.5-cm diameter), deep scarlet-red, highly pungent, flattish-round with high TSS of 21%. Malaysia, Indonesia, Singapore, Sri Lanka, Brunei, Bangladesh and a few countries in West Asia such as Bahrain, Dubai constitute their main market. Premature bolting and high percentage of splits are major breeding issues for this segment. Three rose onion varieties—Arka Bindu and Arka Vishwas from the IIHR, Bengaluru, and Agrifound Rose from the NHRDF, Nashik, have been developed, which are found good for export.

Breeding for resistance

Purple-blotch, *Stemphylium*-blight, basal-rot and thrips are major diseases and pests of onions in India. Much of the resistance to pests and diseases has been derived by field selection under pressure of natural attack by pathogens. Availability of efficient screening technique for diseases is still a limitation. The resistance sources identified for some of the diseases and pests in India (VeereGowda, 1997) are listed in Table 4.5.

Purple-blotch (Alternaria porri)

Purple-blotch is presently the most severe disease in India, which can result in 100% losses of bulbs and seed crops in storage. Srivatsava *et al.* (1994) observed that the disease incidence was high in both *kharif* and *rabi* seasons when high

Table 4.5 Sources of resistance for diseases and insect- pests of onion

Sl No	Disease/pest	Level of resistance	Name of variety/line
1	Purple-blotch	R	IHR 56-1
		MR	Arka Kalyan, AFDR, IHR 25, VL 67, Red Creole and Pusa Red
		T	Rampur local and Patna Red
2	*Stemphylium*-blight	T	40 accessions (NBPGR)
3	*Stemphylium*-blight and purple-blotch combined resistance	R	IC 32176, IC 48954, IC 48710, IC 48724, IC 485754 and IC 49012
4	Basal-rot	R	IHR 506, IHR 141, Sel 13-1-1, Bellary Red
5	Thrips	R	White Creole, N 2-4-1, Sel 171, Kalyanpur Red Round
		T	Hisar 2, Panipat local, Bombay White

MR: Moderately resistant; R: Resistant; T: Tolerant humidity prevailed during 5 years of their survey (1988–93). Varieties like 'Red Creole' that have good wax covering on foliage and seed stem were found more resistant. Cuticle thickness was consistently greater in resistant varieties than susceptible ones. Resistance in such lines was markedly reduced by abrasion of leaves and by prolonged post-infection incubation at high relative humidity. Purple-blotch resistance has been found a recessive trait (Singh *et al.*, 1992).

Sources of resistance have been reported against purple-blotch (Pathak *et al.*, 1986; Dhiman *et al.*, 1986). Singh *et al.* (1992) reported that cultivars, VL1, PBR 1, PBR 5 and Arka Niketan were most tolerant. Agrifound Light Red (Sharma, 1997), N 53-3 (Pandotra, 1965), Agrifound Dark Red, Red Globe (Sugha *et al.*, 1992) and RO 59 (Mathur *et al.*, 2006) were reported to be moderately resistant.

Basal-rot

Fusarium basal-rot (FBR), caused by *Fusarium oxysporum* f. sp. *cepae,* is an important soil-borne disease of onions worldwide. The causal organism infects basal stem plate of the bulb and eventually kills entire plant through degradation of basal plate. Cramer (2000) reviewed breeding and genetics of basal-rot resistance in onion. Monogenic (Tsutsui, 1991), digenic (Bacher *et al.*, 1989) and polygenic inheritance (Villanueva-Mosqueda, 1996) of basal-rot resistance were reported. Breeding programmes have successfully used screening procedures to develop intermediate- and long-day, FBR-resistant cultivars. Cultivars showing adequate levels of resistance to FBR were developed (Gabelman, 1988). Sintayehu *et al.* (2011) identified some tolerant genotypes that could be used as a valuable source to enhance resistance against *Fusarium* basal-rot disease. High level of FBR resistance is still lacking in short-day onion cultivars.

Neck-rot

This, caused by *Botrytis allii*, commonly called grey mould neck-rot, is probably the most widely distributed and destructive disease of onions in storage. Owen *et al.* (1950) found mild flavoured cultivars in each colour group (red, yellow and white) suffering more with neck-rot than strongly pungent varieties. Difference in susceptibility among various mild pungent coloured bulb cultivars was not significant. Among the pungent ones, white suffered considerably more than coloured types. However, evidence suggests that pungency is more important than colour in giving resistance to neck-rot. Resistance has been reported in inbred lines, W420, W202 and B6693, developed at the University of Wisconsin. Other sources of onion germplasm showing resistance to *Botrytis* neck-rot were also reported by Van der Meer *et al.* (1971) and Miyaura *et al.* (1985).

Neck-rot resistance is a quantitative character, which shows continuous variation and is fixable in part by selection (Vik and Aastveit, 1984). Lin (1989) observed a moderate positive correlation between TSS and pyruvic acid content, a low negative correlation between pyruvic acid content and neck-rot disease index, and a medium negative correlation between TSS and neck-rot. Hence, use of simple and rapid hand refractometer method to select high TSS was effective in selecting high pungency and indirectly neck-rot resistant bulbs.

Lin *et al.* (1995) observed broad-sense heritability estimates, ranging from

42% to 63%, and primary importance of additive gene action for this trait, and suggested that selection for neck-rot resistance should be effective using methods appropriate for quantitative traits. Recurrent and mass selection would be effective in a breeding programme for high pungency and high TSS cultivars with neck-rot resistance.

Stemphylium-blight

This disease is caused by *Stemphylium vesicarium* (Wallroth) Simmons. Singh *et al.* (1992) reported that this was one of the most serious diseases which can result in 100% crop losses. The NBPGR collections IC 32176, IC 48954, IC 48710, IC 48724 and IC 49012 have been reported to be tolerant to this disease. However, no systematic breeding efforts have been made for understanding genetics and improvement of resistance to this disease.

Thrips

They are the most severe pest of onions not only in India but throughout the world. Further, it has been reported to predispose the host to purple-blotch disease. Wide angle of divergence of innermost leaves and glossy foliage (absence of wax on leaves) have been found to contribute towards resistance to this pest. Pawar *et al.* (1987) screened 36 diverse onion varieties and 28 local collections for resistance to *Thrips tabaci* from 1978–79 to 1984–85. Among varieties Kalyanpur Red Round, Udaipur 103 and N 53 were found to be most resistant. Among the local and exotic collections, Safedgol, N5 White, Mathewad 1, Shirwal 2, White Creole and Kagal 2 showed least infestation.

Jones *et al.* (1934) first reported resistance to thrips in cultivar White Persian. Varieties from Senegal were also reported to be resistant to thrips (Messiaen and Rouamba, 2004). The heritability of thrips resistance was found low, around 5%, suggesting that family selection would be more effective than individual plant selection for this trait (Hamilton *et al.*, 1999).

The basis of this resistance appears to be reduced waxiness (glossy) of the foliage. The USDA has released four glossy inbreds (B9885, B9897, B11278 and B111377) useful in the production of glossy hybrids. Molenaar (1984) studied genetics of glossiness in terms of thrips resistance with following phenotypes—nonglossy foliage with nonglossy scapes (nonglossy, Ng1), glossy foliage with nonglossy scapes (single glossy, Sg1) and glossy foliage with glossy scapes (double glossy, Dg1). The gene controlling nonglossy foliage (*G1*) was dominant to that controlling glossy foliage, and epistatic to that controlling glossy scape. Two loci were observed to control scape glossiness, and were designated as $G1s_1$ and $G1s_2$. The dominant $G1s_1$ allele (nonglossy) was epistatic to $G1s_2$. The 3 loci gave strong evidence of being linked, with $G1s_2$ being further from *G1* than $G1s_1$. Based on this genetic model, they proposed the genotypes: Ng1, *G1/- -/- -/-*; Sg1, $g1/g1\ G1s_1/$- -/-; and Dg1, $g1/g1\ g1s_1/g1s_1\ g1s_2/g1s_2$. On the basis of the number of thrips collected from onion umbels, glossy foliage plants were more resistant than nonglossy, and Dg1 plants were more resistant than Sg1 plants.

Natural variation exists in onion (*A. cepa* L.) for amount of epicuticular waxes on foliage; and plants with lower amounts of these waxes suffer less direct damage from onion thrips (*T. tabaci* Lindeman) (Steven, 2014). Wax crystals were clearly visible on the surface of the waxy foliage, with decreasing amounts on the semi-glossy and none on the glossy leaves. Ketone hentriacontanone-16 was the most prevalent wax on the leaves of the waxy onions and was significantly less on the semi-glossy relative to waxy plants and on glossy relative to waxy and semi-glossy plants. Numbers of adult and immature onion thrips were significantly reduced ($p<0.05$) on the glossy and/or the semi-glossy accessions relative to waxy in field and greenhouse cage experiments. These results indicate that semi-glossy plants possess intermediate amount of epicuticular waxes, which may protect leaves from environmental and spray damages, while still conferring resistance to onion thrips. Therefore, semi-glossy phenotype should be useful in integrated programmes managing thrips.

Genetic mapping of this trait revealed that the amount of hentriacontanone-16 was controlled only by one region on chromosome 5, and amount of several primary alcohols was controlled by a region on chromosome 2. These results indicate that the region on chromosome 2 is likely to be associated with acyl reduction pathway of epicuticular wax biosynthesis, and the region on chromosome 5 may affect decarbonylation pathway. SNPs tagging these regions will be useful for marker-assisted selection to vary amount and type of epicuticular waxes for developing thrip-resistant onion-varieties.

Pre-breeding for disease and pest resistance

Though several reports of disease and insect resistance are available from India; none of the varieties have been found perfectly resistant, based on the trials at the DOGR. Only certain level of field tolerance was observed (Lawande *et al.*, 2011 a, b; Mahajan *et al.*, 2011). Further, studies on pathogen diversity, genetics of inheritance and markers for selection are lacking for short-day onions in India.

No accession of *A. cepa* screened so far in India has registered complete resistance to any of the above diseases. Interspecific hybridization with wild relatives is considered an alternative. Cultivated and wild Alliums possess many disease resistance traits, potentially useful for genetic improvement of bulb-onion. Fertile hybrids between *A. roylei* and *A. cepa* were formed, and successful transfer of downy-mildew resistance was accomplished (Novak, 1986). Hybrids between *A. cepa* and *A. fistulosum* were known long ago (Emsweller and Jones, 1935) but F_1 always showed extremely low fertility due to poor chromosomal pairing. The first attempt to introgress genes from *A. fistulosum* into *A. cepa* were reported by Emsweller and Jones (1935). However, these were not successful, and till lately all attempts to introgress genes from *A. fistulosum* to *A. cepa* failed because of sterility in backcrossed generations. Low degree of fertility exhibited by hybrids between *A. cepa* and other *Allium* spp. restricts successful introgression of disease resistance genes. Ulloa *et al.* (1995) suggested that such sterility was due to an imbalance between nuclear and cytoplasmic genomes. Van der Meer and De Vries (1990) and McCollum (1982) showed that *A. roylei* ($2n=2x=16$) crossed readily with *A. cepa* and *A. fistulosum,* respectively. Hence, *A. roylei* can be used as a bridging species between *A. fistulosum* and *A. cepa*. By means of this bridge-cross not only genes from *A. fistulosum* can be introgressed into *A. cepa* but simultaneously also genes from *A. roylei*. In *A. fistulosum,* resistance genes are present against *Botrytis squamosa* (Currah and Maude, 1984), *Pyrenochaeta terrestris* (Netzer *et al*., 1985), *Colletotrichum gloeosporioides* (Galvan *et al*., 1997), *Urocystis cepulea* and OYDV (Rabinowitch, 1997), and in *A. roylei* resistance is available against *Peronospora destructor* (Kofoet *et al*., 1990) and *Botrytis squamosa* (De Vries *et al*., 1992). Hence, *via* bridge-cross approach unique populations can be developed in which these resistant genes can be pooled. Introgression of *A. fistulosum* into the genome of *A. cepa* using *A. roylei* as a bridging species by means of genomic *in-situ* hybridization was reported by Khrustaleva and Kik (2000), and is the first such successful effort.

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Breeding for Hybrid Technology

5

Amar Jeet Gupta, R VeereGowda and Vijay Mahajan

The commonly practised breeding methods in onion are mass selection, recurrent selection, selfing and massing, hybridization, followed by different population improvement methods and heterosis breeding (Pike, 1986). Heterosis breeding is an opportunity for improvement in productivity, earliness, and uniformity in yield-attributing characters. Even though most of the area under onion in India is covered by open-pollinated varieties, cultivation of hybrids is rapidly increasing; most of the hybrids are produced by private seed companies using cytoplasmic male-sterile lines.

Use of male sterility

The most important qualitative genes in onion are those causing male sterility. Pollen fail to develop in male-sterile plants, and thus there is no self-pollination; and seed production, therefore, would be through cross-pollination. This property has been utilized to produce F_1 hybrid cultivars, which show hybrid vigour, hence these genes are vital for hybrid breeding. In the absence of male sterility, controlled cross-pollination without any self-pollination can be achieved by manually removing ripened anthers from a flower-head before pollen are shed, and by transferring desired pollen to stigmas. This is labour-intensive and is practically useful only in breeding or in experimental work (Brewster, 1994).

Male sterility in onion was first exploited by Jones and Clarke, using a male-sterile genetic stock of cultivar 'Italian Red', found in breeding plots at Davis, California, in 1925 (Jones and Emsweller, 1936). When this plant was not allowed to cross-pollinate, bulbils were produced on the flower-head, and it could be propagated. Jones and Clarke (1943) published this classical work describing genetics of male sterility, and indicated how to use sterility to produce hybrid cultivars. On the basis of this technique, developed originally in onions, male sterility has since been exploited in hybrid breeding in more than 150 crop species (Kale and Munjal, 2005).

Male sterility in onion is expressed due to combined effects of a nuclear (i.e. chromosomal) gene and a cytoplasmic factor. The nuclear gene has two forms—the dominant *Ms* form, which when present, results always in fertile pollen and recessive *ms* form, which, if homozygous, may result in sterile pollen. Homozygous *ms* genotypes are male sterile only if they are combined with cytoplasmic sterility factor *S*. The cytoplasm of the egg cell can carry factor *S*, allowing *msms* genotypes for expression of sterility, or it can carry factor *N,* which results in a plant with fertile pollen, irrespective of *ms* and *Ms* alleles of its nuclear genes. Three following genotypes for male-sterility gene can exist in a diploid onion—*MsMs, Msms* and *msms*. Each genotype can occur in cytoplasm carrying either *N* or *S* factor. The only combination that results in male sterility is *Smsms*. The cytoplasmic factor (*S*) is transmitted only *via* female (pistillate) parent in a cross, not by pollen parent. If a male-sterile mother-plant is pollinated by various possible fertile pollen donor genotypes, there will be varied results (Table 5.1). Only the third combination in Table 5.1, would result all male-sterile offspring (Brewster, 1994).

Table 5.1 Male-sterile plants pollinated by various fertile pollen donor genotypes

Mother plant (male sterile)	Pollen donor (male fertile)	F_1 offspring
Smsms	*NMsMs*	All *SMsms* – male fertile
Smsms	*NMsms*	*SMsms* – male fertile and *Smsms* – male sterile
Smsms	*Nmsms*	All *Smsms* – male sterile
Smsms	*SMsMs*	All*SMsms* – male fertile
Smsms	*SMsms*	*SMsms* – male fertile and *Smsms* – male sterile

A: *Smsms*; B: *Nmsms*; C/R: *SMsms* or *NMsMs*; F_1 = A ×R Hybrid production; A = A × B Maintaining A line

The male-sterility gene has been found widespread in several genotypes, collected from many parts of the world (Little *et al.*, 1946; Davis 1957). The male-sterile plants have translucent, green anthers in contrast to normal, dark-green anthers. Their pollen mother cell (PMC) meiosis is normal and degeneration of microspores starts after tetrad stage, which leads to complete pollen sterility. Li *et al.* (2006) suggested that microspore abortion in male-sterile anthers can be attributed to premature degeneration of middle layer and tapetum. The *N*-cytoplasmic onion populations often possess relatively high frequency of *Ms* allele, which has no obvious function (Gokce and Havey, 2006). Computer simulation was done to estimate changes in allelic frequencies at *Ms* for onion populations possessing *S*-cytoplasm or a mixture of *N*- and *S*-cytoplasms and to determine if frequencies of *Ms* allele stay constant or change due to failure of male gamete production from male-sterile (*Smsms*) plants. The models revealed selection against recessive *ms* allele over generations in onion populations possessing *S*-cytoplasm, and varying amounts of self-pollination may lead to inbreeding depression. These models were consistent with field and molecular analyses documentation that *N*-cytoplasm and dominant *Ms* allele predominate in open-pollinated onion populations.

Cytoplasmic-genic male-sterility system (CGMS) is presently used widely in onions for commercial exploitation of heterosis (Kaul, 1988). The second source of CMS (*T*-cytoplasm) in onion was discovered in French cultivar 'Jaunepaille des Venus'. This CMS (cytoplasmic male sterile) line was found different from 'Italian Red 13-53', as three independent segregating restorer loci were identified in this line, which were responsible for its complex inheritance. It has common occurrence of restorers, which makes this *T*-cytoplasm more difficult to use. Later, male sterility was observed in several other onion populations, mainly in long-day cultivars—Pukekohe Long Keeper, Red Wethersfield, Scott County Globe, Stuttgarter Riesen and Zittauer Glebe. In India, male sterility was identified in a local cultivar Nasik White Globe at the IIHR, Bengaluru (Pathak *et al.*, 1980). Investigations on the causes of cytoplasmic male sterility in onion indicated that tapetal abnormalities and histochemical changes were responsible for male sterility in onions; there was no role of meiotic abnormalities (Saraswathi and VeereGowda, 2006).

Maintainer lines used to seed propagate male-sterile lines possess normal (*N*) male-fertile cytoplasm and homozygous recessive at *Ms* locus, *Nmsms* (Jones and Emsweller, 1936; Jones and Clarke, 1943). To identify maintainer lines, male-sterile plants were initially crossed with about 50 indigenous accessions and all F_1 hybrids produced were male sterile, indicating widespread distribution of *ms* genes in the population (Pathak, 1997). Transfer of cytoplasms from related species into cultivated populations may produce new sources of CMS. *A. galanthum* was backcrossed for 7 generations to bulb-onion populations to diversify cytoplasm conditioning male sterility. Flowers of *galanthum*-cytoplasmic (GC) populations possess upwardly curved perianth and filaments with no anthers, making identification of male-sterile plants easier than for either *S*- or *T*-cytoplasmic male-sterile onion-plants. Mean seed yield per bulb of GC populations was measured in cages using blue-bottle flies [*Calliphora erythrocephala* (*C. vicina*)] as pollinators, and this was not significantly different from one of the two *S*-cytoplasmic male-sterile F_1 lines, a *T*-cytoplasmic male-sterile inbred line or *N*-cytoplasmic male-fertile lines. Male-sterile lines possessing either *S* or *galanthum* cytoplasm were crossed with populations known to be homozygous dominant and recessive at the nuclear locus conditioning male-fertility restoration of *S* cytoplasm, and progenies were scored for male-fertility restoration. Nuclear restorers of male fertility for *S*-cytoplasm did not condition male fertility for GC populations. It is intended that these GC onion populations may be used as an alternative male-sterile cytoplasm for diversification of hybrid onion-seed production (Havey, 1999). Yamashita and Tashiro (2004) also developed male-sterile lines of Japanese bunching onion (*A. fistulosum*), possessing cytoplasm of *A. galanthum* by backcrossing. Fertility-restoring gene (*Rf*) for cytoplasmic male sterility (CMS) in *A. fistulosum* from segregation of pollen fertility of backcross generation of *A. galanthum* has been confirmed to be located on the 5F chromosome of male-fertile plants (Yamashita *et al.*, 2005).

Identification of *S*-cytoplasm of a single plant takes 4 to 8 years, and is complicated by segregation of a nuclear gene that restores fertility. Although CMS in onion may be due to incompatibility between mitochondrial and nuclear genomes, southern analyses of DNA from individual plants from crosses of *S*- and *N*-cytoplasmic plants supported maternal inheritance of chloroplast and mitochondrial DNA. Therefore, polymorphisms in chloroplast DNA may be used to classify cytoplasm. Amplification by polymerase chain reaction of a fragment that carries an automorphic 100-bp insertion in the chloroplast DNA of *N*-cytoplasm offers a significantly quicker and cheaper alternative to crossing or southern analysis. Molecular characterization of *N*- and *S*-cytoplasms and frequencies of nuclear non-restoring allele allow onion breeders to determine proportion of plants in the open-pollinated populations that maintain CMS, and can significantly reduce investment required to identify individual maintainer plants (Havey, 1995). Various aspects of A, B and C/R lines, their identification, maintenance and uses in hybrid production have been discussed by Kalloo (1988).

Chemicals for producing male-sterile lines

Male sterility of a cytoplasmic genic nature has been utilized in producing commercial onion hybrids for a number of years. This requires time-consuming technique of introduction of male-sterility controlling factors into inbred lines before testing and added cost of maintainer lines for production of male-sterile inbreds. Chemical induction of male-sterility would circumvent both these requirements, as there is no breeding for A line and B line; only maintenance is needed in the case of chemically induced male sterility.

Chemically-induced male sterility has been reported in many crop species. In onions too influence of the same potential gametocides was studied (Chopra *et al.,* 1960; Cohan and Weigle, 1966; Kaul and Singh, 1976). Meer and Bennekom (1976) showed gametocidal effect of $GA_{4/7}$ on onions. Frequent spraying during bolting period with relatively high concentrations (0.1 and 0.3%) resulted a very high number of completely male-sterile plants in the beginning of the flowering period. Gametocidal effect was accompanied by a considerable reduction in seed production. Gibberellic acid use for production of hybrid seeds does not seem to be very attractive, mainly because of reduced seed-set and high price of GA_3 and $GA_{4/7}$. Most likely, phenomenon can be used as a substitute for emasculation when making interspecific crosses, inter-varietal crosses and recurrent crosses, because in these cases only moderate quantities of seeds are sufficient.

Molecular markers for identification of male sterility

Davis (1966) suggested a new method for producing hybrid seeds. He developed a brown-seeded line in which brown seed-coat colour was linked with male sterility. Brown seeds are smaller, rounder and smooth. This seed-coat colour is governed by a single recessive gene (b), while black seed-coat is due to dominant gene (B). A homozygous brown-seeded male-sterile line, B 2246B, was developed from variety 'Brigham Yellow Globe', and the black-seeded line, B 12115C, was derived from variety 'Yellow Sweet Spanish'. Brown-seeded male-sterile line and black-seeded pollen-parent line can be used for producing hybrid seeds. Hybrid seeds harvested from male-sterile line were black. This improved method would be useful in rouging off-types occurring in both the parents.

Identification of nuclear markers tightly linked to *Ms* locus would allow for molecular-facilitated selection of maintainer lines. Restriction enzyme analysis of chloroplast DNA (ctDNA) revealed five polymorphisms between *S* and normal (*N*) fertile cytoplasms. *S*-cytoplasm was different from *Allium* species closely related to bulb-onion, and cladistic estimates of phylogenies supported introduction from an unknown species (Havey, 1995). Both RFLP and PCR approaches gave some proof of existence of mitochondrial heteroplasmy in onion, using probes for mitochondrial genes: *atpA, atp6, atp9, cob, cox1 nad3, nad4 and nad6* (Szklarczyk *et al*., 2002). Gokce *et al.* (2002) evaluated test cross progenies from a segregating family for nuclear restoration of male fertility over at least three environments. Although segregations in F_2 family fit expected 1 : 2 : 1 ratio (P=0.973), proportion of male-sterile test cross progenies showed significant ($p < 0.01$) year effects, and it is, therefore, imperative to score male-fertility restoration over environments. Too many male-sterile test cross progenies were often observed, indicating that dominant allele conditioning male-fertility restoration for *S*-cytoplasm may not show complete penetrance. Segregations of amplified fragment length polymorphisms and restriction fragment length polymorphisms (RFLPs) revealed RFLPs flanking *Ms* locus at 0.9 and 8.6 *cM* distance. An onion *c*DNA, showing highly significant homology to an aldehyde dehydrogenase, conditioned by the *rf2* locus of maize, was identified and mapped to linkage group I, independent of *Ms* locus. A sample of commercial onion germplasm was evaluated for putative allelic diversity at the RFLP loci linked to *Ms*. Genomic region corresponding to *c*DNA (AOB272) revealing closest RFLP to *Ms* was sequenced to reveal numerous single nucleotide polymorphisms. Single-stranded conformational polymorphisms and single nucleotide extensions that revealed genomic variations at AOB272-EcoRI were developed (Gokce *et al.*, 2002). Cho *et al.* (2006) demonstrated usefulness of SNP detected in *psbA* gene for high-throughput discrimination of CMS factors using real-time PCR and a TaqMan probe assay. Cho *et al.* (2005) selected maintainer line with *N*-cytoplasm plants, using sequence characterized amplified region (SCAR) marker linked to cytoplasmic male-sterile factor.

Limited molecular analysis was done on onion male sterility. Molecular analysis of genetic diversity in onion genotypes and hybrids was conducted (Narayan *et al.*, 2006). Genetic relatedness analysis of male sterile and their maintainer lines was done by using RAPD primers (Dhanya *et al.*, 2012). In-silico identification and validation of micro satellite markers from onion EST sequences was conducted (Radhika *et al.*, 2013). Review published on the molecular markers in the improvement of *Allium* crops detailed the information on male-sterility system and its utilization in F_1 hybrids (Reddy *et al.*, 2013). Among different types of molecular markers available for identification of A and B lines, PCR-based markers have gained attention because of ease of use and being comparatively less time-and-labour consuming.

Haploidy

In-vitro haploid production through gynogenesis has been routinely used for one-step inbred production. Induction of haploids was done through *in-vitro* gynogenesis using unpollinated ovule culture and ovary and whole flower culture of long-day cultivars (Campion *et al.*, 1992). Doubled haploids from gynogenic lines of onion, through spontaneous and induced chromosome doubling in *A. cepa*, using unfertilized ovary and flower culture, were obtained (Campion *et al.*, 1995).

Genotype effect on gynogenesis was studied with different explants like flower-buds, ovary and ovules (Ionescu and Popandron, 1995). Gemesne and Martinovich (1995) studied effect of immature flower-buds and ovary on four Hungarian genotypes on BDS medium. Ovary culture gave best results with 80% regenerants being haploid and 20% dihaploid. The effect of flower-buds of thirty Polish onion genotypes on gynogenesis was reported by Michalik *et al.* (2000). It was established that 3.5–4.5 mm long flower-buds were most responsive to gynogenesis. Cultivars differed with regard to their demands for media composition and yield of resultant embryos depended strongly on the genotype. Different mitotic poisons like colchicines, oryzlin and APM were evaluated; oryzalin and APM are being routinely used for chromosome doubling (Jakse *et al.,* 2003).

Bohanec *et al.* (1995) were successful in inducing gynogenesis in four onion cultivars using ovule and ovary. Esterase isozyme analysis showed that 59% of the regenerants were homozygous. RAPD showed that high genetic stability of onion homozygous lines passed through two cycles of gynogenesis (Javornik *et al.*,1998).

Attempts to produce haploid plants *via* androgenesis failed as reviewed by Keller and Korzun (1996). Campion *et al.* (1985) were successful in having anthers with 1–3 nuclei microspores; microspores did not survive due to degeneration of tapetum.

Maintenance breeding of male sterile, maintainer and pollen lines

Seeds of A, B and C/R lines during initial stages are produced in the insect-proof cages, followed by an increase in the open-isolated fields. Seeds of A and B lines can be maintained/increased in the same cage, while C/R line is maintained/increased in a separate cage. A plastic, nylon or wire-net cage of 20´20 or 24´24 mesh, measuring 6-m long, 3-m wide and 2-m high with a small door at one corner for entrance, is suitable and accommodates 4 rows of bulbs at 60-cm spacing. Seeds to the tune of 1.0 to 2.5 kg can be produced from this nylon cage. The cage covers over plants before flowering, and necessary care should be taken that umbels do not touch the net, otherwise protruded stigma will get contaminated with foreign pollen, carried by insect-vectors. The scape (seed-stalk) should be kept straight by staking. In each cage, a medium-sized bee colony with a queen inside is kept and bees are fed with 10% sugar solution. Honeybees colony before placing under the cages should be fed on sugar solution for 3–4 days in isolation to ensure them to be free from foreign pollen. Roughing of off-types should be done every morning before anther dehiscence. At the same time, pollen-bearing plants (shedders) from A line and male-sterile line from B line, if any, should be rouged out. Later, initially multiplied seeds are further maintained/increased in the open-planting under isolation.

Hybrid Breeding

Male-sterile line is crossed with a pollen donor to produce F_1 hybrid with desirable traits. Jones and Clarke maintained their male-sterile lines vegetatively using bulbils produced on the flower-head. However, bulbils are difficult to store, and viruses tend to accumulate in plants. Male-sterile lines are also maintained by male-fertile ‘maintainer lines’ with the genetic constitution *Nmsms*. Such a line will produce pollen which can fertilize male-sterile line, but its offspring has the constitution *Smsms*, and is therefore male sterile (Table 5.1). Using these two lines, it is possible to propagate male-sterile line from seeds.

Once a maintainer line has been identified in a locally adapted inbred population, male-sterile line must be developed so that it is near-identical genetically to it, apart from presence of *S* cytoplasmic factor. This is done by repeatedly backcrossing male-sterile offspring with original *Nmsms* adapted maintainer line. With each generation of such a cross, genetic contribution from the original sterile *Smsms* parent gets diluted by a factor of two; and after four generations, 96.87% of the genes in the resultant *Smsms* line are derived from the original *Nmsms* line, and is near isogenic, similar to use as a male-sterile line in test crosses to identify vigorous hybrids. The procedure of developing A and B lines by backcrossing has been outlined in Table 5.2.

Table 5.2 Development of A and B lines

Male-sterile line (A)		Male-fertile line No. 2 (B)
S msms	×	N msms
F_1 S msms (50% No. 2)	×	N msms
BC_1, S msms (75% No. 2)	×	N msms
BC_2, S msms (87.5% No. 2)	×	N msms
BC_3, S msms (93.75% No. 2)	×	N msms
BC_4, S msms (96.87% No. 2)	×	N msms
BC_5, S msms (98.44% No. 2)		

A schematic plan for breeding improved onion hybrids, as outlined by Pike (1986), is given as follows.

Year	Procedure
1	Grow and select 100 bulbs, store, and plant, also grow supply of male-sterile bulbs for use in test crosses
2	Self selected bulbs and at the same time test cross with the known male-sterile line
3	Grow-out bulbs from self and F_1 test crosses, select, discard poor progeny rows and their F_1 pairs, store
4	Plant bulbs for seed production, observe sterility characters in F_1 lines, if 100% sterile, self selections and make backcross to F_1, discard pairs with fertile F_1 lines
5	Grow out A and B lines as pairs, continue to select in B line side, save best bulbs from A line for the next backcross
6	Self B line of selected progenies and make backcross to the sterile side of pair
7	Grow bulbs and make final selection on the basis of B line side
8	Mass B line using 10–20 bulbs in cage while backcrossing to the sterile side of pair
9–12	At this point, begin seed-to-seed and continue through the fifth backcross, using the same procedure as in the 8th year; several A and B lines should have been developed, begin making hybrid combinations for testing

When large numbers of test crosses are made, only certain crosses result in desirable F_1s. Therefore, a number of adapted male-sterile and maintainer lines need to be used in the development of F_1 hybrids. The breeder must make many crosses on to male-sterile lines, and grow and evaluate progeny that gives desirable hybrids. By accumulating data from such test crosses one can build-up information that would help predict crosses giving good hybrids. As with the maintainer lines, pollen-donor lines used to produce hybrids have normally been inbred for a few generations to eliminate deleterious recessive and off-type alleles from the gene-pool. Many practicalities of breeding onion hybrids of improved short-day onion hybrids for Texas were described by Pike (1986). Development of hybrids in onions was also described by Gupta (2014). Development of new hybrid onions involves a 15–20 year time-scale as most seed-to-seed cycles in onion breeding involve two years. Seeds are sown and bulbs are selected, harvested and stored in year one. In the second year, selected bulbs are grown for flowering and seed production (Fig.5.1; Dowker, 1990).

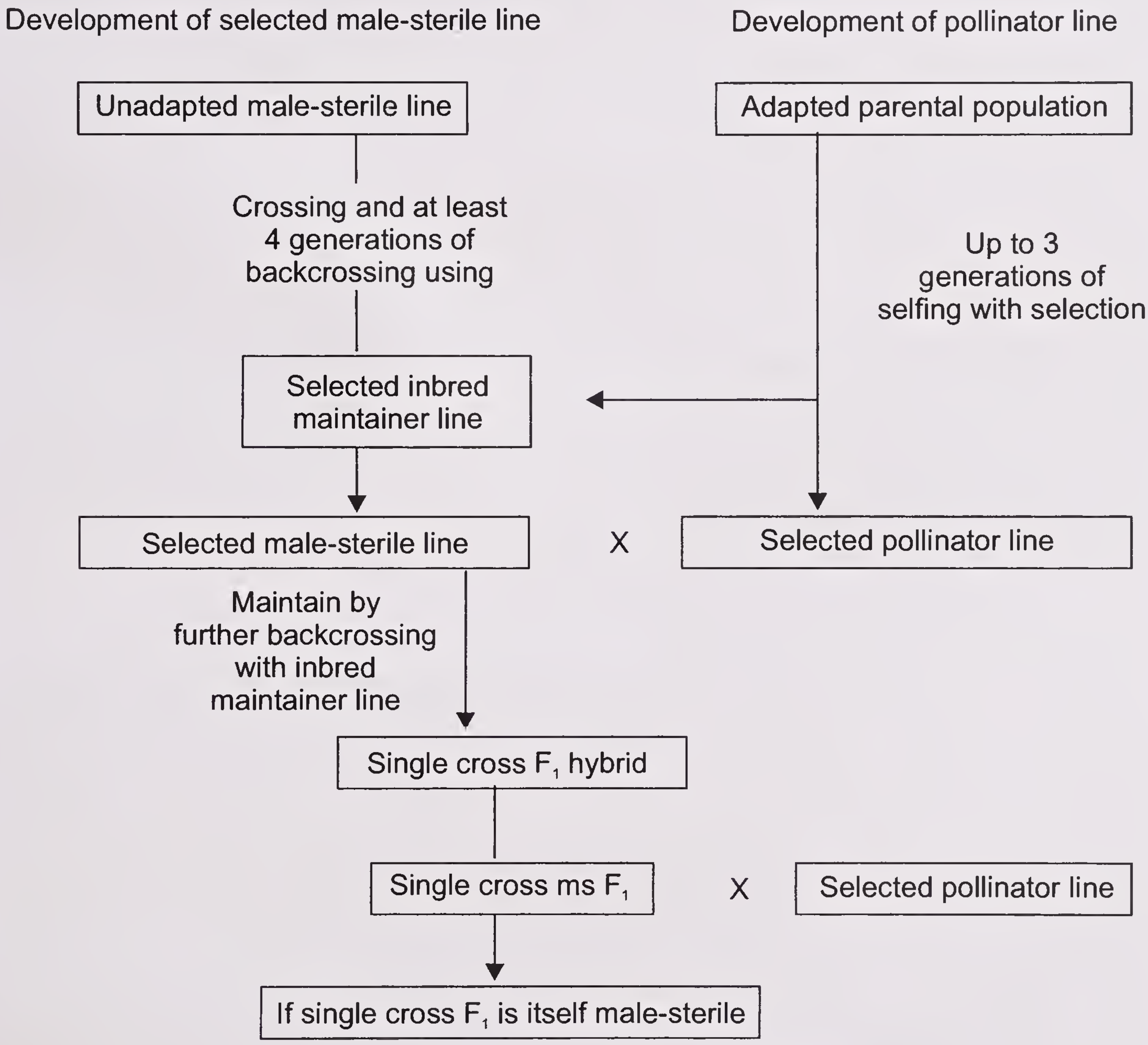

Fig. 5.1 F_1 hybrid scheme for onion breeding

Studies conducted at the IIHR, Bengaluru, indicated strong cytoplasmic factor for male sterility in Indian short-day onions (Pathak *et al.,* 1986). The cytoplasmic factors operating in Indian short-day onions were further confirmed by male-sterile lines developed at the IIHR (Rao *et al.,* 2005). Male sterility could be successfully transferred to several breeding lines of different genetic backgrounds by backcross method, and two F_1 hybrids (hybrid 1 and hybrid 5) were identified with significant increase in bulb yield of 40.89% and 25.82% over check variety

(Pathak and Gowda, 1994). The adaptation of hybrids by farmers was slow due to inherent problems associated with traditional onion-production system (VeereGowda *et al.,* 2002).

The weak parental inbred line may give a low seed yield. Adequate seed production is essential if a hybrid has to be commercially viable. The parent lines of a hybrid must also flower simultaneously so that they cross-pollinate. If a cross is made between a male-sterile line and a related maintainer line, resulting hybrid will itself be male sterile. Being a hybrid it may well be more vigorous than parental lines, and consequently it may have greater potential for seed production. This male-sterile hybrid may itself be crossed with another male-fertile line to produce what is termed a 'three-way hybrid'. The extra vigour of male-sterile parent in a three-way hybrid makes seed production easier, but some genetic uniformity of a F_1 between two inbreds is lost. As with two-way hybrids, various three-way hybrid combinations must be made and tested.

Single-cross/three-way hybrids

Most of the commercial onion hybrids are single crosses. Hybrid seed is produced on the plants, usually weakened by inbreeding, which generally causes a rapid vigour loss. Comparison between F_1 hybrids and inbreds showed that F_1 hybrids produced 91% more seeds than inbreds. The seeds were also of better quality (Erickson and Gableman, 1964). The uniformity of the bulb-crop need not be sacrificed, provided parental material is selected and combined in such a way as to minimize segregation of unlike inbreds. Where inbreds chosen are phenotypically alike and perform similarly in 3-way crosses, uniformity of a 3-way hybrid is equal to that of a 2-way hybrid (Davis, 1966).

Heterosis and combining ability

Onion is one of the pioneer crops in which since about six decades heterosis has been commercially exploited. Although India is one of the leading onion producers, not much emphasis was given to heterosis breeding in the past. One of the main components for exploiting heterosis in onion is the availability of stable male sterility. In India, development of suitable male sterile and fertile inbred lines has remained very slow. Sen and Srivastava (1957) attempted to develop F_1 hybrids in onion as early as in 1948 using exotic male sterile lines and Indian local male stocks. The exotic male sterile lines were found unsuitable in photoperiodically different environments in India. Later, very few workers attempted to test different hybrid combinations for heterosis and combining ability studies using male-sterile lines (Pathak *et al.,* 1987). Male sterility was isolated from indigenous germplasm by several workers in India [Patil *et al.* (1973) in cv. 'Niphad 2-4-1'; Pathak *et al.* (1980) in cv. 'Nasik White Globe']. Further studies indicated strong cytoplasmic factor responsible for male sterility in cv. 'Bombay White Globe' (Pathak *et al.,* 1986). This male-sterility factor has been transferred to several breeding lines by backcross breeding method.

Bulb weight is an important character directly related to bulb yield. Joshi and Tandon (1976) noted heterosis to an extent of 72% over the mid-parent value and up to 37% over the better parent in onion hybrids. Hosfield *et al.* (1977) observed significant heterosis for bulb weight based on the mid-parent. However, heterosis over better parent was significant but comparatively low. Vadivel *et al.* (1982) evaluated 30 hybrids and their parents. The results showed both positive and negative heterosis for bulb weight; one cross recorded significant heterosis for yield and most yield components. Aghora (1985) observed that seven crosses of onion were with significant heterosis over better parent and 13 crosses over mid-parent. VeereGowda (1988) also observed significant positive heterosis for onion bulb weight in seven crosses out of 55 crosses over better parent. Doruchowsk (1986) crossed eight male-sterile lines with eight pollen parents and heterosis was observed only for bulb weight. In a study involving 10 × 10 half diallel, out of 45 crosses, 8 had significant positive heterosis over mid-parent for bulb weight, 30 over better parent and 15 were found significant over standard check (Divakar, 2001).

In hybrids of 3 male-sterile lines and 20 inbreds, various economic traits were studied by Pathak *et al.* (1987). Positive heterosis was observed in 9 hybrids over better parent for total bulb yield, and it ranged from 47.9 to 89.5%, while heterosis over best parent for marketable bulb yield was over 35% in three hybrids—MS1 × NER1, MS1 × IIHR21-1and MS8 × IIHR 52-1. Popandron (1998) obtained three F_1 hybrids by crossing a male-sterile line of onion with inbred lines in S_2 studied for 3 years. Biometrical measurements of plant height, leaf breadth, number of leaves per plant and yield were made for both F_1 hybrids and their parents. Heterosis was clearly evident for plant height and yield, less for leaf breadth, and was completely absent for number of leaves per plant. According to Janik *et al.* (1999), crop uniformity is considered a desirable character in modern agriculture because product uniformity is essential in marketing; uniformity in maturity permits crop scheduling, and uniformity in plant structure and maturation permits efficient mechanical harvest.

Line × tester cross of 3 lines (male-sterile parents) and 23 testers (fertile-male parents), thus making a total of 26 inbred parents, and their 69 F_1's along with 6 controls; quite a good number of F_1s, showed desirable heterosis over top parent for all characters except a few for maturity and neck thickness (Netrapal and Singh,1999). All the characters revealed superiority of F_1s over standard controls. Mostly the better performing F_1s also expressed higher heterosis over better parent, top parent and standard control. Mani *et al.* (1999) crossed 5 red-skinned open-pollinated populations as males to 4 exotic yellow-skinned cytoplasmic male-sterile inbred lines. The resulting 20 F_1 hybrids and their 9 parents were evaluated at 2 locations in the Uttar Pradesh hills. The results indicated positive and significant heterosis over better parent for bulb yield in a cross inbred 13 × L 43. In this, F_1 between inbred 13 × L 43 was used as a base material, advanced to F_2, and was subjected to 3 cycles of mass selection for bulb yield, skin colour, shape and size. An improved, high-yielding onion strain was thus developed and designated as VL Piaz 3.

Crosses PBR 139 × AN 184 and PBR 140 × AN 187 recorded high heterosis of 45.31 and 32.83% over the better parent and 27.40 and 31.01% over the standard check (Arka Kalyan), respectively, for marketable bulb yield, and were identified as the best hybrid combinations (Shashikanth *et al.,* 2007). According to Abubakar and Adu (2008), crosses Red Creole × Kaharda and Kaharda × Red Creeole recorded highly significant ($P < 0.01$) positive high parent heterosis for disease incidence. Red Creole × Kaharda and Kaharda × Red Creeole also recorded highly significant ($P < 0.01$) positive high parent heterosis for fresh bulb yield. Cross Kaharda × Ori recorded highly significant ($P < 0.01$) positive high parent heterosis for bulb weight. Gupta *et al.* (2011a) evaluated different F_1 hybrids developed through male-sterile lines, and six F_1 hybrids—DOGR Hy 7, DOGR Hy 29, DOGR Hy 1, DOGR Hy 41, DOGR Hy 27 and DOGR Hy 17 were found superior over the standard check.

Analyses of combining ability among onion inbreds have demonstrated consistent heterosis over the best inbred parent and occasionally over the leading commercial OP population. Large general combining abilities (GCA) and specific combining abilities (SCA) were reported for bulb maturity, yield and its components (rings per bulb, ring thickness), firmness and storability (Dowker and Gordon, 1983; Hosfield *et al.*, 1976, 1977b; Joshi and Tandon, 1976). Diallel crosses of onion inbreds were generated, and consistently greater GCA over SCA for bulb yield and weight, earliness, rings per bulb, ring thickness, number of centers and storage loss was observed (Hosfield *et al.*, 1976, 1977b). The SCA effects were about 10% of the GCA, but significant for 19 out of 24 comparisons. Dowker and Gordon (1983) observed that most reports of heterosis in onion compared hybrid with inbred parents and not with the best commercial cultivar. Significant heterosis over widely grown OP populations was reported by Jones and Davis (1944) and Joshi and Tandon (1976). Most publicly released onion inbreds were developed by selfing individual plants from OP cultivars or recombining previously developed inbreds. The large GCA effects indicate that superior inbreds are more likely to be selected from populations improved by recurrent selection or synthesized by recycling inbreds with good combining ability. However, it is important that inbreds should be evaluated over years and locations before recycling into new populations (Hosfield *et al.,* 1977a).

Performance of F_1 hybrids

In USA and Japan, F_1 hybrids occupy large-growing areas, while in European countries like Netherlands, UK, and many others, open-pollinated varieties are more commonly grown. Heterosis for yield, earliness, uniformity, storability and dry-matter content has been reported by many workers. In 1959, onion hybrids in New York surpassed open-pollinated varieties by 30% in yield and increase in storage life up to 40%, which stimulated growing of F_1 hybrids in the northern United States and Canada. Variety protection is the second strong stimulus for popularity of F_1 hybrids in onion.

Commercially available F_1 hybrids suitable for tropical regions are mainly of yellow skin, and they are generally of poor storability. In the USA, almost 100% area of onion is under hybrids. Some of the male-sterile lines have been developed in India but in most cases sterility is not stable and even inbred lines developed are not pure due to inbreeding depression, long breeding cycle, less storability of seeds and difficult seed production processes for inbreds and male-sterile lines. Very few seeds are produced through manual crossing, and for commercial scale production, this is not practical. First attempt for the development of hybrid in India of onion was made as early as 1948 using exotic male-sterile lines. But these lines were found unsuitable for short-day conditions of our country. Despite reports of high percentage of heterosis, the hybrids in onion did not made much headway in India due to non-availability of stable male-sterile lines along with maintainers for short-day onions. The work got momentum in eighties at the IIHR (Bengaluru), IARI (New Delhi) and MPKV (Rahuri). At the IARI, male sterility was isolated in a commercial variety 'Pusa Red'. Only two onion hybrids 'Arka Kirthiman' and 'Arka Lalima' have been released from the IIHR. Some new hybrids are being developed and are under evaluation. Some of the exotic hybrids are performing well during late *kharif* in Indian conditions, and their yields are almost double than Indian varieties at the DOGR, but they have less TSS, less storability and are of yellow colour, which lacks consumer preference in India. They can be exploited to trap European and Japanese market where there is great demand of these onions, but it can be only through cool chain export.

Unfortunately in India, absence of male-sterile lines along with maintainer for short-day onions remained a bottleneck in heterosis breeding programme. Private seed companies lately have started selling F_1 hybrids, however, rigorous testing is required in different agroclimatic zones for different purposes. Knowing the importance of F_1 hybrids, the DOGR has started research on F_1 hybrids. Trials conducted on exotic F_1 hybrids of yellow type exhibited very good performance in late *kharif* and *rabi* (Table 5.3).

Table 5.3 Performance of exotic hybrids/varieties under Indian plain conditions (2000–2008)

Exotic hybrids/varieties	Late *kharif* (yield: tonnes/ha)	% increase over Bhima Super	*Rabi* (yield: tonnes/ha)	% increase over N 2-4-1
HN 9539	54.03	22.34	–	–
HN 9733	31.13	–29.52	65.90	52.55
HN 9935	36.09	–18.29	68.00	57.41
Hy 3404	57.36	29.89	56.45	30.67
DPS 2023	60.87	37.84	59.80	38.43
Early Supreme White	54.65	23.75	41.50	–3.94
Cougar	56.50	27.95	67.84	57.04
DPS 1008	31.80	–27.99	52.50	21.53
DPS 1009	31.12	–29.54	64.45	49.19
DPS 1024	38.62	–12.55	66.05	52.89
DPS 1031	5.10	–88.45	54.30	25.69
DPS 1034	59.66	35.10	58.60	35.65
DPS 1043	–	–	61.45	42.25
Linda Vista	50.58	14.53	59.59	37.93
Mercedes	47.93	8.53	63.27	46.46
Lexus	59.66	35.10	63.83	47.75
Reforma	37.67	–14.70	66.53	53.99
Gobi	42.22	–4.39	52.67	21.92
Kalarahi	53.10	20.23	38.04	–11.94
Rio-Tinto	54.37	23.11	34.52	–20.09
Serengeti	55.87	26.52	50.85	17.71
Bhima Super (C)	44.16	–	–	–
N 2-4-1 (C)	–	–	43.20	–

Table 5.4 Heterosis and percentage superiority over better parent and check varieties of F_1 hybrids with MS65A

Entries	Marketable yield of parents (tonnes/ha)	Marketable yield of F_1 hybrids with MS65A (tonnes/ha)	% Superiority of the F_1 hybrids over	
			N 2-4-1	ALR
MS65A	33.50	–	–	–
444	40.00	73.34	43.80	35.81
14-2W	54.33	78.28	53.48	44.95
465	38.00	71.65	40.49	32.69
153	55.66	81.30	59.41	50.56
133	48.66	67.95	33.24	25.83
169-2	41.33	71.35	39.90	32.13
131	35.00	63.35	24.22	17.31
208	45.00	79.15	55.20	46.57
A. Niketan	48.33	70.25	37.75	30.09
179	39.67	69.90	37.06	29.44
147	11.67	59.95	17.55	11.02

Out of 90 exotic lines tested during 2000 to 2008, 10 lines had more than 20% higher yield than Bhima Super during late *kharif* and 16 during *rabi* over 'N 2-4-1' in Maharashtra. Further, F_1 hybrids developed under hybrid network programme at the DOGR by using two CMS lines indicated very high percentage of heterosis over standard checks (Table 5.4), which ranged from 17 to 59% over 'N2-4-1' and 11 to 50% over 'ALR' (Lawande, 2004). Out of 60 F_1 hybrids evaluated during *rabi*, five F_1 hybrids, viz. DOGR Hy 50, DOGR Hy 2, DOGR Hy 5, DOGR Hy 7 and DOGR Hy 8 showed more than 30% heterosis in marketable yield over standard check Bhima Kiran (25.3 tonnes/ha) whereas 10 F_1 hybrids showed more than 20% heterosis in marketable yield over standard check Arka Lalima (20.6 tonnes/ha) (Fig. 5.2) during *kharif* (DOGR, 2013). Commercially released F_1 hybrids of onion from different organizations have been listed in Table 5.5. Progress and future of onion hybrids has been discussed by VeereGowda and Gupta (2014).

Fig. 5.2 Promising F_1 hybrids along with Arka Lalima

Table 5.5 F_1 hybrids developed through male-sterile lines

	Remarks	Reference
Tamara	12% dry matter content in bulbs	Skofand Ugrinovic (2004)
Donglingbai	244A × 244B, higher vigour	Tong *et al.* (2005)
Early Globe	W202A × S87-707, less foliage, poor in storage	Muro *et al.* (2006)

(Contd...)

(...Table 5.5)

	Remarks	Reference
Liaocong No.6	2000Y24-3S98 × 244-152A, resist wind, stalk single, edible rate 60.63%, yield 69.0 tonnes/ha	Cui *et al.* (2007)
Safrane Hypark Alonso	Severity of downy mildew achieved is 1.6% 3.1% (Hypark) and 4.5% (Safrane)	Bimsteine *et al.* (2009)
Musica Vaquero Manas Sedona	High yield, Musica (82 tonnes/ha), Vaquero (77.4 tonnes/ha), Manas (78.6 tonnes/ha), Sedona (78.3 tonnes/ha)	Popandron *et al.* (2009)
Jinqiu	B2354A × 3104, bulb growth period about 120 days, yellowish bulb colour, bulb weight 203 g, yield 67.5 tonnes/ha	Cui *et al.* (2009)
Jinxing	Round bulb, golden-brown, bulb weight 370–430 g, sweet pungency	Yan *et al.* (2009)
Yeongpunghwang	MOS8 × Mokpo 11, broad ovate bulb, lodging date May 26	Lee *et al.* (2009)
Jintianxing	HG02 A × K400C, long day, round bulb, yellowish, bulb weighs 216 g	Ma *et al.* (2009)
Wonye 30002	402AC203 × M1, circular bulb, bulb weight 283 g	Kim *et al.* (2010b)
Wonye 30001	Ginque × YG1-1, circular bulb, bulb weight 260 g, mid-late maturing type	Kim *et al.* (2010a)
Quer-rich	NOR1A × SRG12, 20% higher quercetin content	Muro *et al.* (2010)
Baifeng	Good for dehydration, higher dry matter	Zeng *et al.* (2011)
DOGR Hy 7	High yield, significantly superior over N 2-4-1, red bulb, suitable for *rabi*	Gupta *et al.* (2011a)
Hybrid Nun 3001 Hybrid Orient	High yield, poor in storage	Gupta *et al.* (2011b)
Sojiro	Extremely early maturity, attractive dark brown coloured skin, strong resistance to *Fusarium* basal-rot	Maekawa *et al.* (2012)
2572, 2573, 2578	High yield, earliness	Faria *et al.* (2012)
Hybrid Optima	Good commercial bulb yield and average mass of commercial bulbs	Boas *et al.* (2012)
Daekwanhwang	Manchuhwang × NIHA5001, yellowish brown bulb, is good storer	Kwon *et al.* (2013)
Arka Kirthiman* Arka Lalima*	Released from IIHR Bangalore for high bulb yield and quality	VeereGowda *et al.* (1998)
Hybrid 63* Hybrid 35*	Released from the IARI, New Delhi, for high bulb yield and quality	Dhall (2010)
DOGR Hy 1*	Light red, flat-globe, 41.30 tonnes/ha marketable yield is 42.84% higher than check Bhima Kiran	DOGR (2013)
DOGR Hy 2*	Dark red, globe, 34.96 tonnes/ha, marketable yield is 20.91% higher than check Bhima Kiran	DOGR (2013)

*Short-day F_1 hybrids

Hybrid seed production

Investigations conducted on seed-set and seed-yielding abilities of male-sterile and male-fertile lines and their F_1 hybrids of onion (VeereGowda and Saraswathi, 2002) have indicated that number of seeds per flower is influenced by fertilization and availability of pollen and abortion of embryo. Recovery of seeds per umbel and seed-set percentage may depend on number of flowers per umbel, number of flower stalks per plant and pollen germination. Higher seed weight was observed in crosses than selfed parents. This may be due to contribution of genes from parenting combination. Parental synchronization and efficiency of F_1 hybrid-seed production were investigated in two F_1 hybrids Arka Kirthiman and Arka Lalima (Padmini *et al.*, 2008).

Hybrid seeds are produced in open isolated fields where pollination is carried out mainly by bees. The bulbs of male-sterile line (A line) and pollen parent (C/R line) are planted alternatively in 4 : 1 or 8 : 2 ratio. Hybrid seed yield can be improved by taking the following steps.

- Flowering time of A and C/R line must synchronize, which can be accomplished by adjusting either storage temperature of parental bulbs (9–14°C) or planting dates.
- Keeping 3–5 fully developed bee-colonies per acre to ensure large population of bees for effective pollination.
- A single application of 50 ppm GA_3, at the time of first seed-stalk emergence, reduces time of 80% flower-stalk emergence by half besides ensuring uniformity in length of flower stalk.

Daily roughing of pollen-bearing plants and other off-types in A line (pollen shedders) in the morning before anther dehiscence is essential. Seed stalks of A and C lines should be harvested separately with great care to avoid intermixing. It is always better to harvest seeds of C lines first to avoid mixing with A line. The seeds collected from A lines are F_1 hybrid seeds. Harvesting of seeds should be done when seeds are with 60–70% dry matter content while still in capsule attached to stalk. Spraying of anti-shattering chemical like polyvinyl acetate may be done to avoid shattering of seeds. The harvested umbels from A and C lines are heaped separately for a few days before threshing to ensure proper curing of seeds, drying and for threshing. Yield of hybrid seeds ranges from 400 to 600 kg per hectare, depending upon the ratio of A and C lines, climatic conditions, cultivation practices and honey-bee colonies.

Reverse Breeding

It is a novel plant-breeding technique that involves suppression of meiotic recombination to recreate homozygous parental lines that, once hybridized, reconstitute composition of an elite heterozygous plant without backcrossing or selection. Reverse breeding enables breeder to go backwards from such an individual to directly recreate homozygous parental lines that created it – essentially allowing mass production through seed of an elite heterozygous genotype. Reverse breeding process begins with the production of gametes (haploid microspores) from heterozygous starting plant in which meiotic recombination has been suppressed.

Convergence Breeding

It is a breeding method which involves reciprocal addition to each of the two inbred lines with the dominant favourable genes, which are lacking in one line and are present in the other. In this, backcrossing and selection are simultaneously performed, with each of the original lines, which serve as a recurrent parent in one series. Thus, it is a special case of backcross; a single cross is backcrossed separately to two parental inbreds. Selection is made on the basis of the phenotype during backcrossing. It is hoped that two parental inbreds, e.g., A and B, would be improved by retention of some of the favourable genes contributed by the other inbred. Thus A is expected to improve by genes from B, and B by genes from A. There is some evidence that this method improves, to some extent, performance of inbreds as well as that of hybrids produced by them. Promotion of F_1 hybrids in onions is top priority and can be achieved with reverse breeding/convergence breeding, as most of the private seed companies have followed these methods for achieving desirable F_1 hybrids.

Future Strategies

F_1 hybrids will play an increasingly important role in future breeding because of the advantages to breeder of exclusive ownership of the parental lines. The full exploitation of the potential of F_1 hybrids is hampered by difficulties of commercial seed production from relatively weak parent inbreds. Further biometrical work is needed to predict vigour of recombinant inbreds, derivable from appropriate crosses; in parallel, more rapid ways of getting homozygous inbred lines, e.g., by anther culture, are required. There are obvious dangers in relying on a male-sterility system based on a single sterile cytoplasm type, especially one which shows some evidence of instability. Work is needed at the molecular level to determine biochemical basis for male sterility and hence possible ways of manipulating and controlling.

Male-sterile lines developed at various institutes need to be tested at different locations for stability and transferred into the background of best selected varieties and genotypes with diverse nature along with the development of maintainer lines. Constant upgradation and improvement of parental lines by reciprocal recurrent selection and introgression of genes from long-day types would elevate genetic potential of parental lines. Development of 100% homozygous lines through haploidy by anther culture and deploidization would be the best option for developing quality inbred lines. Training of the elite farmers for seed production and making available quality seeds of F_1 hybrids at reasonable rate are the need of the hour. Besides, potential of F_1 hybrids needs to be demonstrated through frontline demonstrations vis-à-vis farmers own material and released open-pollinated varieties. This will definitely lead to successful commercialization of F_1 hybrids.

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Aggregatum Onion and Shallots

6

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Two types of onion are commercially grown in India; one is common onion *Allium cepa* var. *cepa,* which is most important in commercial trade. Common onion bulbs are large, normally single, and its plants are propagated through seeds. The second type is multiplier onion *A. cepa* var. *aggregatum*, which produces small size bulbs, many in number, to form an aggregated cluster. Multiplier onion is also known as country onion or potato onion or Egyptian ground onion, and is being grown since ancient times in India. It has got a Sanskrit equivalent 'Palandu', mentioned in *Apastamba Dharma Sutra I* (dated 800 BC to 300 BC), which confirms its early introduction into India. In Tamil Nadu, aggregatum onion is grown in 26,491 hectares with a production of 2.56 lakh tonnes.

Aggregatum Onion

Varieties

Cuddalore, Podusu, Dindigul Red, Mutlore Natu and Palluvengayam are local cultivars in Tamil Nadu. The Tamil Nadu Agricultural University, Coimbatore, is the only institute in India working on breeding multiplier onions (Table 6.1).

Cultivation

The aggregatum onion is gaining momentum among progressive onion- growers of Tamil Nadu. Certain types of aggregatum onions, grown particularly near seashores of east coast of Tamil Nadu (Thengaithittu and Gnanamedu, near Cuddalore; and Puducherry and Mutlur, near Chidambaram), exhibit seed-setting ability.

Twelve seed-setting onion types were collected from different regions of Tamil Nadu and evaluated with Co (On) 5 (check) to study *per se* performance (Kumaravelu, 2009). Cultivars Aca 12, Aca 3 and Aca 7 were found performing better for yield and quality compared to the check (Table 6.2). Aca 12, a collection from Puttarsal (near Palladam,) was superior with respect to bulb yield, growth parameters, bulb characters and quality characters, mainly ascorbic acid content. Moderate estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for number of leaves per plant, leaf girth, shoot girth, bulblet weight, number of bulblets per bulb and bulb weight were recorded. High heritability estimates in conjunction with high genetic advance were observed for number of leaves per plant, leaf girth, shoot girth, bulblet weight, number of bulblets per bulb and bulb weight (Kumaravelu, 2009).

The major expenditure in aggregatum onion cultivation is that large quantities

Table 6.1 Varieties of aggregatum onion

Variety	Characters
CO 1	It is a clonal selection from a germplasm type CS 450, introduced from Manachanallur. The crop duration is 90 days and its yields 10 tonnest/ha. Bulbs are medium in size, red in colour. The bulb weight per plant is 55 to 60 g with an average of 8 bulbs per plant. The plant is medium in height (30 cm) with green leaves. It is fairly pungent with a medium TSS content (8–9°brix).
CO 2	It is a selection from a germplasm type CS 911. The crop yields 12 tonnes/ha in 65 days. The bulbs are crimson and moderately bigger in size. The bulb weight per plant ranges from 60 to 65 g, with an average of 9 bulbs per plant. The leaves are green with cylindrical shape. The plant height is 30 cm. The number of shoots per plant ranges from 7 to 9. The weight loss during storage is lesser than CO 1. This variety is pungent with high TSS content (12°brix).
CO 3	It is a clonal selection from open-pollinated progenies of CS 450. The crop duration is 65 days and its yields 15.8 tonnes/ha. The bulbs are pink and bolder in size. The bulb length and girth are 3.5 cm and 8.3 cm, respectively. The mean bulb weight per plant is 75 g. Number of bulbs per plant range from 8 to 10. The plant has light-green erect cylindrical leaves. Its height is 40 cm. The number of shoots ranges from 6 to 8. Its bulbs are bigger than CO 2 with good consumer appeal. Plants are moderately resistant to thrips. The bulbs store well for 120 days, devoid of sprouting in well ventilated store-rooms. The variety contains 17.5% dry matter with 0.53% sulphur and 13.0% TSS.
MDU1	It is a selection from Sempatti local. It has uniform big size bulbs of bright red colour and with better keeping quality without any weight loss. Its yield potential is 13,000 kg/ha.
CO 4	It is a hybrid derivative of the cross AC 863 × CO 3. The crop duration is 65 days and its yields 19.0 tonnes/ha. Its leaves are light-green, erect and cylindrical. The number of bulbs per plant varies from 8 to 13 with an average weight of 90g per clump. Bulbs are attractive, light-pink, bold with good consumer appeal. They store well over 150 days.
CO (On) 5	It is a high-yielding variety, developed by mass pedigree method. It has the ability of free flowering and seed-set throughout Tamil Nadu. It possess high bulb yield 18.9 tonnes/ha (18.8% higher than CO 4) in a crop duration of 90 days. It is free-flowering type with seed-setting ability of 250–300 kg/ha and thus is propagated through seeds. March–July is for bulb production and November–January is for seed production. It possesses attractive pink-coloured bold bulbs. Its total soluble solids content is 13%. Its pungency principle measured as pyruvic acid is 2.37 μm/g of fresh weight.

of seed bulbs are needed for planting, 1,000 kg bulbs/ha; and thus the cost of the planting material is high. Alternative way to reduce cost of production is to propagate through seeds.

Seedling raising and planting

Among aggregatum onions, Co (On) 5 is a free-flowering and seed-setting type, and can be propagated both by seeds and by bulbs. In plains, seeds are sown during October–November for a *rabi* crop, and in hills, seeds are sown from March to June. Sowing is first done in well-prepared nursery beds of 90–120 cm width, 7.5–10.0 cm height and of convenient length.

Area ratio between nursery and main field is 1 : 20, and seed rate varies from

Table 6.2 Performance of seed-setting aggregatum onion types

Cultivar	Source	Weight of Bulb/plant (g)	TSS (°Brix)	Pyruvic acid (μ mol/g)
Aca 1	Coimbatore	64.63	14.42	2.45
Aca 2	Ottanchatram	60.69	13.80	2.64
Aca 3	Dindigul	68.50	13.18	3.12
Aca 4	Dindigul	51.64	12.92	2.22
Aca 5	Rasipuram	49.64	12.67	2.28
Aca 6	Salem	55.52	13.10	2.70
Aca 7	Gnanamedu	69.68	13.68	2.95
Aca 8	Gnanamedu	61.58	12.88	2.33
Aca 9	Gnanamedu	66.19	13.15	2.77
Aca 10	Gnanamedu	55.18	12.75	2.54
Aca 11	Palladam	54.17	13.32	2.26
Aca 12	Palladam	73.70	13.92	2.84
Co (On) 5	Coimbatore (Check)	65.22	13.40	2.60
	Mean	61.26	13.32	2.59
	CD (P=0.05)	4.64	1.01	0.20

Source: Kumaravelu (2009)

8 to 10 kg/ha. Seedlings of 15 cm height and 0.8 cm neck diameter are ideal for transplanting, and they are ready in eight weeks (period varies from 6–10 weeks depending on soil, climate and rains). At the time of transplanting, practice of topping of seedlings is done if seedlings have over-grown. To avoid seedling mortality owing to damping-off, drench beds with copper fungicides at 2.5–3.0 g or Carbendazim at 2 g per litre of water. Bulbs are planted at a spacing of 10 cm between plants on the both sides of the ridges. Onion seedlings are transplanted at a distance of 15 cm ×10 cm.

Soaking of onion-seeds in water or sodium phosphate solution for 2–6 hours, followed by drying was found beneficial for vigour and viability (Basu *et al.,* 1975). Highest yield was obtained with planting of eight week-old seedlings (Rathore and Yadav, 1971). Partial pruning of seedlings at the time of transplanting augmented crop stand and increased bulb size (Maiti and Sen, 1968); similar results were reported by Rathore and Kumar (1974). Top pruning may add to convenience in transplanting, and no adverse effects of it are seen on bulb yield.

Manuring and fertilization

Onion-crop yielding 300 q/ha removed 73 kg of nitrogen, 36 kg of phosphorus and 68 kg of potash (Yawalkar *et al.,* 1962). Zink (1966) reported uptake of onion-crop from the soil to the tune of 66 kg nitrogen, 11 kg phosphorus and 52 kg potash and 40 kg calcium per hectare. Use of slow-release N fertilizer, sulphur-coated urea as pre-plant application in direct-sown crops with furrow irrigation was beneficial for onions (Brown *et al.*, 1988).

Higher amounts of nitrogen reduced development of premature seed-stalk formation (Singh and Kumar, 1972). N higher dose reduced bolting percentage also (Verma *et al.,* 1972; Hassan and Ayoub, 1978). Onion-bulbs are often stored for varied time periods depending on the necessity. Hence, NPK dose should be optimum so that bulb quality does not deteriorate, and spoilage is not much. Application of sulphur is found to improve quality and pungency of onion bulbs; higher doses of sulphur reduced bolting.

In Tamil Nadu, application of FYM 25 tonnes/ha, *Azospirillum* 2 kg and *Phosphobacteria* 2 kg/ha, N 30 kg, P 60 kg and K 30 kg/ha as basal and 30 kg N/ha on 30th day of sowing gave maximum bulb yield (HC&RI,2013). Whereas under fertigation systems, 75% of the total recommended dose of superphosphate (285 kg/ha) as basal dose and *Azospirillum* and *Phosphobacteria* each @ 2 kg/ha along with FYM 50 kg and neem cake @ 100 kg are applied before the last ploughing. Raised beds of 120 cm are formed at an interval of 30 cm, and laterals are placed at the centre of each bed.

Fertigation

Fertigation, a hi-tech agro-technique combining water and fertilizer application through drip irrigation, is one of the most effective and convenient methods of supplying nutrients and water at the root zone specific to crop requirement to maintain optimum soil fertility and for getting better quality produce (Shirgure *et al.,* 2000).

Fertigation allows application of nutrients exactly and uniformly only to root volume, where active roots are concentrated. This refined technology remarkably increases efficiency of applied fertilizers, thus economizing on fertilizer quantity, water and cost of labour and energy, and thus also reduces cost of cultivation. Normally, for fertigation high-cost water soluble fertilizers are used. If there is a possibility of using easily available water-soluble straight fertilizers through drip, a drastic reduction in cost of cultivation can be achieved.

Taking these aspects into consideration, studies were undertaken to standardize fertigation for Co (On) 5. Superphosphate was given as a basal dressing and N and K were applied through drip fertigation. In Co (On) 5, fertigation with 75% of the recommended fertilizer dose (i.e., 45 : 45 : 22.5 kg of NPK/ha) registered higher bulb yield (8.34 and 11.05 tonnes/ha) compared to soil application of fertilizers. The higher yield was due to increased plant height, number of leaves and root length, leaf area index, total chlorophyll content and dry matter content. Quality parameters like TSS, pyruvic acid, ascorbic acid, protein and total sugar content were also high. Its benefit; cost ratio was 3.72.

Application of micronutrients improved quality of bulbs. Zinc at 1, 2 and 3 ppm significantly increased yield and quality of bulbs by increasing TSS, sugars and ascorbic acid (Mayura and Lal,1975). Rao and Deshpande (1971) reported appreciable increase in bulb yield with copper and boron at 13.4 and 1.8 kg per hectare, respectively.

Abrol and Dixit (1972) recorded significant increase in yield and water-use efficiency in drip irrigation than conventional methods of check-basin. The field should be irrigated immediately after planting and again on the third day. Afterwards field needs to be irrigated once in 7 or 10 days, depending on the soil moisture (Veeraragavathatham, 1998). In general, irrigation should be given as and when required based on the soil moisture and prevailing weather.

Weed management

Onion, being a short-duration crop, is affected by weed competition severely at bulb initiation and development stage. As the crop is closely planted and possesses shallow roots, hand-weeding is difficult, and may damage the crop. Manual weeding is expensive also. Therefore, it is suggested to use safer herbicides along with one or two hand-weedings based on the field condition, especially at the critical stages of growth.

Patel *et al.* (1988) suggested that for overall weed control efficiency, Fluchloralin at 0.9 kg/ha before planting should be applied along with weeding at 40 days after sowing (92.1%). Pre-emergence application of Fluchloralin at 1.0 kg/ha with two hand-weedings at 30 and 60 days after transplanting recorded least weed count and dry matter production, favouring highest yield of bulbs (72.4 tonnes/ha) (Warade *et al.*, 2007; Warade *et al.,* 2008).

Harvesting

Harvesting of the bulbs at the appropriate maturity stage is very important in deciding its storage life. The bulbs reach maturity when plants cease to produce new leaves and roots. In onions, neck fall is the indication of maturity. Bhonde *et al.* (1983) reported that onions could be safely harvested a week after 50% of the crop was with neck fall; three days field curing was desirable to improve storability. All plants in the field do not mature at the same time. Harvesting should start when 25–50% of the top falls.

Harvesting time depends on the planting, season, variety, market price and condition of the crop. If immature bulbs are harvested, longer time is required for their drying, and keeping quality is also affected adversely. Late harvesting results in sunburn and poor storability. The bulbs are harvested by pulling if soil is light textured. They are also harvested by hand implements or modified potato-digger. *Kharif* onion is harvested when leaves are still green; the tops and roots are removed and bulbs are ready for market.

On an average, crop yield is 12–16 tonnes/ha in 70 to 90 days. However, Co (On) 5 yields 18 tonnes/ha in 90 days.

Post-harvest technology

Out of the total annual production of over 45 lakh tonnes, 25–30% is lost during handling in storage and transportation. Major loss is noticed during storage. It is very well established that pre-harvest factors, such as variety, nitrogen application, irrigation, plant protection and harvesting affect bulb quality. Post-harvest factors like field curing, grading, packing and transportation are also responsible for the quality. Respiration, growth and development, transpiration and natural water loss, physical damage and pathological breakdown are biological factors involved in deterioration of onion-bulbs (Pandey *et al.,* 1999).

In India, about 35 – 40% of onion yield is estimated to be lost as post-harvest losses. In general, losses are owing to reduction in weight (20–25%), sprouting (4–5%) and rotting (decay) (10–12%).

In aggregatum onion var. Co (On) 5 experiments were conducted to reduce post-harvest losses. Pre-harvest spraying and standardization of curing methods and packing and storing were done by Anbukkarasi (2010).

In pre-harvest spraying, foliar spraying of maleic hydrazide @ 2,000 ppm + Carbendazim @ 1,000 ppm at 30 days before harvest recorded relatively low percentage of weight loss in storage (Table 6.3). Maleic hydrazide was found to reduce physiological loss in weight and Carbendizim was protective against pathogenic infections (Rao and Chundawat, 1990). Maleic hydrazide has, however, been banned.

Table 6.3 Effect of curing on aggregatum onion, var.Co (On) 5

Treatment	Physiological loss in weight (%)	Sprouting (%)	Moisture content	TSS content (°Brix)	Pyruvic acid (μ mol/g)
Bulbs with 2 cm neck length + Maleic hydrazide @ 2,000 ppm + Carbendazim @ 1,000 ppm as pre-harvest spray	1.28	0.02	94.63	13.97	2.71
Bulbs with tops removed	3.23	0.15	93.98	13.57	2.60

Source: Anbukkarasi (2010)

Drying and curing

Drying is for removing excess moisture from outer skin and neck to reduce infestation by disease-causing organisms and with the minimal shrinkage.

Curing is a process that aids in the development of skin colour and also for removing field heat before storage of bulbs. The length of curing time depends largely on the weather, and in winter season in north, thorough curing requires 2–3 weeks as temperature is low at the harvesting time.

Curing in shade improves bulb colour and reduces losses significantly during storage. This curing system may be practised for multiplier onions also to minimize losses in handling and storage. As period of field curing depends on the type of onion and temperature prevailing, drying of foliage is considered completion of field curing.

Different curing methods with bulb tops removed, bulbs with 2-cm neck length and 4-cm neck length such as sulphur fumigation (50 g/m^3) for three hours, bulbs treated with gamma rays @ 2 kr and 4 kr were studied. In aggregatum onion Co (On) 5, harvested bulbs are to be pre-cured in fields for three days and in shade for two days before curing. Retaining 2-cm neck length of the top leads to reduction in physiological weight loss, sprouting, loss in moisture content and improved quality characters, TSS and pyruvic acid content.

Packaging

Cured bulbs stored under low-cost bottom ventilated storage structure improved quality parameters, enzyme activities and shelf-life of onion bulbs (Table 6.4).

Onions are packed in jute (hessian) bags for transporting to yards or brought as loose material. For safe handling, 40-kg open-mesh jute bags of 200–300 g

Table 6.4 Effects of packing and storage methods on aggregatum onion (var. Co (On) 5) bulbs 90 days after storage

	Physiological loss in weight (%)	Sprouting (%)	Rotting (%)	Total loss (%)	Sulphur content (%)	Total sugars (%)	Marketable bulbs (%)	TSS content (°Brix)	Ascorbic acid content (mg/100g)	Pyruvic acid content (µmol/g)	Protein content (mg/g)
Spreading bulbs in ventilated storage	9.83	1.15	1.08	12.07	0.77	8.06	81.33	19.33	9.99	2.44	22.92
Spreading bulbs in room (control) temperature	17.47	1.40	2.07	20.93	0.71	6.37	71.63	18.03	8.47	2.25	19.68
Perforated plastic crates + room temperature	10.52	1.15	1.33	12.98	0.77	7.97	72.23	18.80	9.82	2.40	21.90
Nylon net-bags	11.83	1.23	1.35	14.42	0.76	7.33	70.77	18.62	9.75	2.37	20.98

Source: Anbukkarasi (2010)

weight should be used for domestic market. For export, common big onions are packed in 5–25-kg size open-mesh jute bags. Bangalore Rose and multiplier onions are packed for export in 14–15 kg wooden baskets. Plastic-netted bags are attractive and also better in strength, but these are not being used commercially either in domestic market or for export markets. In foreign countries, plastic-netted bags for onion packing are common.

Storage

Onion is a delicate and perishable commodity and it cannot be stored for a longer duration at room temperature due to high moisture content and other associated factors. In temperate countries, climatic conditions are more favourable for onion storage, since bulbs are harvested in autumn and stored during low temperature.

But in tropical and subtropical countries, like India, the crop is harvested in summer and stored for 4–6 months in ambient conditions of high temperature and high humidity. During this period, the bulbs sprout easily, besides rotting due to fungal and bacterial diseases. In these countries, proper storage of bulbs is necessary both for consumption and also for seed production purposes.

The post-harvest period of onion-bulbs has been separated into two well defined stages like the rest period, when bulbs would not sprout even under conditions favourable for growth, and a dormant period, when sprouting occur under high humidity and suitable temperature. Sprout activation is controlled by a complex natural inhibitor-promoter interaction, and sprout extension is controlled by natural gibberellins (Thomas and Isenberg, 1972). Thus, a growth inhibitor may be a prime factor involved in dormancy process. Kato (1966) suggested that inhibitor was produced in leaves during bulbing and translocated into bulbs during senescence. Defoliated onions sprouted much earlier in storage than those in which senescence occurred naturally in the field. It indicated that the growth inhibitor was present in the bulbs after harvesting but it decreased gradually until the onset of sprouting while both auxin and gibberllins increased around the beginning of the sprouting period.

In India, different storage methods are adopted by farmers. Onions are bulk stored in special houses or structures with thatched-roof and sides covered by bamboo-sticks with a provision of good air circulation. In north India, the sides are also covered with gunny cloth. The bulbs are stored in these sheds by spreading them on dry and damp-proof floor or racks. Periodical turning of bulbs or removal of rotten, damaged and sprouted bulbs needs to be done. Well-ventilated room with racks or tiers having two or three layers of bulbs would be desirable for proper storage.

Onion-bulbs packed in gunny bags and stored in modified storage structure for three months showed minimum storage losses (34.65%). Adamicki (1998) reported that 17 onion cultivars stored in an ambient ventilated store at 0°C for 6 months suppressed sprouting to a great extent, and had no effect on root development.

Benkeblia *et al.* (2004) noted an increase of fructans, particularly DP 5–8, in onion-bulbs after six months at 10 and 20°C. High dry matter onion cv. Sherpa when stored in controlled atmosphere (1% or 0.5% O_2 with less than 0.3% CO_2 at 2°C) had an improved shelf-life (when tested for 3 weeks at 18°C after 9, 27 and 36 weeks storage) compared with those stored in refrigerated condition (Praeger *et al.*, 2003). Pyruvate concentration in onion-bulbs cv. Hysam decreased 9 weeks after storage at 0.5°C in the CA conditions (2% 0_2, 2% CO_2, 2% O_2 and 8% CO_2) and increased in ambient atmospheric storage (Uddin and Mactavish, 2003).

Processing

Pickles: Pickled onions are very popular in UK and other European countries. The pickles can be made by the following methods.

Without fermentation: Select fully dried onions which are free from adhering soil and grade them according to the size. Remove outer layer of brown skin, tops and tails with a stainless steel knife. For pickling without fermentation, pack onions fairly tight in a cask and fill the cask with brine of 850 salometer. After 48 hours, run-off the brine and replace it with saturated brine. Fifty five grams of potassium metabisulphite for a 200 to 225-litre cask may be added to bleach onions.

With fermentation: For adopting fermentation process, soak onions in water for 2–3 days then place them for a further period of 4–5 days in 5% brine. This will leach out strong taste and give a whiter product. Drain brine and replace it with fresh brine of 600 salometer and increase this to 800 for longer storage.

Drain brine from onions and leach out salt by soaking in hot water for about 12 hours. Run the water-off and pour 4% acetic acid solution over the onions. Allow mass to stand for 24 hours. Then remove onions from the cask. Fill them into wide mouthed bottles, covered with 5% acetic acid or white vinegar and seal bottles airtight. A few fresh red chillies and a small quantity of white mustard seeds may be added for better appearance. Suitable spice may also be added.

Dehydration

Preserving vegetables by drying them is one of the traditional methods. Sun-drying, is however, good and housewives dry vegetables for off-season by this method. Onion slices, rings or shreds could be dried and packed in moisture proof containers like high-density polythene bags having gauge 750 or above, sealed tins or jars. The leaves are removed and onions are cut into 2.5-mm thick slices. These slices are immersed in 5% solution of common-salt for about 10 minutes and then drained. They are dried at 60–65°C for 11–13 hours. However, it is better to keep temperature below 57°C. The drying ratio depends on the varieties and varies from 1: 7 to 1: 9.

Vijayalakshmi *et al.* (2005) studied dehydration of different forms of onions to suit varied needs of consumers and stated that moisture content of dehydrated onion products declined rapidly during the first month of storage and declined gradually during the second and third month. The vacuum packed samples had better quality and retained pungency than the control. There was a reduction in ascorbic acid content throughout the storage and only minimal increase in reducing and total sugars was noticed during storage. Browning of samples was observed during third month of storage, which made products less acceptable.

Transportation

Onion stocks are transported in tractor-trolleys and trucks. Railway wagons are used for longer distance transport within the country. Besides, onions are transported in ventilated ships as well as sailing vessels/motorboats for export to Gulf and South-East Asian countries. They are also shipped in 20-ft containers or 40-ft containers through ships.

For safe transportation of onions, sorting and grading must be practised thoroughly. Also suitable packages of jute having 9×10 mesh per inch^2 should be used. It is desirable to have cushioning material below bags to avoid damage from jerks due to poor roads. Overloading should be avoided. Hooks should not be used while loading or unloading bags. Though losses on account of rotting are lower in trucks than wagons, transport by trucks is costlier than railway wagons. Further to save onions from damage due to high heat, modified ventilated wagons by providing ventilators should be used. For transportation of onions to foreign markets, particularly yellow onions, ventilated container vessels should be arranged to minimize losses. It is also better to load bags on pallets for easy handling at the destinations in importing country. Disinfection of containers and other transport means should also be practised.

Marketing

About 10–15% of total production is exported and used for processing, and remaining produce is consumed internally or used as seed material.

Lasalgaon and Pimpalgaon in Nashik district in Maharashtra are the leading onion markets in India. About 40% of onion production arrives in these markets; totalling 4.5–5 lakh tonnes annually. Peak period of arrival in this market is December to June when 60% of the total arrivals are received. Chakan (Pune), Lonand (Satara), Gultekdi (Pune), Nashik, Dhule, Malegaon, Yeola, Niphad, Saikheda, Chandwad, Marunad, Dindori and Sinnar in Maharashtra are other major assembly markets for onion. Major markets for aggregatum onion are as follows.

Crop-growing districts in Tamil Nadu	: Perambalur, Trichy, Dindigul, Namakkal, Coimbatore, Erode, Tirunelveli
Major markets in Tamil Nadu	: Dindigul, Palani, Palladam, Madurai, Trichy, Ottanchathiram, Coimbatore and Chennai
Preferred variety	: Co (On) 5
Grade specification	: Shape, size, skin colour, moisture content

Various methods for sales followed in different assembling and distributing markets are: (1) open auction system, (2) tender system and (3) open agreement system.

Onions are also moved for exports to ports like Mumbai, Chennai and Tuticorin. All big city markets like Kolkata, Mumbai, Delhi, Guwahati, Bengaluru, Hyderabad and Kanpur are major consuming centres of onions.

Seed production

Production of quality seed is an important factor for successful onion cultivation (Tomar, 2005) with the growing consciousness about the high-yielding varieties among farmers. Onion is grown as a *rabi* crop in northern plains, while it is grown both as *kharif* and *rabi* crops in southern plains (Gupta *et al.,* 1979). The time of planting is the most important factor in seed set (Mishra and Mishra, 1991). Delayed or early planting adversely affects seed yield (Sumanaratne, 2000).

Onion growth for seed production requires vernalization for flowering and cold stimulation for bolting (Rabinowitch, 1990). Mostly, bulb to seed method is used for seed production, since it permits selection of true-to-type and healthy bulbs with comparatively high seed yield.

The major constraint in the cultivation of aggregatum onion is the requirement of large quantity of seed-bulbs for planting and cost of planting material. For production of seeds, genotypes, which exhibit good seed-setting ability like Co (On) 5, Puttarasal type and Santhaipadugai local can be used. These genotypes showed both high bulb yield and better seed-setting ability. Growing of such seed-setting aggregatum onions commercially need standardized cultural practices.

Seed-setting season for aggregatum onion was studied with three genotypes—Co (On) 5, Puttarasal type and Santhaipadugai local. The bulbs were planted in September, October, November and December. Among different genotypes, Puttarasal recorded better flowering and seed characters. Among different seasons, planting of bulbs during September recorded more flowering, seed yield and seedling vigour characters. It is recommended to plant aggregatum onion-bulbs during September for better seed yield and vigorous seedlings.

Shallot (*Allium cepa* var. *ascalonicum*)

All cultivated shallots, onions and leeks are hybrids–some are natural, some are not, but all of them are of obscure parentage. Shallots flower rarely, if ever, and multiplier onions, and in particular white ones, flower annually or at irregular interval. This clearly emphathetically indicates the necessity of vegetative propagation for production of traditional shallots.

Differences between shallots and multiplier onions are: shallots flower rarely and they on an average have two eyes per asymmetrical bulb while multiplier or potato onions, regardless of their size, usually have only one eye. There are some varieties that are intermediate between the two, as all *A. cepa* are believed to be hybrids of various wild *Allium* species (Table 6.5).

Table 6.5 *Allium* species used as vegetables

Botanical name	Common name	Chromosome number	Character
Allium cepa var. *cepa*	Common onion	2n=16	Large bulbs, born singly, and propagated through seeds. It is mainly used as salad or in curries
A.cepa var. *ascalonicum*	Shallot		Produces bulbs in clusters on the surface of the soil. This perennial onion rarely produces seeds and is propagated through bulbs
A.cepa var. *aggregatum*	Multiplier onion or potato onion	2n=16	Produces small bulbs borne in clusters and is generally propagated through small bulbs. Mainly used for seasoning curries

Source: Vishnu Swarup (2006)

True shallots

True shallots (*A. cepa* var. *aggregatum*) are grown primarily for their bulbs, although green tops may also be consumed. Each compound bulb consists of several sets/cloves ideally 30 to 40 mm in diameter, with brown skin and purplish tinge inside the bulb. These shallots are used in place of onions as they have a delicate, yet distinctive, flavour that persists even after cooking.

Medicinal properties: Shallot-bulbs have mild pungent taste and distinct smell as compared to onion and garlic. Shallots add flavour to dishes and is a popular ingredient used by chefs around the world. They are used as a condiment in various Asian cuisines in a finely sliced or deep-fried form, and are popularly used in cuisines like Malaysian and Thai.

Table 6.6 Nutrient composition of *Allium* species

Species	Water (%)	Calories (K cal)	Carbo-hydrate (g)	Prot-ein (g)	Fat (g)	Fibre (g)	Ash	Vitamins in (mg)					Ca	P	K (in mg)	Na	Mg	Fe
								A	C	B_1	B_2	Niacin						
Allium ampeloprasum, great headed garlic (bulb)	86.3	45	10.3	2.2	0.30		0.90						52	50				1.1
Allium ampeloprasum, leek (pseudostem and leaves)	83.0	56	12.6	1.9	0.30	1.40	1.10	75	15	0.08	0.05	0.45	55	43	230	16	25	1.9
Allium cepa, shallot (bulb)	79.8	72	16.8	2.4	0.10	0.70	0.80		8	0.06	0.02	0.20	37	60	334	12		1.2
Allium cepa, shallot (leaves)	91.0	30	5.0	1.8	0.90	1.60			19	0.07	0.12	0.40	86	25				3.7
Allium cepa, onion (bulb)	90.8	36	8.0	1.3	0.18	0.52	0.40	40	9	0.05	0.03	0.15	26	33	156	6	11	0.4
Allium cepa, onion (leaves "Scallions")	91.9	25	5.6	1.7	0.14	0.90	0.70	5000	45	0.07	0.14	0.20	60	33	257	14	20	1.1
Allium Chinese, rakkya (bulb)	86.0	50	12.0	2.2	0.30	0.50	0.50		10	0.05	0.03	1.0	22	66				0.5
Allium fistulosum, Japanese bunching onion	90.5	34	6.5	1.9	0.30	1.00	0.70	380	27	0.05	0.09	0.40	55	49	200	10		1
Allium sativum, garlic (bulb)	64.0	131	27.9	6.20	0.35	1.00	1.30	0	11	0.20	0.08	0.50	32	187	465	17	25	1.3
Allium sativum, garlic (leaves)	86.4	12	9.5	2.60	0.50	1.50	1.00	680	38	0.08	0.16	0.70	82	66	326	4		0.5
Allium schoenoprasum, chives (leaves)	92.0	26	3.9	2.80	0.60	0.90	0.80	6400	70	0.10	0.12	0.60	82	46	25	6	55	1.2
Allium tuberosum, Chinese chives	93.1	23	2.8	2.10	0.10	0.90	1.00	1800	25	0.06	0.19	0.6	50	32				0.6
Allium wakegi, Wakegi onion	91.2	29	5	1.90	0.30	1.00	0.60	500	30	0.05	0.15	0.4	38	35		20		1.2

Source: Rubatzky and Yamaguchi (2001)

Shallots have various health benefits and have high nutrient content. Their bulbs contain antihelmintic, anti-inflammatory, antiseptic, antispasmodic, carminative, diuretic, expectorant, febrifuge, hypoglycaemic, hypotensive and lithontripic properties (Sheela *et al.*, 1995; Augusti, 1996). Shallots contain very less amount of calories and loads of nutrients. Their calories depend on cooking procedure. Shallots are more nutritious than onions (Tables 6.6, 6.7). They have more minerals, vitamins, flavonoid, antioxidants like quercetin and kemferfol. Shallots contain iron, required for proper functioning of red blood cells and help in proper digestion also. Due to dietary fibre content, water is absorbed and stomach appears to be full after a meal. Shallots release sugar slowly in the bloodstream and helps soften stool and is a preventive for constipation. They are useful in reducing blood cholesterol level and are curative against many heart diseases. One cup of shallots yields 5.1 g of dietary fibres (20% of the daily required fibre for women and 13% for men), and gives 534 milligrams of potassium (11% of daily required intake).

Table 6.7 Nutrient composition of onions

Characters	Common onion *A. cepa* var. *cepa*	Aggregatum onion *A. cepa* var. *aggregatum*
Moisture (%)	86.6	84.3
Proteins (g)	1.2	1.8
Fat (g)	0.1	0.1
Minerals (g)	0.4	0.6
Fibre (g)	0.6	0.6
Carbohydrates (g)	11.1	12.6
Energy (K cal)	50	59
Calcium (mg)	47	40
Phosphorus (mg)	50	60
Iron (mg)	0.7	1.2
Carotene (mg)	0	15
Thiamine (mg)	0.08	0.08
Riboflavin (mg)	0.01	0.02
Niacin (mg)	0.4	0.5
Vitamin C	11	2

Source: Shanmugavelu (1989)

Shallots contain phyto-chemicals, allicin and allyl disulphide, which have anti-diabetic properties: lower blood sugar level in diabetics. They are the richest source of vitamin A (an antioxidant), which protects eyes from harmful free radical damage, and promotes healthy immune system, and proper growth and development. Shallots are the oldest and the most efficient home remedies for hair growth. They are rich in sulphur that helps in production of collagen tissues.

Varieties

Red Sun: French-type with golden-red skin and reddish interior rings. Days to maturity 80.

Gray Shallots: 20 to 28 bulbs per pound.

Prisma: Hybrid, red-to-the-core bulb with strong onion flavour with high-gloss finish, and long-day type. Days to maturity 100.

Bonilla: Hybrid, round, straw-coloured, thick-skinned, very pungent, white-fleshed, 2-inch bulbs. Produce 4 or 5 separate bulbs by mid-summer. Store well in spring and early summer. Days to maturity 100–105.

Olympus: Hybrid, produce 1½ inch, white-skinned, white-fleshed bulbs. Stores well. Days to maturity 90.

Armador: Dia. 3 inch with deep-red colour. Produce only one bulb.

Ambition: Hybrid, large, French-style half-long teardrop-shaped bulbs with reddish-copper skin and creamy-white flesh. Suitable for long-term storage through spring. Best grown in northern climate. Days to maturity 100.

Holland Red: Short, plump, flat bulbs with reddish skin and white-flesh tinged with purple. Store well.

Matador: Dia.2 inch, round, reddish-brown, thick-skinned bulbs with white flesh. Days to maturity 90.

French Red: Single bulbs multiply into 10 to 15 reddish-purple shallots in just one season. Easy to peel. Days to maturity 100.

Mirage: Large, French, half-long style shallots with reddish-copper skin and white flesh. Very firm and can store through spring. Adaptability: 35–65° latitude. Days to maturity 92.

French Gray: Plants produce pear-shaped, purple-fleshed bulbs with tough, thick, grey-blue, wrinkled skins. Days to maturity 100.

Picador: Large, French, half-long style hybrid. Plants produce single, reddish-brown bulbs with white flesh. Store well. Adapted for 35–65° latitude. Similar to 'Ambition'. Days to maturity 105.

Pikant: Large, French style. Plants produce mahogany bulbs with reddish flesh. Store well. Adapted to 35–65° latitude. Days to maturity 80.

Saffron: Hybrid, produce bright copper-skinned bulbs with pale-yellow flesh. Store well. Adapted for 35–65° latitude. Days to maturity 100.

Conservor: Hybrid, produce single, reddish-brown bulbs. Similar to 'Ambition'. Store well. Adapted to 35–65° latitude. Days to maturity 110.

Ed's Red: Plants produce 1- to 2-inch, red-skinned, red-fleshed bulbs. Days to maturity 100.

Cultivation

Shallots are adapted to grow in cool mild to mild tropical climates. Seeds germinate at a temperature range of 10 to 30°C, with an optimal germination temperature between 18 and 24°C. The ideal growing temperature is in the range of 13 to 24°C. Plantings should be timely to avoid periods when daytime temperature exceeds 27°C. In most regions of Queensland, shallot production is restricted to winter and it stops before hot summer months. Only in areas where summers are very mild (e.g. Stanthorpe) they can be grown over summer months. Shallots can be grown over a wider climatic range than common onion as they do not have specific day-length or temperature requirement.

The best soil for growing shallots is deep, well-drained clay-loams of *p*H 6.5 to 7.5 with high levels of organic matter. However, they have grown successfully on a wide range of soils, from relatively shallow, low-*p*H sandy soils to alkaline alluvial soils.

Land preparation reduces weeds to minimum. Ground should be worked to provide a fine tilth at planting. This may include ploughing, several discings and either one or two passes with a rotary hoe or a power harrow. A bed former is used to create beds (about 1.2-m wide) into which seed or seedlings will be planted.

Shallots are usually grown on beds of four to six rows; they may be planted as single rows 20-cm apart or as three or four double rows on each bed. This is best achieved by using a precision planter, although it is not as critical for shallots as for other *Allium* species, as relatively high plant density is required. The seeding rate is around 8 kg/ha to 10 kg/ha, at a depth of 1 cm to 2 cm.

Direct-seeded shallots are planted dry, then are given a light irrigation. Frequent light irrigations of about 12 mm are required until plants emerge and develop a good root system. The top soil should not be allowed to dry until plants are well established.

Shallots have nutritional requirements similar to other alliums, removing about 130 kg of nitrogen (N), 30 kg of phosphorus (P) and 60 kg of potassium (K) per hectare, as well as other nutrients in smaller quantities.

They are ready for harvest in about 10 to 12 weeks after planting, but some hybrid varieties may mature a little earlier. Their stem should ideally be more than 25-cm long and 8 mm to 10 mm in thickness. They are hand-pulled, washed and bunched with trimmed roots. Any damaged or diseased leaves should be removed, and then they should be packed in bunches of 10 to 12, depending on the size with a rubber-band or wrapped in plastic.

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Biotechnology

7

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Biotechnological tools for onions namely—tissue culture for production of doubled-haploids, somatic embryogenesis, transgenic development; use of molecular markers for diversity analysis, varietal identification, colour and quality improvement, male-sterility analysis; and the latest efforts for genome sequencing in Alliums—have been detailed in the following paragraphs.

In-vitro Techniques

In-vitro culture is a technology that includes broad areas of cell, tissue and organ culture, and has played an important role in breeding, production and improvement of crops. Non-conventional techniques for breeding such as gynogenesis, gene transfer through wide-hybridization and genetic transformation have been used extensively for onion improvement. Parthasarathy and Nagaraju (2001) have presented a detailed review on the biotechnology of onions, including various *in-vitro* techniques.

Plant regeneration–Organogenesis and somatic embryogenesis

Kahane *et al.* (1992) succeeded in cultivating onion-plants *in-vitro* with a high potential of shoot regeneration from the basal plate, where apex may have been destroyed or injured for multiplication of axillary buds. A procedure for bulb formation from onion, garlic, and shallot using cut-stem bases as explants was described by Mohamed *et al.* (1995). Adventitious shoots were induced on twin scales cut from small bulbs and on split *in-vitro* shoots as secondary explants (Hussey and Falavigna, 1980). A novel method of direct organogenesis in onion resulting in formation of multiple shoot structures induced on mature flower-buds or ovaries in a two-step culture procedure was described by Luthar and Bohanec (1999). Shoots were produced on explants from flower-head receptacles in *A. porrum* (Novak and Havel, 1981). Different organogenic responses like induction of multiple shoots from shoot tip (Khar *et al.*, 2002a), seeds, flower-bud (Asha Devi and Khar, 2000) and root tip (Khar *et al.*, 2002b) were studied in a few short-day Indian onions. Somatic embryogenesis was observed in callus cultures of *A. cepa, A. fistulosum* and of F_1 hybrids between *A. cepa* and *A. fistulosum*. Seedling shoot meristem-tip explants were successfully used by Phillips and Luteyn (1983) for having high frequency somatic embryogenesis from two onion lines, 'Yellow Grano' and 'Yellow Sweet Spanish'. Somatic embryogenesis for having true-to-type and more number of plants was reported from mature zygotic embryos of *A. cepa, A. fistulosum*, their interspecific hybrids, and from mature seeds, flower-buds, immature zygotic embryos and mature flower-buds or ovaries of *A. porrum*.

Doubled-haploids production

Doubled-haploids (produced after doubling of haploid chromosomes) gained importance for generating homozygous and homogenous populations for varietal improvement in self-pollinated crops, inbred development in cross-pollinated crops and for experiments involving use of plants with uniform genetic background. Though chromosome doubling is daunting task in many crop species, haploid induction is an attractive area for plant breeding and has become important used technique for generation of homozygous populations.

Attempts to produce haploid plants *via* androgenesis failed; as reviewed by Keller and Korzun (1996). The first report on successful haploid induction *via* gynogenesis by using unpollinated ovaries was by Muren (1989), which was followed by other researchers. Several attempts to improve haploid induction procedure using different cultural conditions or altering media components were tested later. Effects of media additives for increased haploid induction were also studied. Effects of flower part, cultivar and megaspore development stage on the plant and haploid regeneration frequency from *in-vitro* culture were investigated, and some researchers reported unpollinated flower-buds and ovaries as better explants for haploid induction, while others opined that ovary or flower culture showed similar induction frequency.

Haploid induction was reported from *in-vitro* gynogenesis from isolated flower-bud culture (Campion *et al.*, 1992; Bohanec and Jakše, 1999). *In-situ* induction of maternal haploids was also achieved by pollination with irradiated pollen (Dore and Marie, 1993) and with sterile pollen from triploid donor in the case of shallot onion (multiplier type) (Endang-Sulistyaningsih *et al.*, 1997). To induce regeneration through androgenesis was not successful (Keller, 1990a). There are only a few reports on the isolated flower-bud culture (Campion *et al.*, 1992; Bohanec and Jakše, 1999); may be due to comparatively low rate of haploid induction in other methods than *in-vitro* gynogenesis.

Genetic factors: Gynogenic induction is a routine method for haploid regeneration in onions (Muren, 1989; Campion and Alloni, 1990; Keller, 1990). The gynogenic response has been reported to vary in genotypes originated from different regions of the world. Many American long-day onion genotypes (Bohenac and Jakse, 1999) showed highest gynogenic potential (51.5% in Rocket F_1). Shallot-type onions are reported to possess the highest (55.2%) regeneration efficiency (Cohat, 1994). In bulb-onion, gynogenic efficiency varied even over seasons as was reported by Geoffriau *et al.* (1997), however, Bohenac and Jakse (1999) reported a few genotypes which were stable in gynogenic efficiency over seasons.

Possible variation in the regeneration efficiency in individual plant population may be due to genetic structure of the population. Inbreds and synthetics performed better than open-pollinated populations (Geoffriau *et al.*, 1997) which might be due to recessive genes in the population affecting embryo development efficiency.

There could be possibly two levels of genetic effects on the genotype of the donor and genetic structure of the population. The genotypes also vary in response on the days taken for regeneration; only a few reports are available on the duration required for regeneration. Further, even the time requirement also varied with season. Systematic study on the genetic the effects of gynogenesis revealed that gynogenic potential was controlled by recessive factors and it displayed non-additive action (Bohenac *et al.*, 2003).

Explant selection: Ovule, ovary and unpollinated flower-bud are used as explants for gynogenic studies. In unpollinated flower-bud culture, stage of the flower plays an important role in determining its gynogenic efficiency. In general, large size buds yield higher number of gynogenic plants (Campion and Alloni, 1990), which can be correlated with embryo-sac maturity. Flower-buds, which were to open in 3–5 days, responded better than small buds (Smith *et al.*, 1991). In an intercross BC_1F_1 population of *A. cepa* × *A. roylei*, only small buds responded for gynogenic induction (Alan *et al.*, 2003). Diversity among the *Allium* species indicates possible strategy needed while dealing with the interspecific hybrids, which are targeted to transfer desirable traits.

Ovary culture is generally used for *in-vitro* seed development and haploid production. It is also being used for recovery of interspecific hybrids among many *Allium* species. About nineteen species belonging to different subgenera of *Allium* were crossed to onion-seed parent, and from 18 crosses, hybrids were successfully obtained through ovary culture (Keller *et al.*, 1996). Ovule culture (Ohsumi *et al.*, 1993), embryo culture (Dubouzet *et al.*, 1998; Dubouzet *et al.*, 1998) or combination of both (Peterka *et al.*, 1997; Gonzalez and Ford-Lloyd, 1987), were also employed for production of interspecific hybrids. Usually flowers are pollinated in the field and ovaries are excised after pollination. The excision of the ovaries vary with crosses as it depends on the stage of the embryo degeneration *in-vivo*. But early excision, i.e. immediately after style senescence, was successful for crossing many species (Keller *et al.*, 1996).

Pre-treatment: As the floral explant is derived from the stock-plant, the environment in which it grows may also affect gynogenesis potential. A ten-fold increase in embryogenesis was observed when flower-buds were cultured from stock-plants maintained at 15°C compared to 10°C or at ambient temperature of a glasshouse (Puddephat *et al.*, 1999). Temperature improved gynogenesis efficiency than time required to embryo germination. The effect could possibly be due to elimination of variations in the external factors. Exposure of cut-umbels for 4–23 days to water at 10°C had efficiency comparable with fresh buds (Alan *et al.*, 2004). Apart from environmental factors, pre-conditioning with a spray of CCC and an injection of putrescine (Ponce *et al.*, 2006) at lower concentrations was observed improving gynogenic efficiency.

Culture medium: Apart from genotypic factors, medium composition was found to affect to some extent gynogenesis efficiency. High sucrose concentration (10%) (Muren, 1989) and high level of growth regulators (2, 4-D and BAP each at 2 mg/litre) (Campion *et al.*, 1992;Bohanec and Jakše, 1999) in the medium promoted gynogenesis in onion. Other growth supplements like polyamines were reported to be essential for growth and development of living tissues (Geoffriau *et al.*, 2006). Putrescine and spermidine induced onset of embryogenesis and increased number of gynogenic embryos and plantlets of onions (Martínez *et al.*, 2000). The gelling agent is another factor that may contribute to success of the technique. Jakše *et al.* (1996) reported that gellan gum (*Gelrite*) doubled number of regenerated embryos, compared to agar-solidified medium.

Chromosome doubling: Although several groups have shown that gynogenesis can be achieved in a wide range of onion materials; reports of successful application of the system to onion improvement are rather limited. Barriers include variations in donor response to induce gynogenesis (genotype specificity), low frequency of diploid regenerants and lack of efficient chromosome doubling procedure. Spontaneous chromosome doubling is rare in the gynogenic onion-plants; usually induced chromosome doubling is required to re-establish diploidy and fecundity. There are a few published procedures for obtaining DH gynogenic onion-plants, and they are limited to *in-vitro* plants (Alan *et al.*, 2004; Geoffriau *et al.*,1997; Campion *et al.*, 1995) and emerging plantlets (Jakse *et al.*, 2003; Grzebelus *et al.*, 2004). Based on the explants used in chromosome doubling treatment, procedure can be categorized as split basal (Geoffriau *et al.*, 1997; Campion *et al.*, 1995), intact plantlet (Jakse *et al.*, 2003; Grzebelus and Adamus, 2004), and whole basal (Alan *et al.*, 2004). In protocols for split basal explants, lower portions of the young *in-vitro* gynogenic plants are longitudinally sliced into halves or quarters to allow exposure of damaged apices to anti-mitotic chemicals and then they are cultured in regeneration medium with or without growth regulators. Campion *et al.* (1995) suggested treatment of split basal halves with 25 mM colchicine for 72 hr in solid medium that resulted 46% diploid regenerants; as determined by chromosome counts in shoot apices. According to Geoffriau *et al.* (1997), the best doubling efficiencies were achieved by treatment of split basal quarters with 2.5 mM colchicine or 50 mM oryzalin for 24 hr, yielding 65.7 and 57% diploid regenerants, respectively. However, the split basal explant method did not perform well owing to losses of treated explants up to 85% (Alan *et al.*, 2004). According to Jakse *et al.* (2003) and Grzebelus and Adamus (2004), a strategy based on the treatment of intact plantlets with antimitotic chemicals for 24–72 hr in liquid or solid medium can help re-establish diploid state in about one-third of the surviving gynogenic plants. This approach has many drawbacks—high mortality of treated explants, inability to determine whether diploid plants are of spontaneous or induced origin, and loss of spontaneous diploid plants due to cytotoxicity or polyploidization. An alternative is to induce spontaneous doubling in plants from flower-bud culture (Alan *et al.*, 2007). Sixty per cent regenerants obtained from flower-buds of haploid plants were diplodized.

Origin of gynogenic embryo: *In-vitro* gynogenesis in *A. cepa* revealed that there was no callus formation before regeneration of gynogenic plants (Muren, 1989; Campion and Alloni, 1990). A low percentage of callusing ovaries was observed only by Keller (1990). Musial *et al* (2001) confirmed that gynogenic embryos were produced directly from a reduced cell of female gametophyte and embryo developed from egg cell (parthenogenesis). In *in-vitro* cultures of *A. cepa*, endosperm develops autonomously without fertilization (Musial *et al.*,1999, 2000). Induction of multicellular endosperm is common in *in-vitro* cultures, and endosperm can also develop from unfused polar nuclei of embryo-sac (Musial *et al.*, 2001).

Application of DH inbreds: DH plants are a valuable resource in a number of crop species, both for rapid generation of inbred lines for hybrid production and for creation of recombinant inbred lines (RILs), useful for developing molecular markers, mapping genes of interest, and detecting QTLs affecting quantitative traits. When working with a trait that is difficult to screen on a single plant basis, generation and evaluation of lines with fixed loci is of considerable value.

Protoplast fusion

Somatic hybridization is used to create variability in nuclear and cytoplasmic genomes; but there are a few reports for its use in Alliums. Polyethylene glycol (PEG)-based fusion of protoplast was reported between *A. ampeloprasum* and *A. cepa* (Buiteveld *et al.*, 1998) and *A. sativum* and *A. monanthum* (Kim *et al.*, 1986). Chromosomal elimination was observed in somatic hybrids (Buiteveld *et al.*, 1998). Though there were many reports of use of interspecific gene transfer, the hybrids displayed either sterility or reduced fertility (Peterka *et al.*, 1997). This could be possibly due to variations in ploidy (Yanagino *et al.*, 2003; Peterka *et al.*, 1997) or aberrations in meiotic pairing of chromosomes (Kielkowska, 2012).

Genetic transformation in *Allium*

Introduction of genes into crops through biotechnological approaches acts as a complement to field-breeding programme. An efficient *in-vitro* regeneration system is a prerequisite for genetic transformation in any crop. It provides opportunity to introduce genes across barriers of reproduction. Also the recent developments, like silencing targeted genes specifically using RNAi technology, provide opportunity to develop resistance or tolerance to biotic stresses where source is not available within crossable germplasm.

Explants and regeneration system for Alliums: Regeneration has been achieved through somatic embryogenesis, direct regeneration and callus induction in onion (Eady *et al.*, 2000; Aswath *et al.*, 2006) and shallots (Zheng *et al.*, 2000). For genetic transformation in *A. cepa*, callus from immature embryo has been preferred. Callus from other explants like root and root-tip (Zheng *et al.*, 2004), stem disc (Xu and Cui, 2007), immature leaf tissue (Kenel *et al.*, 2010) has also been proven useful for transformation. When the callus is used for regeneration, efficiency decreases with age, and aged callus (more than 3 months) are not preferred. Root explants are preferred over embryo explants as roots can be obtained from aseptic cultures, and thus contamination can be avoided.

Transformation: As monocotyledons, *Allium* species are predisposed to be recalcitrant to transformation. By mid-nineties, both particle bombardment and *Agrobacterium*-mediated DNA delivery systems were successfully used for transformation with *uid a* (β-glucuronidase) reporter gene. Microprojectile bombardment for transformation was employed on onion (Xu and Cui, 2007). Degradation of naked DNA in the tissue affects transformation efficiency, and treating tissues with nuclease inhibitor [aurintricarboxylic acid (2 mM)] improved transformation efficacy (Barandiaran *et al.*, 1998). But *Agrobacterium*-mediated transformation was frequently used, and it was established to be valuable for different species of *Allium*. This could possibly be because of the ease of use even in small lab and availability of chemicals like acetosyringone, which proved effective for infecting *Agrobacterium* in monocots. Variations in efficiency could be due to the methods or inherent variations among genotypes for competency to transformation.

Agrobacterium-mediated transformation was successfully carried out using immature embryos as explants (Eady *et al.*, 2000). Recently, Zheng *et al.* (2001) developed a reproducible *Agrobacterium tumefaciens*-mediated transformation system for onion and shallot with young callus, derived from mature embryos with two different *Agrobacterium* strains. In India, Khar *et al.* (2002b) reported, callus to be the best explant in onion for genetic transformation, followed by shoot-tip and root-tip. A common feature among transformation studies in onion was the use of immature embryos as target explants due to their excellent morphogenetic competence (Eady *et al.*, 1996, 2000). However, contamination rate in these explants ranged from 40 to 100%; probably from infected embryos. Zheng *et al.* (2001) used mature embryos, which were tedious to remove, and required stereomicroscope to identify shoot-apex portion. Klein *et al.* (1987) and Scott *et al.* (1999) used epidermal tissues with high velocity microprojectiles resulting in transient expression of *chloromphenicol acetyl transferase* and *green fluorescent protein* genes, respectively. Contamination rate was also high in epidermis. Seedling radicle, which is in no way inferior to other explants, has an added advantage of ease in extraction with zero contamination.

Selectable markers: The most common selective protocols for plant transformation are the use of kanamycin, hygromycin and phosphinothricin. In onion, Eady and Lister (1998) demonstrated kanamycin ineffective up to 200 mg/litre and they used 50–100 mg/litre geneticin. Kanamycin is not recommended for spray, as it is expensive (Altmann *et al.*, 1992); Though hygromycin is moderately expensive and works well both in medium and soil, it is not recommended because of its high toxicity to humans (Altmann *et al.*, 1992); even 20–50 mg/litre hygromycin in onion resulted in a few escapes (Eady and Lister, 1998). Phosphinothricin is an excellent marker for soil-grown plants. Selection on culture medium-plates requires purified and expensive phosphinothricin. Additionally, a large number of escapes were noticed during selection on a medium containing 10–30 mg phosphinothricin/litre (Eady *et al.*, 2000). Unlike most selectable markers, *pmi* confers a positive advantage to plants grown in tissue culture using mannose, which is a carbon source. In addition it does not lead to necrotic cells, which may release toxic compounds, and thus is non-toxic to humans. Mannose selection of resistant plants works equally well in soil and in medium-plates, and is very cheap, perhaps the least expensive among all the agents (Todd and Tague, 2001).

As there is growing concern for use of antibiotic markers for transgenic selection, the efficiency of selection using bacterial *pmi* gene (*phosphomannose isomerase*) was demonstrated in onion by Aswath *et al.* (2006). The *pmi* gene helps cells utilize mannose as carbon source, thus providing positive selection for transformed cells. The selection system used *Escherichia coli* gene that encodes phosphomannose isomerase (pmi). Transgenic plants carrying *mannose* gene that codes *pmi* can detoxify mannose-6-phosphate by conversion to fructose-6-phosphate, an intermediate of glycolysis *via pmi* activity. Six-week-old embryogenic callus initiated from seedling-radicle was used for transformation. Transgenic plants were produced using *Agrobacterium* and biolistic system, with transformation rate of 27 and 23%, respectively. Untransformed shoots were eliminated by a stepwise increase from 10 g sucrose/ litre with 10 g mannose/litre in the first selection to only 10 g mannose/litre in the second selection. Integrative transformation was confirmed by PCR, RT-PCR and southern hybridization.

Traits: Resistance against beet armyworm (*Spodoptera exigua* Hubner) in shallots was the targeted trait to be developed through *cry* genes (Zheng *et al.*, 2005). *OSISAP1* gene was used to impart salt tolerance in onion, and transgenic plants showed survival up to 400 mM of NaCl, and control plants showed mortality at 200mM of NaCl (Xu and Cui, 2007). Imai *et al.* (2002) have discovered an enzyme, which catalyzes specifically lachrymatory factor, named as lachrymatory factor synthase (lfs). This has led to the development of genetically modified onions that do not bring tears while chopping, and hence can be aptly named as "tearless onions". Eady *et al.* (2008) used RNAi to develop tearless onions by silencing *lachrymatory factor synthase* gene. Silencing of *lfs* also induced metabolic changes.

There are many traits of economic importance which need to be further explored, like purple blotch and a few for viral resistance in vegetative Alliums.

Molecular Breeding

Research on physiological, biochemical and genetic traits of Alliums is gaining momentum. With the advent of molecular techniques, it has been possible to study evolutionary details and differentiate cultivars for germplasm management, patent protection and detection of major genes of economic importance. In onion-crop, these techniques are being used in a moderate way. Markers are of two types—isozymes and DNA markers. The latter are preferred because of their polymorphic nature, co-dominance, selective neutral behaviour, easy and fast assay, high reproducibility and easy exchange of data between laboratories (Joshi *et al.,* 1999). There are different marker systems available for crop-plants such as restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD), inter simple sequence repeat (ISSR), microsatellite or simple sequence repeat (SSR), amplified fragment length polymorphism (AFLP), sequence characterized amplified region (SCAR), cleaved amplified polymorphic sequences (CAPS) and single nucleotide polymorphism (SNP) etc. (Semagn *et al.*, 2006).

In spite of advances in sequencing technologies, sequencing of onion (*A. cepa*) remains a huge challenge because of its 16.4 giga base genome size. It has one of the largest nuclear genome (Arumuganathan and Earle, 1991). The use of genetic markers in Alliums has increased several-fold with the development of different marker systems.

Development of genomic resources in Alliums

With the development of different easy tools and protocols, SSR development has been initiated in Alliums. Tsukazaki *et al.* (2006) isolated more than hundred simple sequence repeats (SSRs) of clones from size-fractionated genomic DNA libraries of Japanese bunching onion. The clones were highly polymorphic and cross applicable to related species such as bulb onion. They have showed that bunching onion SSRs are very rich source of highly informative genetic markers; by isolating 1,796 SSR clones by large-scale sequencing of SSR-enriched genomic DNA libraries (Tsukazaki *et al.*, 2007). Of these, 74.1% contained $(GT)_n$ repeats $(n > 5)$, while 17.5% $(GA)_n$-contained clones. The average number of SSR repeats was 10.5 and 10.4 in the $(GT)_n$ and $(GA)_n$-containing clones, respectively. The MISA (Microtellite identification tool) programme has revealed 336 dinucleotide to hexa-nucleotide SSRs among 313 unique onion ESTs; representing a frequency of 1 SSR/25 kb, similar to 1 SSR/27.2 kb in the survey of higher plants (Cardle *et al.,* 2000). Joseph *et al.* (2004) generated 11,008 unique ESTs from a normalized cDNA library of the onion to assess genomic differences between *Asparagales* and *Poales;* sequence analyses of these ESTs revealed microsatellite markers, single nucleotide polymorphisms and homologs of transposable elements.

Molecular markers development in *Allium* have been restricted due to giga base genome size and costs of sequencing. Expressed sequence tags (ESTs) from the onion, that showed significant similarities (70–80%) to single positions in rice genome, revealed scant co-linearity, demonstrating grasses are not appropriate genomic models for *Asparagales*; this indicated necessity to develop genomic resources for these important plants (Martin *et al.*, 2005). Tsukazaki *et al.* (2009) developed a SSR tagged breeding scheme for bunching onion (*A. fistulosum*). Samantha *et al.* (2010) reported application of Roche 454 technology to develop sequence resources for population analyses and genetic mapping. So far, 170 genomic SSRs, 9 EST-SSRs, 31 Indels and 156 CAPS markers have been developed and tested (Table 7.1).

Table 7.1 Development of SSRs in Alliums

Method	Marker developed	Reference
MISA programme	Revealed 336 SSRs, 1 SSR/25kb	Cardle *et al.,* 2000
Normalized cDNA library of onion	11,008 unique ESTs generated	Joseph *et al.,* 2004
Size fractionated genomic library	Thirty-two SSR and 18 bulb onion expressed sequence tag (EST)	Tsukazaki *et al.,* 2006
Large-scale sequencing of SSR-enriched genomic DNA libraries	1,796 SSRs isolated	Tsukazaki *et al.,* 2007
Roche 454 technology	170 genomic SSR, 9 EST SSR, 31 InDels and 156 CAPS markers developed	Samantha *et al.,* 2010

Molecular markers in diversity analysis and varietal identification

RAPD, AFLP, ISSR markers are widely used by onion-breeders due to their low cost, simplicity and absence of prior sequence information in Alliums diversity (Table 7.2). Knowledge on molecular genetic diversity perhaps helps in efficient management of germplasm pool, drawing of mini-pool, and selection of parents in crossing progeny for various commercial traits. Diversity analysis of seven cultivars of *A. cepa* and single cultivar of Japanese bunching onion, chive, leek and a wild relative of onion (*A. roylei*) with RAPD showed *A. roylei* as the closest relative of *A. cepa*, putting a question at the current classification of *A. cepa* in section Rhizideum (Susan *et al.,* 1993). Mes *et al.* (1998) included 29 species of *Allium* and seven species of related genera in a phylogenetic study using RFLP data from PCR amplified cpDNA for differentiating between subgenera Rhizirideum and Allium. Their study confirmed artificial nature of subgenera Rhizirideum, Bromatorrhiza and Allium. Phylogenetic relationships between *Allium* and *Milula spicata*, a rare Central Himalayan-south-eastern Tibetan endemic species, closely related to genus *Allium*, were analyzed using molecular markers, which unambiguously placed the former within Allium subgenus Rhizirideum. These studies help in addressing crop evolution and the inter-relationships of cultivars and varieties. The determination of genetic diversity of crop accessions is of direct use in a gene bank, both to access value of a collection and to direct future collection missions. Sangeeta *et al.* (2006) used 90 RAPD primers and grouped 24 onion cultivars into northern and southern region of India. Ten varieties of onion (*A. cepa*) were analysed by Maniruzzaman *et al.* (2010), and they found, Bermis and India-2, most dissimilar, while Faridpuri and Bhati were most similar genetically.

Table 7.2 Diversity analysis and fingerprinting of Alliums using molecular markers

Marker	Population	Reference
RAPD	Cultivars of onion, chives, bunching onion and leek	Susan *et al.,* 1993
RAPD	24 cultivars of short-day onions	Sangeeta *et al.*, 2006
ISSR	32 onion cultivars	Qijiang *et al.,* 2007
SSR	Fourteen short-day and two long-day onion cultivars	Mahajan *et al.,* 2009
EST SSR	Tropical Indian onion	Khar *et al* 2010
ISSR	*In-vitro* regenerated clones for fidelity test	Gantait *et al.,* 2010
RAPD	10 varieties	Maniruzzaman *et al.*, 2010
AFLP	Argentinean collection	Lampasona *et al.*, 2012

Abdoli *et al.* (2009) found paradox in genetic diversity detected by RAPD technique with reference to geographical origins of onion. This may be due to limited genome coverage and poor reproducibility of RAPDs; it indicated the need of alternative more efficient marker systems.

ISSRs exhibit high specificity like microsatellite markers, but can be used on genome with no sequence information for primer synthesis, enjoying advantage of random markers (Joshi *et al.,* 2000). Thirty-two onion germplasm resources analysed using ISSRs, divided them into five groups—first group consists of

Yellow sweet Spanish system; second with Bejo Dyatona cultivar; third Yellow Globe system; fourth Yellow Globe Danvers system; and fifth group with Yellow Danvers system (Qijiang *et al.,* 2007). The exotic cultivars Alisa Craig and Brigham Yellow Globe were different compared to Indian cultivars, and Nashik Red and Poona Red were indistinguishable and similarly N 53 and Bombay Red were quite close (Mahajan *et al.*, 2009). The genetic fidelity of *in-vitro* regenerated clones of *A. ampeloprasum* and *A. sativum,* using 10 ISSR primers, revealed significance of shoot-tip explants in maintaining their regeneration frequency with morphogenetic competence even after prolonged *in-vitro* culture (Gantait *et al.,* 2010). Jakse *et al.* (2005) identified 398 SNP, indels and SSRs, which in turn distinguished 35 elite onion populations. The diversity assessment of tropical Indian onion and cross amplification of genomic and EST-SSR markers in distantly related native wild species were estimated. Clustering revealed five groups, and indigenous short-day onions formed separate cluster from exotic short-day and long-day onions (Khar *et al.*, 2010).

The AFLP is one of the powerful techniques used for diversity analysis. It combines RFLP and PCR; therefore, it is more specific, gives large number of bands and allows more genome coverage.

In-silico mining of markers

Microsatellites or simple sequence repeats (SSRs) play an important role in plant genetics and breeding. The development of microsatellites is a time-consuming and expensive process. *In-silico* mining of microsatellites from expressed sequence tags (ESTs), which are available in electronic molecular databases, is a cheaper alternative. Radhika *et al.* (2013) used a computational approach for mining SSRs from 20,159 ESTs in *A. cepa*. These onion ESTs, representing a total length of 13.2 Mb, were downloaded from dbEST database of the National Centre for Biotechnology Information (NCBI) and were subjected to various pre-processing steps. The pre-processed ESTs were clustered, resulting in non-redundant unigenes. These unigenes were analysed for their SSR content and distribution.

In all, 1,464 SSRs consisting of di-, tri-, tetra-, penta- and hexa-nucleotide repeats were mined from non-redundant ESTs (contigs and singletons). Tri-nucleotide SSRs were most abundant, followed by tetra-, di-, hexa- and pentanucleotide SSRs. Among the tri-coding repeats, leucine and serine codons were more abundant. The SSR-containing sequences were annotated and grouped into their respective functional categories. The predominant functional group among the annotated unigenes was "metabolism", followed by "transcription factors" and "transporter proteins". Primer pairs could be designed for 1,092 SSR-containing sequences. Of these, 51 primer pairs were validated in the laboratory. A database has been developed to store unigenes, primer pairs, putative annotations, and BLAST results. After validation, EST-derived microsatellite (SSR) markers can be used in studies related to marker-assisted selection, detection of polymorphism, DNA fingerprinting and diversity analysis in onion.

Molecular marker-assisted selection

Colour improvement: Bulb colour is one of the important traits in onion (*A. cepa*). Three major colours white, yellow, red, and a variety of other bulb colours, such as chartreuse and golden, exist in onion germplasm. The colour is due to flavonoid compounds, and 54 types of flavonoids were reported in onion (Slimestad *et al.,* 2007). Flavonoids are involved in UV protection, fertility and pigmentation in plants (Shirley, 1996) and act as antioxidants when consumed by humans (Lotito and Frei, 2006). Bulb colour is inherited in a complex manner and involves epistatic interaction, and loci might code for enzymes involved in the anthocyanin synthesis (El-Shafie and Davis, 1967; Koops *et al.,* 1991).

Unusual gold-coloured onions showed reduced amount of quercetin, the most abundant flavonoid in onions. Kim *et al.* (2004) identified critical mutations in *chalcone isomerase* (*CHI*) gene resulting in golden onions. The colour difference between yellow and red onions revealed involvement of two complementary genes in anthocyanin production (Kim *et al.,* 2005a). Inactivation of dihydroflavonol 4-reductase (DFR) in anthocyanin synthesis pathway was responsible for the colour differences between yellow and red onions, and two recessive alleles of *anthocyanidin synthase* (*ANS*) gene were responsible for a pink bulb (Kim *et al.,* 2005b). Based on the mutations in the recessive alleles of these two genes, Kim *et al.* (2007) developed PCR-based markers for identification of polymorphism between pink and red alleles of the ANS gene. Most pink onions are homozygous recessive for *ANS* gene. The two pink onions, heterozygous for *ANS* gene, were also heterozygous for *DFR* gene, indicating pink colour formation by incomplete dominance of a red colour gene over yellow colour. Kim *et al.* (2006) identified allele of ANS, *ANS-h1,* in a dark red doubled haploid line. F_2 populations originating from crosses between wild-type (*ANS-L*) allele containing red and pink (*ANS-p*) allele containing white or yellow parents show a discrete segregation ratio of 3 red to 1 light pink; suggesting that the wild-type allele is completely dominant over pink allele.

Two novel inactive alleles of *DFR-A* in yellow onion cultivars and breeding lines from Korea and Japan were identified (Kim *et al.*, 2009). Deletion of 20 bp of a simple sequence repeat in the promoter region of the *DFR-APS* allele was used to develop a simple PCR-based molecular marker for selection of *DFR-APS* allele. Furthermore, RT-PCR results showed that no *DFR-A* transcript was detected in any yellow F_2 individuals. Further, Park *et al.* (2013) developed functional CAPS markers for two inactive DFR-A alleles, DFR-A^{PS} and DFR-A^{DEL}, for detection of inactive DFR-A alleles responsible for failure of anthocyanin production in onions. Of these, two alleles, DFR-A^{PS} exists predominantly in yellow onion cultivars.

Quality traits: Onion and other Alliums have been valued since antiquity for their pungent flavour and aroma. Modern science has confirmed the traditional beliefs that organosulphur compounds that impart flavour have significant human health benefits. Flavour precursors of onion are 1-propenyl, propyl and methyl cysteine sulfoxides (Randle and Lancaster, 2002). Galmarini *et al.* (2001) derived a genetic map to identify and estimate effects of QTLs on the phenotypic correlations among soluble solids content (SSC), total dry matter, pungency and onion-induced *in-vitro* anti-platelet activity. McCallum *et al.* (2006) found polymorphic SSR marker, which exhibited strong disequilibrium with bulb fructan content, and it was mapped to chromosome 8 in interspecific population of *A. cepa* × *A. roylei*. QTL analysis of total bulb fructan content in intraspecific mapping population, using a complete molecular marker map, revealed only one significant QTL, which may account for major difference in bulb carbohydrate content between storage and sweet onion varieties. Candidate genes for sulphur assimilation were used to identify genomic regions affecting pungency. Linkage mapping has revealed that genes encoding *ferredoxin-sulfite reductase* and *ATP sulfurylase* (*ATPS*) are closely linked (1–2 cM) on chromosome 3. QTL analysis has revealed significant associations of both pungency and bulb soluble solids content with marker intervals on chromosomes 3 and 5 (McCallum *et al.*,2007). Non-structural dry-matter content of onion-bulbs principally consists of fructose, glucose, sucrose and fructans. A cDNA subtraction library has been constructed to differentiate high and low fructan accumulating background (Raines *et al.*, 2007).

Identification of sex-linked markers and hybrids: Interspecific hybridization is known in many *Allium* groups as a mode of speciation through evolution of the genus. Usually interspecific hybrids are recognized from intermediate morphological features and chromosomal variability. Lately, molecular techniques have been assigned to identify hybrid nature of many cultivated crops. Hybrid nature (*A. fistulosum* × *A. cepa*) of *A. wakegi*, a sexually sterile species, was initially proven by Genome In-Situ Hybridisation (GISH) (Hizume 1994). Additional evidence for the nature was gathered by localization of 5S RNA loci at chromosomal positions corresponding to *A. cepa* and *A. fistulosum*. *A. fistulosum* was identified as the maternal parent by the RFLP on purified plastid DNA that was hybridized to an *A. fistulosum* cpDNA probe (Tashiro *et al.*, 1995). Other examples of use of different markers for identification of hybrids in *Allium* includes, top onions and viviparous onions, of suspected *A. fistulosum* × *A. cepa* origin, with the RFLP probes (Havey, 1991b), using isozyme assays (Maa, 1997a) and GISH (Friesen and Klaas, 1998). The ambiguous parentage of ‘Pran’, a cultivated species in Kashmir, was also analyzed (isozyme analysis, Maa, 1997b; RAPD analysis, Friesen and Klaas, 1998; cp DNA pattern, Havey, 1991a) and the data suggested that ‘Pran’ originated from a cross between a so far unknown seed parent and *A. cepa*. Further, identification of the diploid grey shallot, a distinct form of shallot, long cultivated in France and Italy, was done using the RAPD (Le Thierry D’Ennequin *et al.*, 1996), where affiliation was shown with other normal shallots, belonging to *A. cepa*. However, GISH and RAPD data of Friesen and Klaas (1998) showed that most of the chromosomes of grey shallot belong to *A. oschaninii,* with only one-and-a-half chromosome arms derived from either *cepa* or *vavilovii*. Although there is a need to address these contradictions; in general, application of molecular markers has become more of a routine in *Allium* research due to their ease of use and standardization of new and effective techniques and procedures.

Identification of cytoplasmic male sterility (cms): Cytoplasmic male sterility is a maternally inherited trait. CMS observed in many of the flowering plants is mainly due to chimeric mitochondrial open reading frames (ORFs) originated through recombination. In most of the CMS forms, transcripts originating from these altered ORFs are translated into unique proteins that appear to interfere with mitochondrial function and pollen development. Nuclear restorer (*Rf* or *Fr*) genes function to suppress deleterious effects of CMS-associated mitochondrial abnormalities. In onion, CMS condition exists widely in most natural populations of welsh and bulb onions (*A. fistulosum*, *A cepa*), which makes it possible to breed male-sterile lines for heterosis utilization. Unfortunately, the breeding of CMS in onion has made little progress owing to limitation of its biological characteristic and traditional selection approach. Identification of male sterile lines and their maintainers is a major hurdle in exploitation of male sterility in onion hybrid-seed production.

A low-density genetic map of onion (*A. cepa*) using RFLP was developed to distinguish fertile (N) and sterile (S) cytoplasms. A correlation was observed between expected and observed numbers of plants maintaining cytoplasmic-genic male sterility (Havey *et al.,* 2001). The RFLP approach was applied to identify CMS genotypes using probes for the following mitochondrial genes: atpA, atp6, atp9, cob, cox1, nad3, nad4 and nad6 (Szklarczyk *et al.,* 2002), and these markers are located in a chloroplast psbA gene amplicon, which distinguishes male-fertile (N) and male-sterile (S) cytoplasms (Cho *et al.,* 2006). Genomic and mitochondrial genome diversity was evaluated by RAPD, SSR and RFLP markers (Chaurasia *et al.,* 2010). Specific cytoplasm types of all tested cultivars were identified. At least three restorer genes are involved in restoration of fertility in CMS-T male-sterile, while fertility restoration in CMS-S is controlled by only a single gene, rendering it suitable for establishment of molecular breeding systems (Kim *et al.,* 2009). One SCAR marker and one RAPD marker were identified, which could distinguish between N and S cytoplasms in several welsh onion cultivars, confirmed by Southern Blotting (Gai *et al.,* 2010). Park *et al.* (2013) developed a high resolution linkage map of *Ms* locus, which was involved in restoration of fertility. Tightly linked RAPD and CAPS markers were used to construct this fine map using F_2 populations. Such closely linked markers could be utilized in marker-assisted selection of *Ms* locus and map-based cloning. Further, origin and dynamics of genome rearrangements between normal and male-sterile onions were studied (Kim *et al.*,2013). Very recently, Havey (2013) studied linkage disequilibrium in male-fertility restoration (*Ms*) locus in open-pollinated and inbred populations using single nucleotide polymorphism (SNP). Three SNPs were identified which were tightly linked to *Ms* locus on chromosome 2; these SNPs can be helpful in the development of maintainer lines for hybrid onion development (Table 7.3). RAPD markers analysis was performed by Dhanya *et al.* (2013) to investigate genetic relatedness among nine sterile (A), maintainer lines (B), and male parents (C). Initially, 180 arbitrary decamer primers were screened; of these 20 primers were selected, which yielded 812 bands, 45.34% of which were found polymorphic. Squared-Euclidean Distance matrix revealed a minimum genetic distance between genotypes MS 48A and MF 65C and a maximum genetic distance between genotypes MLT 84C and MF 65B. Cluster analysis grouped nine onion genotypes into two major clusters—the first cluster consisted of two male sterile groups, i.e.

Table 7.3 Molecular markers for cytoplasmic male-sterility analysis in Alliums

Marker	Application	Reference
RFLP	Identify cytoplasmic genotypes	Szklarczyk *et al.*, 2002
PCR-RFLP	Distinguish male-fertile (N) and male-sterile (S) cytoplasm	Cho *et al.*, 2006
RFLP	CMS-T and CMS-S cytoplasm type identification	Kim *et al.*, 2009
RAPD, SSR, RFLP	Genomic and mitochondrial genome diversity	Chaurasia *et al.*, 2010
SCAR and RAPD	Distinguish between N and S cytoplasm in welsh onion	Gai Shu-peng *et al.*, 2010
RAPD and CAPS	High-resolution linkage map of the *Ms* locus	Park *et al.*, 2013
Chloroplast and Mitochondrial markers	Study of mitochondrial genome rearrangements	Kim *et al.*, 2013
SNP	Linkage disequilibrium study in the male-fertility restoration (*Ms*) locus	Havey, 2013

MS 65 (Arka Lalima) and MS 48 (Arka Kirthiman) of single bulb onions; and the second consisted of MLT (Multiplier) group. PCA re-confirmed results of the dendrogram, revealing the precision in estimation of genetic relatedness among the tested genotypes. None of the primers produced unique banding patterns to distinguish all nine genotypes. This information about genetic relatedness among the nine genotypes would be better utilized in onion breeding programmes in future.

Linkage and QTL mapping studies

In onion breeding, traits such as size, shape, colour, pungency, soluble solids and disease resistance are important objectives. Quantitative trait loci (QTL) analysis based on a genetic linkage map would be effective for revealing mode of inheritance of these traits. Large genome size, clonal propagation and lack of flowering in some clones are some problems with mapping population development, however, with the availability of self pollinating and male-sterile lines, mapping has been initiated.

The first genetic linkage map of Japanese bunching onion, based primarily on AFLP markers by using reciprocally backcrossed progenies, has been constructed (Takayoshi *et al.* 2005). A P_1 linkage map comprising 149 AFLPs, 2 CAPSs, and 12 SSRs from Japanese bunching onion, and 1 SSR from bulb onion (*A. cepa*) on 15 linkage groups covering 947 cM has been built by Tsukazaki *et al.* (2008). The P_2 linkage map composed of 105 AFLPs, 1 CAPS, and 13 SSRs has been developed from Japanese bunching onion and 1 SSR from bulb onion on 14 linkage groups, covering 775 cM.

Two partial bacterial artificial chromosome (BAC) libraries of the *A. sativum* were constructed and sequence compositions of these BAC clones have been characterized by southern hybridization, and BAC clones have been localized by FISH (Hye-Ran *et al.,* 2003).

Future Trends

There are almost no known stable sources of disease and pest resistance within the species, *A. cepa*, and source of resistance for salinity and drought are yet to be identified. However, there are known sources of resistance in wild *Allium* species. But the problem encountered is of cross incompatibility between many of the species, which could be either pre- or post-fertilization barriers. Where cross-fertilization occurs, embryo survives seldomly; herein the technique of embryo-rescue would be of help. The studies need to be intensified on these aspects. Besides the molecular markers and linkage mapping, sequencing of genome of onion has been initiated with the development of high throughput methods but collaborative international efforts are crucial for sequencing of large genome of onion. Initially, McCallum *et al.* (2001) and Kuhl *et al.* (2004) did Sanger sequencing of random cDNAs from non-normalized and normalized libraries of onion. Then Jakse *et al.* (2008) undertook pilot sequencing project of onion genomic DNA to estimate gene densities and investigate nature and distribution of repetitive DNAs. Complete sequences from two onion Bacterial Artificial Chromosome (BACs) were AT rich (64.8%) and revealed long tracts of degenerated retroviral elements and transposons, similar to other larger plant genomes. Samantha *et al.* (2010) reported application of Roche 454 technology to develop sequence resources for population analyses and genetic mapping to develop SSRs and ESTs. Bhasi *et al.* (2010) developed 'RoBuST' (http://robust.genome.com), an integrated genomic resource, for families, Apiaceae and Alliaceae, which can be used for sequence annotations, access to traits, biosynthetic pathways, genetic linkage maps and comparative analysis of plant splicing patterns. McCallum *et al.* (2012) developed a comparative genomics resource 'Allium Map' for cultivated *Allium* vegetables, which is first online resource providing genetic map and marker data from multiple *Allium* species and populations. In future, we need to exploit high throughput SNP genotyping, functional genomics using RNAi or other mutagenic methods and transcriptome mapping to know function of each gene in *Allium* genome. Genomic resources and databases thus developed will be very useful for onion improvement.

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Production Technology

8

V. Sankar, P.C. Tripathi, K.E. Lawande and A.N. Ganeshamurthi

Onion is an environment-sensitive crop; it is relatively a cold-tolerant species. For proper development of onion-plant, environmental factors should be considered carefully in the production areas. In India, both short-day and long-day onions are grown. Almost all short-day onions are grown in the plains and require 10–12 hours day-length, whereas long-day type onion varieties are grown in hills, requiring 13–14 hours day-length. Day-length requirement may differ for different onion varieties. It has been observed that long-day varieties, if planted under short-day conditions, do not form bulbs, however, short-day varieties form bulbs even under long-day conditions.

Onion is adaptable to a wide range of temperature. It is frost-tolerant also. Its leaf, root and bulb develop in cool temperature between 12.5°and 24°C. Optimal growth of onion leaf takes place at 20°to 25°C. Once bulbing begins, onion-plant tolerates even temperature higher than 25°C. The plant occasionally tolerates quite well to extremely low temperature also. Seedling can withstand 2°C in soil (in this case germination can last up to 1 month, which affects yield). The optimum temperature for germination is above 10°C. Three important factors of temperature change effect development of the plant. Low temperature combined with shorter daylight period (11–13 hours) induces foliage and root development. Therefore, proper timing of the sowing should be carefully considered. Late sowing considerably reduces time for plant development, which results in lesser yield at the end of the season as foliage biomass and roots are vital for good bulb development. It is obvious that opposite temperature and light conditions (high temperature + longer daylight) induce bulb formation during summer-time. However, extremely high temperature for a longer period may cause stress, which may shorten crop cycle, weaken foliage development and lead to early bulbing (especially, in late sowing it can happen often), resulting in much lower yields at harvest.

Relative humidity at 70% is found good for onion growth. The plant grows well in places where average annual rainfall during monsoon is 650–750 mm with good distribution. It does not thrive well in places where average rainfall exceeds 750–1,000 mm during monsoon. There it can be grown only as a summer crop (Rao and Purewal, 1957; Chandrasekaran *et al.,* 2010).

Soil

Onion grows in all types of soils with *p*H varying from 5.5 to 8.0—sandy-loam, clay-loam, silt-loam and heavy soils. The best soils for onion cultivation are deep, friable loam and alluvial soils with good drainage, moisture-holding capacity and sufficient organic matter. Soils with high organic matter, enough drainage and no persistent weeds favour bulb production (Yawalkar, 1969; Kandil *et al.,* 2013). High marketable bulbs are obtained on heavy soils such as clay, provided adequate quantity of organic matter is supplied to loosen soil. In light-sandy soils, bulbs mature early but yields are low (Dhesi *et al.,* 1965; Ortola 2013). In light-textured soils, bulbs are often softer with less dry matter content, and in heavy clay soils frequently infested with soil-borne pathogens, like *Fusarium* (Ozer *et al.,* 2009). Types of tillage also affect production considerably. Onion roots are mainly in the upper 30-cm soil layer, and desirable soil structure in this layer is essential for uniform bulbs (Enciso *et al.,* 2007). Proper water supply is also needed to attain higher yields.

The crop is very sensitive to highly acidic soil, alkaline soil and also waterlogging. The optimum *p*H, regardless of soil type, is 6.0–7.5, but onion can grow in mild alkaline soils also. Onion may not grow in soils with *p*H below 6.0, as these soils may have trace element deficiencies or occasionally toxicity of Al or Mn. Threshold electrical conductivity of a saturation extract (ECe) for onion-crop is 4.0 dS/m. When ECe level exceeds this, crop yields decline. Marketable bulb yields of onion were reduced by 50% when ECe was 4.1 dS/m (Russel, 1974). Vegetative growth of most of the onion cultivars was inhibited when salt concentration was above 4.0 dS/m (Shannon and Grieve, 1999).

Season

The optimum season for onion planting is important as it affects its marketable bulb yield and its post-harvest shelf-life. Sowing, transplanting and harvesting timing of onion varies from region to region (*see* Table 2.1, Chapter 2). *Kharif* onion in many parts of the country is grown during rainy season through transplanting. In Nashik (Maharashtra), *kharif* onion can be transplanted during May to June. Early *rabi* or late *kharif* crop can be sown during the first week of September and transplanted during November first week in western Maharashtra (Bhonde *et al.,* 1987; Sankar *et al.,* 2002). *Rabi* season crop is sown in October and November, and seedlings are transplanted in December to January (Sankar *et al.,* 2003).

Table 8.1 Growth stages of onion-crop

Short	Long duration	Growth stage duration
8–25	10–30	Radicle and flag leaf emergence
25–40	30–50	1–2 true leaves
40–55	50–70	3–4 leaves; 4 leaves
55–70	70–90	5–7 leaves
70–85	90–110	8–12 leaves, bulb initiation
85–100	110–130	bulb diameter of 1–1.5 inches
100–120	130–150	bulb diameter of 1.5–3.0 inches
120–135	150–170	bulb enlargement complete, 50% + topped
135 +	170 +	dry down from pre-harvest to harvest

Growth and developmental stages

Apart from germination stage, onion cycle has 9 developmental stages—from planting to bulb

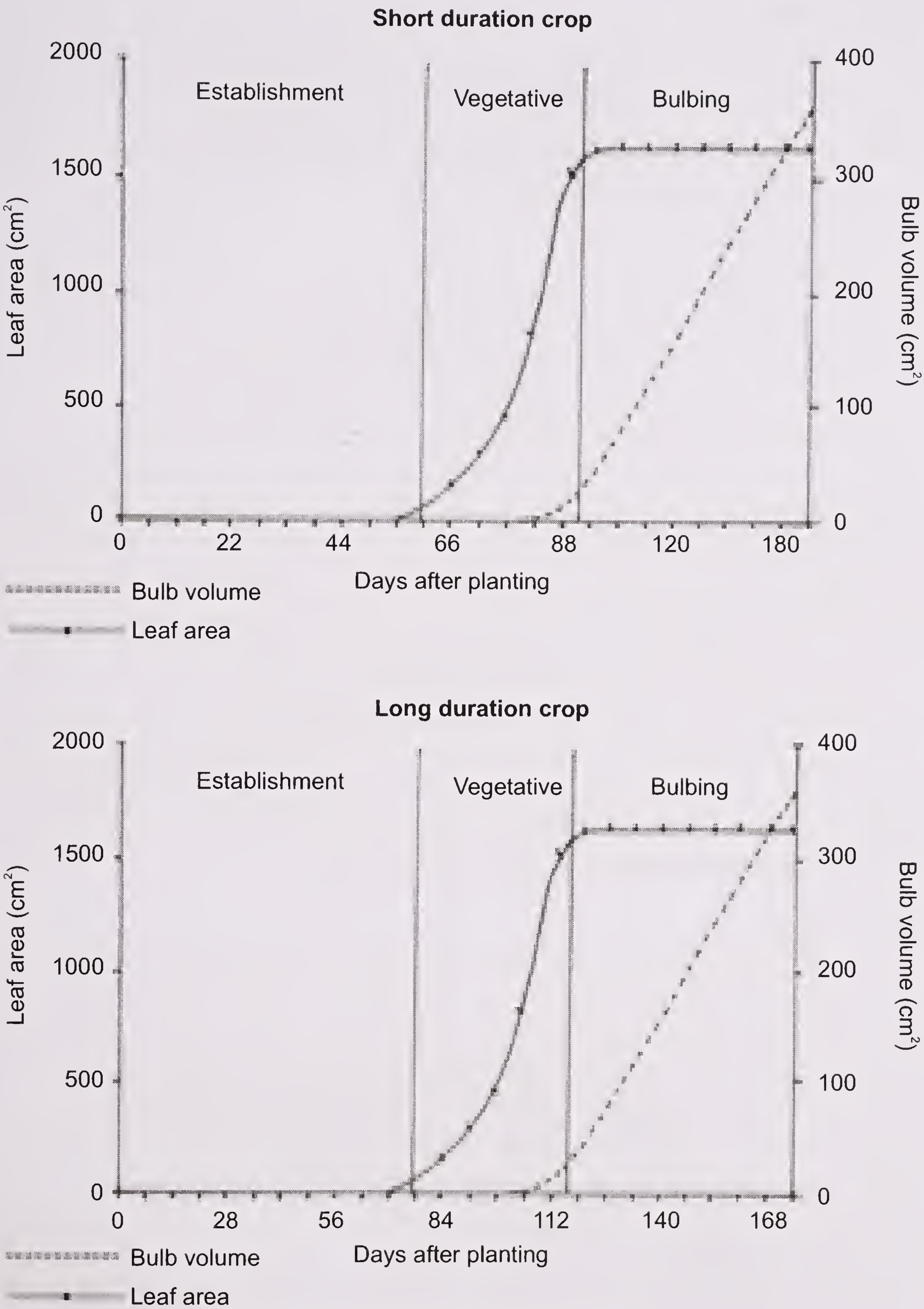

Fig. 8.1 Onion developmental stages

maturity. To recognize each stage is imperative for implementing an efficient crop-management programme (Table 8.1; Fig. 8.1). Environmental factors influence growth, development and biological yield of plants primarily by affecting physiology. Plant responses and myriad possible interactions are very extensive and also complex to be predictable. Analysis of this set of factors would contribute in understanding the system and may offer valuable insights and may enable efficient management.

Raising onion-crop

Onion can be grown from seeds, sets or transplants. Precision seeding leads to easier controlled plant spacing and also improves seed survival rate. Since most varieties in India are of short duration, growers usually raise onion from direct seeding. The seed requirement and nursery management for raising a successful onion crop are covered in Chapter 2.

Land preparation

Before land preparation, primary weed control is a must. This can be done manually or by non-selective herbicides, e.g. Glyphosate (2–4 litres/ha). Apply herbicides when weeds are growing actively, prior to 10–14 days before land preparation. Plough the land to a depth of 15 cm. Bed width and length are decided according to the irrigation facility. Normal recommendation for bed is 1 m × 3 m × 15 cm. In some regions of Tamil Nadu and Karnataka, ridges and furrows are formed at a distance of 30 cm × 30 cm or 30 cm × 45 cm or raised beds of convenient length and width for both *kharif* and *rabi* onion production. To avoid waterlogging during *kharif* or rainy season, flat beds should not be formed. And before planting, apply any type of well-decomposed organic manure at least at the rate of 10 metric tonnes/ha. Planking should be done for proper soil levelling.

In case of microirrigation (drip and sprinkler irrigations), 1 to 1.5 m wide and 50 to 60 m long raised beds or BBF (Broad based furrows) can be prepared. BBF is the best method for *kharif* onion production, as excess water drains off through furrows. This method also improves aeration and helps in reducing anthracnose incidence. BBF of 15 cm height and 120 cm top width with 45 cm furrow are formed for optimum spacing and population density.

Direct seeding

Sowing density should be adopted according to the final product specification of the market. A good example is the processing onion market, where most important grade portion is the bulb size of more than 7 cm, herein sowing density optimum should be around 750,000 seeds, approximately 3.0 kg/ha. Plant density is also adjusted to seed quality and variety type. Open-pollinated varieties are sown at 5–6 kg/ha, while hybrids are sown at 4 to 5.5 kg/ha, as hybrids are more uniform in vigour, growth habit and germination. Precise sowing method would also help optimize amount of seeds and would reduce cost, if we consider cost of hybrid seeds. Several types of onion planters are available for direct seeding, proper accuracy can be reached with different instrumental variations of machines.

Transplanting

Onion seedling transplanting is more commonly practised in most part of the country for an irrigated crop, and this results in high yield combined with large-sized bulbs. Seedlings are ready for transplanting in 35–40 days after sowing for *kharif* and 45–50 days after sowing for late *kharif* and *rabi* seasons. Proper care should be taken while selecting seedlings for transplanting. Seedlings of 0.8–0.9 cm in diameter and about 20–35 cm in height are optimum for transplanting. Plant population needs to be optimized to get higher marketable bulb yield per unit area. Optimum use of spacing or plant population results in no competition among plants for growth factors—water, nutrient and light— and enables efficient use of available crop-land without wastage (Geremew *et al.,* 2010). For achieving high productivity, optimum plant density is 65 to 70 plants per m^2; higher plant density may reduce bulb size while lower plant density may result in bulb splitting (double bulbs). It has been reported that total bulb yield increases significantly as population density increases and number of marketable bulbs increases significantly with higher planting density (Kantona *et al.,* 2003). Intra-spacing of 7.5 cm recorded good yield, bigger bulbs combined with better quality bulbs for market and storage (Kahsay *et al.,* 2013). Spacing of 15 cm between rows and 8 to 10 cm between plants has been found conducive for high marketable bulb yield in the most parts of the country. In case of ridges and furrow method, plant-to-plant distance has been reduced to 6–7 cm to accommodate optimum number of plants. Irrigate fields soon after transplanting. Seedlings should be transplanting either in early hours or late in the evening to avoid their drying. Care must be taken to cull-out seedlings with damaged roots or diseases. At the time of transplanting, one-third of the seedling top should be cut to have good establishment. It has been reported that larger seedlings yield higher, but they should be topped to facilitate transplanting. There are reports that yield and bulb weight decline when seedling tops were removed 25, 50 or 70% before planting as compared to whole seedlings. Simulated damage of up to 75% at the early stage of crop growth (15 days after transplanting) had no adverse effect on onion-bulb size and weight. Artificial defoliation slightly delayed maturity of bulbs, except when simulated damage was done at the early stage of crop growth. Partial trimming of onion seedlings at the time of transplanting augmented crop stand and increased bulb size. Similar results were also obtained by Rathore and Kumar (1974). Onion seedlings should be transplanted after dipping roots in Carbendazim solution (0.1%) to contain incidences of fungal diseases.

Sets planting

Sets are small-sized onion produced by allowing seedlings to mature in nursery-beds as such, instead of transplanting. These bulbs are used as sets and planted in the next season to ensure early crop. In some parts of Gujarat, Maharashtra and Rajasthan, onion is grown in *kharif* by sets (Pandey and Singh, 1993). Mahuwa and Talaza areas in Gujarat are the major areas where quality onion sets are raised for local use and also for supply to other states. Seed sowing is done by the end of January or February, and small bulbs are harvested in April–May. The plants form small sets due to close spacing. It has been reported that seed sowing in January with 50 g seed per m^2 gave maximum quality sets. The topped and graded sets are stored in hessian-cloth bags or in shallow baskets or in racks in layers, not more than 8-cm deep. One tonne of sets of 1.5 to 2.0 cm diameter are enough for one hectare. But higher yield and net returns could be obtained with 2.0–2.5 cm size sets (Pandey *et al.,* 1990). For good marketable bulb yield, sets are planted 10-cm apart in rows on both sides of the ridges. The distance between two ridges should be 30–45 cm. A light irrigation should be given immediately after sowing. The subsequent irrigations are to be given after every 10 days.

Fertilization

Onion is highly nutrient-responsive crop. Conventional methods of fertilization have undoubtedly helped improving bulb yield and quality. But lately, routine management practices in India are apparently not sufficient in maintaining yields over long-term. Steady depletion of native soil fertility and multiple nutrient deficiencies in onion fields have indicated nutrient management as the key factor limiting sustainable onion production (Sharma *et al.,* 2003). Integrated nutrient management (INM) offers an effective strategy (Santhi *et al.,* 2005). Fertilizer prediction equations for onion for targeted yields are available in different regions of the country. These equations can be used for efficient management of plant nutrients for targeted yields (Sonar and Kadam, 2002; Santhi *et al.,* 2005).

General effects of major nutrients

Nitrogen: It strongly supports plant development resulting in foliage growth during the day, and bulb growth in night. Overdosed N can increase yield, however, a negative impact on late maturity and less storability can also occur. Even severe thrips infestation may also occur. Continuous application of N during the growth period can deteriorate bulb skin quality.

Phosphorus: It supports development of roots and skin-leaves. Addition of P in the last phase of bulb development helps grow thick and strong skin.

Potassium: It is an essential element for the proper dry matter content, especially for flesh firmness and good storability. This can improve effectiveness of water uptake and also help utilize applied N. Ideal K supply reduces disease susceptibility owing to stronger epidermis. Plants supplied with adequate K are more tolerant to low temperature and drought.

General recommendations of fertilization

Fertilization should be based on soil analysis. For example food-legumes, vegetables or sunflower as prior crop results in considerable organic matter in the soil that may cause problems in bulb quality, skin retention and earliness. Application of chloride-based fertilizers like muriate of potash before sowing should be avoided. Onion-plant is sensitive to chloride at any stage. KCl affects even germination negatively when applied as a basal dose.

Nutrient application guidelines

Nitrogen: Total applied N should be around 200 kg/ha, 50% of this is to be applied as the basal application and the remaining at the vegetative stage as well as bulb formation stage in equal splits. The amount of N can be added based on soil test values.

Phosphorus: It should be around 100–160 kg/ha, depending upon the soil type and soil-test values. Traditionally, 100% of it is given during planting. But if this can be split into 75% at planting and 25% at bulb formation, it would be beneficial. This allows more phosphorus in the soil during bulb-skin development.

Potassium: The total amount to be applied is 120–200 kg/ha, depending upon the soil type and soil-test values. Traditionally, it is applied as 100% basal application. But 50% of the K at planting and 50% during growth season would improve yield and also bulb quality.

Sulphur: Onion-crop requires sulphur at higher levels even more than phosphorus for enhancement in yield and bulb quality. Indian soils are generally low in available sulphur (Ganeshamurthy and Saha, 1997). But a general recommendation for sulphur application is lacking. However, based on the general status of available sulphur in soils, 20 kg S/ha benefits crop.

Micronutrients: They have an important role in obtaining potential yield, improving quality and improvement in storability and skin quality. It is recommended to apply 10 kg Zn/ha and 1 kg boron/ha after every 2nd or 3rd year.

Foliar nutrients can also be applied with fertilizers, containing more of N and K and less of P. For example, during vegetative growth, foliar application of 19 N, 11 P and 24 K is beneficial and at the bulbing stage, foliar spray of NPK at 10–5–26 ratio would benefit the crop.

Water requirement

Water requirement of any crop depends upon the nature of crop, soil, evapotranspiration rate of that particular area and plant growth stage. Onion has very shallow roots and frequent irrigation is necessary for better growth and bulb development. Irrigation schedule depends upon the plant cycle and planting system. Crop at the initial growth period requires less water, which also depends on crop growth, soil type and planting season. In case of direct-seeded crop, the first stage when proper and accurate irrigation is necessary is the pre-emergent stage. This is vital to realise proper germination and uniform vigour of the crop. The amount varies between 8 and 14 mm with a low intensity of 5 to 7 mm/hr.

The second irrigation is given at the bulb initiation and development stage to obtain marketable size and quality and for hybrids to realise their yield potential. The crop is very sensitive to moisture stress during this stage. The crop root system is normally restricted to top 5 cm, and roots seldom penetrate deeper than 15 cm. Farmers need to ensure proper growth of the plant by regular watering and keeping water availability in the profile up to 15 to 20 cm.

Onion requires less water immediately after the crop establishment but the consumption increases with advancing season. Extensive research work has been done in scheduling irrigation water and total water requirement of onion in India (Table 8.2). The most common method of applying water is basin or border-strip flooding or furrow irrigation. Onion needs to be irrigated at transplanting, three days after transplanting, and the subsequent irrigation at 7–10 days interval depending upon the soil type and moisture content. In general, *kharif* crop needs 5–8 irrigations, late *kharif* 10–12 and *rabi* crop 12–15 irrigations. Transplanted seedlings should be irrigated as soon as possible after being set, if the soil is dry. Well-hardened seedlings will survive for 12 or more days, but delayed irrigation results in lowering of yield. For irrigated crop, just before transplanting or at the time of transplanting, field is irrigated, and life irrigation is given on the third day after planting. Frequent irrigations are given during the early crop growth, and more frequent are essential during bulb development. Do not irrigate the crop when it matures (10–15 days before harvest) and when its top starts falling; this

Table 8.2 Onion water requirement

Optimum soil moisture	No. of irrigations	Depth of irrigation (cm)	Total water requirement (mm)	Consumptive use of water (mm)
Based on soil type	16 (sandy-loam soil) 12 (clay-loam soil)	–	–	–
Based on season	5–6 (*kharif*) 10–12 (late *kharif*) 12–15 (*rabi*) 15–20 (summer)	–	–	–
Based on soil-water potential	16–18	7.5–8.0	640–720	450–630

controls rotting during storage. Excessive irrigation is always harmful, and dry spell followed by irrigation would result in splitting of outer scales and also formation of bolters. Irrigation at 10–12 days interval during November – December, 10 days interval during January and 7 days interval during February has been optimum for successful *rabi* onion production in Maharashtra, particularly Pune area. In clay soils of Andhra Pradesh, irrigation at 5 days interval gave higher yields in December–May crop, and an average total of 12–15 irrigations were essential to complete life-cycle of onion, grown during *rabi*.

At Bengaluru, maintaining soil-water potential at –0.85 bar or less, either during pre-bulb development (20–60 days after transplanting) or at bulb development stages (60–110 days after transplanting), reduced bulb yield significantly; bulb development stage was found more sensitive to moisture stress than pre-bulb development stage (Hegde, 1986). According to Saha *et al.* (1997), for optimum yield potential of Taherpuri onion, irrigation at 10 to 20% depletion of field capacity moisture maximize efficiency of irrigation. Consumptive use of water increased with increased available soil moisture (Koriem *et al.*,1999). Water-use efficiency was the highest when irrigation was withheld, followed by irrigation after depletion of 30% of available soil moisture. Bulb yield increased as IW/CPE values increased (Ramamoorthy *et al.,* 2000). Water-use efficiency was higher at IW/CPE of 1.2.

Bulbs grown at low moisture can dry out earlier, and lose more weight during storage than those grown with adequate moisture. Over irrigation as well as under irrigation may result into lowering of yields. Onion foliage becomes yellowish-green in colour with excessive irrigation. Heavy irrigation at harvest time or 1–2 weeks prior to harvest may cause immature thick-skinned bulbs. Frequent irrigation delays maturity of onion-bulbs. When plants begin maturing, irrigation should be discontinued, and soil should be allowed to dry out, which facilitates quick maturing of bulbs, otherwise secondary growth may start, which is difficult to be stopped and would complicate the process of proper onion curing. Irrigation after leaf withering pre-disposes bulbs to infection with *Fusarium.* Frequent irrigations reduce total soluble solids of bulbs. Moisture stress increases No_3 - N content of the bulbs.

Microirrigation

The most advanced method is drip irrigation. It is expensive but is most appropriate for water usage and precision irrigation as fertigation can be done with it. In drip irrigation, seedbeds should be laid with dripping tapes between 1st–2nd and 3rd–4th rows. Onion seedlings need to be planted at a spacing of 10 cm × 15 cm in a broad-based furrow (BBF); 15-cm high, 120-cm top width and with 45-cm furrow. Each BBF should have two drip laterals (16-mm size) at 60- cm distance with in-built emitters. The system requires 30–50-cm distance between two in-built emitters and the discharge flow rate of 4 litres/hr. Its only serious bottleneck is high investment cost of the main pipe network and tape set-up. It means considerable investment, but at the same time, water-use efficiency of the properly designed and well-managed microirrigation system may go up to 90%. It can also be compensated by an improvement the marketable bulb yield apart from enhanced yield of 40–60 tonnes/ha compared to 25–30 tonnes/ha with regular irrigation. It is a matter of decision and situation (Bhonde *et al.,* 2003; Sankar *et al.,* 2008).

In the case of micro-sprinklers, the distance between two laterals (20 mm) should be 6 m with a discharge rate of 135 litres/hr. Very high yield (441.76 q/ha) and higher water-use efficiency were obtained with drip irrigation (Gorantiwar *et al.*, 1991) in comparison with flood, furrow and sprinkler irrigations. Irrigation at 100% CPE gave highest bulb yield on medium black soils, and water-use efficiency was higher with all rates of drip irrigation than with surface irrigation. Drip irrigation at 100% pan evaporation recorded higher marketable bulb yield, high percentage of A grade bulbs and improved post-harvest storage-life, followed by micro-sprinkler irrigation at 100% pan evaporation. Drip irrigation could save irrigation water up to 37.8% and sprinkler irrigation system by 32.5% as compared to surface irrigation (Sankar *et al.,* 2008). In white onion on medium black soils during summer season, an overall 53–69% water saving was achieved (Patil *et al.,* 2000). Higher water-use efficiency was also achieved on raised-bed planting with micro-sprinkler irrigation (Gethe *et al.,* 2006).

Weed management

Types of weeds

The common monocot, dicot and broad-leaf weed species found in onion-growing areas are: *Cyperus rotundus, Cynodon dactylon, Chenopodium album, Amaranthus retroflexus, Convolvulus arvensis, Echinochloa colonum, Argimone maxicana, Avena sativa, Portulaca* sp., *Echino chloacrus-galli, Brachiaria ramosa, Phalaris minor, Oxalis latifolia, Poa annua, Ageratum conyzoides*, *Chenopodium murale, Coronopus didymus, Melilotus parviflora, Avena fatua, Euphorbia pilulifera, Amaranthus viridis, Trianthem aportulacastrum, Euphorbia* sp., *Leucas aspera, Eclipta alba* and *Digitaria* sp. More than 30 weed species are recorded in onion fields at various places but *Cyperus rotundus* and *Cynodon dactylon* were the most prominent weeds that limited bulb production in onions (Sinha, 1999; Kalhapure and Shete, 2012).

Crop-weed competition

Onion-crop is usually infested by a wide spectrum of broad-leaf and grassy weeds. Due to its slow initial growth and inherent characteristics of crop such as short stature, non-branching habit, sparse foliage, shallow root systems coupled with frequent irrigations and fertilizer applications at high doses, the crop exhibits greater susceptibility to weed competition than most other crops. Without weed control, onion-bulb yields reduced drastically; losses due to weed infestation were recorded to the tune of 40 to 80% (Channapagoudar and Biradar, 2007). Proper and timely weed control measures are essential for good bulb development. The critical period of crop-weed competition in onions is from 15 to 45 days after transplanting (Shuaib, 2001). Delay in weeding operations results in lanky growth, yellowing of leaves and poor bulb development, besides impairing keeping quality of bulbs. The crop is more sensitive to duration of weed competition than to weed load. Bulb size and marketable yield were affected by weed competition (Sukhadia *et al.,* 2002; Chopra and Chopra, 2007; Channapagoudar and Biradar, 2007). Onion-crop kept weed-free up to 45 days gave significantly higher bulb yield. Weed competition during the whole crop-cycle reduced bulb yield by 86%, and weed competition during the first 15 days had no adverse effect. It indicates that proper and timely weeding is crucial for good quality bulbs. The critical period of crop-weed competition in onion is from 45 to 90 days after transplanting (Sankar *et al.,* 2011). Monocotyledons weed population was found to increase up to 60 days after transplanting. Dicotyledonous weeds dominate with advanced crop age (Singh and Singh, 1994).

Weed control

Manual, mechanical and chemical methods of weed control are practised in India in onion. But very close spacing and shallow root system of onion make the mechanical method of weed control tedious, expensive and time-consuming. Moreover non-availability of sufficient labour at the critical period of crop competition and sometimes field conditions do not permit manual weeding in time, which ultimately results in poor bulb development and yield. Under such situations, chemical weed control becomes effective and economical. Successful pre-emergent herbicide application is crucial. The most common practice is to use Pendimethalin. A list of pre- and post-emergence herbicides used in onion and the dosages used is given in Table 8.3. These herbicides are applied with recommended dose at the time of seedling transplanting or before transplanting

Table 8.3 Pre- and post-emergence herbicides use in onion

Pre-emergence herbicide	Dose (kg/ha)	Pre-emergence herbicide and post date of planting application	Dose (kg/ha)
Metribuzin (SencorLexone)	0.35	Loxynil (Toxynil)	0.5
Propachlor (Ramrod)	4.5	Pendimethalin (Stomp)	2.5–3.5
Oxyfluorfen (Goal)	0.15–0.25	Butralin (Tamex, Sector)	3.5
Fluchloralin (Basalin)	1.5 or 2.0	Oxyfluorfen (Goal)	0.15 or 0.25
Pendimethalin (Stomp)	2.5–3.5	Fluchloralin (Basalin)	1.5 or 2.0
Oxadiazon (Ronstar)	1.25	Oxadiazon (Ronstar)	1.25
Methabenzthiazuron (Tribunil)	1.4	Alachlor (Lasso)	2.0
Nitrofen (Tok)	2.0	Trifluralin (Treflan)	1.0
Linuron (Lorox)	0.94	Oxydiargyl (Raft)	0.25
Trifluralin (Treflan)	1.0		
Oxydiargyl (Raft)	0.25		

or after transplanting followed by irrigation. For effectiveness of the herbicide, it should be supported by irrigation to facilitate its movement to the roots of young weed plants.

After successful pre-emergent herbicide application, next herbicide treatment should be applied at 4–6 leaves stage. Commonly used chemicals include totrli, maloran and goal. These herbicides can temporarily stop plant development (sometimes for 2 weeks); therefore the proper application period is when the plants are getting stronger-bigger (6 leaves stage). Mechanical weeding is also necessary during the season. This also acts as interculturing of the soil for water management. Machine cultivation 2 to 3 times, and, if needed, 1–2 times manual weeding, often before harvest, to pull out the large weeds (not to block the harvest machines) are generally required.

Integrated weed management

It is a science-based decision-making process that coordinates use of environmental information, weed biology and ecology, and all the available technologies to control weeds by most economical means, while posing least risks to people and environment (Sanyal, 2008). By using different appropriate management practices against weeds, farmers have more options for controlling weeds, thereby reducing possibility of escapes and weed adaptation to any single weed management tactic. Because of the diversity and plasticity of weed communities, weed management needs to be viewed as a continuous process. Major thrust on the integrated weed management (IWM) in India is given on herbicide-based IWM. Almost no work is reported on ecological based IWM. In onion, integrated weed management practices are very essential for good quality bulbs. A combination of pre-emergence herbicide Pendimethalin @ 2.5 litres and one hand-weeding helped in maximum number of seedling establishment and minimum fresh weight of weeds (Pandey *et al.,* 1991). Combined application of Fluchloralin @1.25–2.50 kg/ha incorporated in soil 4 days before transplanting, followed by Pendimethalin @ 1.25–2.50 kg/ha applied 1 day after transplanting in addition to one hoeing gave effective control of weeds, besides higher bulb yield in sandy soils (Singh *et al.,* 1991). In Vertisols of Karnataka, pre-emergence application of Pendimethalin (1.0 kg/ha) + hand-weeding at 45 days after sowing proved better for weed control (93.5%), bulb yield (13.16 tonnes/ha), for benefit: cost ratio (4.87) and also in lowering weed index (11.8%) (Nadagouda, 1996). Mulching is an effective way to suppress weeds. Mulching at 30 days after transplanting gave maximum onion-bulb yield (263.34 q/ha), followed by 3 hand-weedings at 30, 60 and 90 days after transplanting. Well prepared and pre-irrigated onion-seedbed plots covered with 50 μm-thick transparent polyethylene mulch for 6 weeks prior to onion planting showed higher seedling emergence (Abdallah, 1998). Work related to non-chemical based IWM is the need of the hour. Effect of crop rotation, tillage, crop competitiveness, solarization and others needs attention to economize production and to reduce environmental damage.

Cropping systems

The success of any cropping system depends upon the appropriate management of resources including balanced use of manures and fertilizers. Integrated use of fertilizers, organic manure and recyclable crop residues along with residual fertility plays an important role in maintaining soil-health as well as raising productivity of the system. Onion is suitable to be adopted for various cropping patterns including intercropping and sequential cropping systems depending upon the location, nature of the soil and climate, as it is a short-duration and shallow-rooted crop. Onion is most commonly grown as an intercrop with chilli and cotton in Karnataka, Andhra Pradesh, Maharashtra and other parts (Elangovan *et al.,* 1985; Dodamani *et al.,* 1993). In Tamil Nadu, it is grown as an intercrop in turmeric and sugarcane field. In high potential but low productive eastern Indo-Gangetic plains, rice–Potato–Onion has been found as one of the most profitable system (Khurana and Bhatia, 1991; Kumar and Lal, 2004). Maize–potato–onion was found most ecologically sound and economically potential rotation in north-western part of Indo-Gangetic plain (Walia *et al.,* 2010). Sugarcane: onion (1 : 1) planting in Punjab was found better in terms of yield and soil-health (Singh and Vashist, 2004). Net profit too followed the same trend. Both cane yield and net profit decreased significantly when the number of onion rows planted in-between sugarcane rows increased to either two or three in comparison to one. Paired-row planted sugarcane with drip irrigation system was the most suitable system than potato, garlic and cabbage under western Maharashtra (Tripathi and Lawande, 2008). In Gujarat, groundnut-onion/garlic was better in terms of soil-health and profitability (Ibrahim *et al.*, 2005).

Crop rotation and cropping sequences varies depending upon the agro-climatic condition of a particular location. Normally food legumes (*mung, urd*, lentil, *rajma*, peas, cowpea), vegetables (cauliflower, tomato, potato), aster, *bajra*, wheat and groundnut are good preceding crops for onion as they require much organic matter in the soil. In western Maharashtra, aster–onion, marigold–onion, groundnut–onion, *bajra*–onion, onion–wheat, potato–onion and cucumber–onion sequences are popularly followed by farmers.

Crop rotation of brinjal as preceding crop, followed by onion as succeeding crop recorded maximum number of micro-organisms in the onion rhizosphere; minimum numbers of bacteria, actinomycetes and other microorganisms were noticed in monoculture (Rankev and Surlekov, 1976).

Crop rotation reduces incidence and magnitude of infested onion debris and pathogens harbouring it during non-host cycles. Small grains, especially barley, are highly recommended to improve organic matter content and reduce problems of pink root and *Fusarium* basal-rot in onion (Schwartz, 2014). Highest onion yields were obtained after preceding crop of celery or lettuce, less after onion and least after carrot (Hamilton and Bernier, 1976). The nematode species occurring in largest numbers after continuous growing of carrot, onion, celery and lettuce were *Meloidogyne hapla, Pratylenchus matu* and *Pratylenchus penetrans,* respectively. Crop rotation of onion with sugarbeet, maize and spring wheat increased marketable yield of onions and decreased basal-rot (Higashida *et al.,* 1982). In Maharashtra and Madhya Pradesh, onion cultivation is more profitable when okra and radish are one of the component vegetables. Aubergine–Chinese cabbage–onion and okra–radish–onion are also promising. The same crop sequence also produced the highest net returns and benefit: cost ratio at Himachal Pradesh. Groundnut–potato–onion cropping system was the best crop sequence with higher yield, more remunerative, and with land-use efficiency of 90% in Punjab (Roy *et al.,* 1999). In Tamil Nadu, populations of *Rotylenchulus reniformis* and *Pratylenchus delattrei* increased in onion–maize–onion cropping sequence, and in onion–tomato–okra cropping sequence, populations of *Heterodora dihystera, H. seinhorsti* and *M. incognita* increased (Vetrivelkalai and Subramanian, 2006). On Vertisols of central India, soybean in *kharif,* followed by onion in *rabi* performed better in terms of yield, soil-health and cost : benefit ratio. Significant improvement in physical and chemical properties of soil can be obtained from legume-based cropping sequences, particularly soybean, followed by *rabi* onion and groundnut, followed by late *kharif* onion (Sankar *et al.,* 2011). Intercropping of onion with some of the vegetables like tomato decreased thrips infestation and increased marketable yield (Afifi and Haydar, 1990; Dilip Singh, 1996; Mishra *et al.*, 2014).

Precision technology

The success of precision agriculture depends on accurate assessment of variability, its management and evaluation in space-time continuum in crop production. The agronomic feasibility of precision agriculture has been intuitive, depending largely on the traditional recommendations at finer scales. The success has been quite convincing in crops like sugarbeet, sugarcane, tea and coffee. The potential for economic, environmental and social benefits of precision agriculture is largely unrealized as space-time continuum of crop production has not been adequately addressed. In India, onion has not received attention for precision agriculture, as it is traditionally grown by small and marginal farmers under intensive cropping system; and very little mechanization is practised for the onion. Some distinct features of this crop such as uniform maturity, one time harvesting and limited crop height offer good scope for partial mechanization and also other sensor-based technologies. The operations like bed-making, precision seed-drilling, spraying of herbicides and pesticides, harvesting, topping, grading can be performed mechanically. Bullock-drawn implements are usually used for field preparation; and use of tractor-drawn implements has increased since a decade. Sowing and transplanting of onion is manually done, and lay out for planting either as flat beds or ridged and furrows is also manual. The development of suitable and cost-effective equipment for these operations may help reduce cost of production. Several prototypes have been developed in the recent years, like bed maker and rotary drum roller, size graders of the DOGR and onion seed-drills. They increased efficiency by 5 and 20 times, respectively, over the normal operations.

Future Strategies

There is a need to develop appropriate eco-friendly agro-techniques specific to various agroclimates for maximum productivity of onion under available natural and other resources vis-à-vis distribution of quality planting material of promising varieties. Moreover, standardization of year-round production technology for onion under changing global climate is the need of the hour. Sensor-based input management practices are very essential for enhancement of onion production and productivity. Development of Good Agricultural Practices (GAP) for export of onion to other countries is very important. Emerging labour problem is becoming a big hindrance for small- and medium-scale farmers. Power supply is another challenge for successful cultivation. Mechanization in onion is becoming critical for increasing production. Short-duration, uniform maturing varieties suitable for mechanical harvesting would be the requirement in future.

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Nutrient Management

9

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To achieve maximum yield potential from any crop, balanced application of required nutrients is imperative. Current fertilizer recommendations for onion are based on the empirical methods. Most of the farmers apply all fertilizer nutrients at the time of transplanting as a basal application without consideration of crop nutrient removal. Further, secondary and micronutrients are rarely applied. Replenishment of nutrients removed by crop-plants through supply of chemical fertilizers and organic manures is essential for sustainable production. Application of plant nutrients through inorganic fertilizers in a balanced manner would increase crop productivity while maintaining soil-health. Organic manures benefit by adding plant nutrients directly on mineralization and indirectly through improved soil-health for plant growth and development. The quantity of plant nutrients supplied through organic manures may not be sufficient to fulfill requisite nutrient requirement. Hence, integrated use of both inorganic fertilizers and organic manures as per the requirement at the right time and quantity would be the ideal option to sustain onion production by increasing fertilizer-use efficiency. In this chapter, nutrient requirements and integrated plant nutrient system for onion have been discussed in details. Organic cultivation of onion has also been discussed, although limited information is available on this aspect.

Nutrient budgeting

The use of nutrient audits and nutrient balances to assess changes in soil-nutrient status and prospects for future generations is incessantly becoming important (Sheldrick *et al.,* 2003). The relevance of soil nutrient balances for agricultural potential of the land has been emphasized. Soil nutrient flow is the amount of plant nutrients that flow in and out of the system (Nkonya *et al.*, 2004). Difference between nutrient inflow (sum of nutrient inputs) and outflow (sum of nutrient outputs) is nutrient balance. Nutrient inputs include application of mineral fertilizers, organic manures, crop residues, biological nitrogen fixation, atmospheric deposition, sedimentation by irrigation and flooding, and nutrient outflow comprises removal of economic crop products, crop residues, gaseous losses, runoff and leaching losses. A situation where inputs exceed outputs is termed as nutrient accumulation, and when output exceeds inputs, it is nutrient depletion. Negative nutrient balance indicates that the system is losing nutrients. On the contrary, excess nutrient accumulation may lead to extended losses as a result of toxicities. Balanced or equilibrium nutrient levels occur when inputs equals outputs. A summary of the nutrient inputs and outputs from a defined system over a definite time is nutrient budget for that spatio-temporal unit (Onenema *et al.*, 2003). Nutrient management practices must underline nutrient balances in the soil for sustaining its health. Soil testing and plant analysis are important tools for determining plant-nutrient requirement.

Soil testing and plant analysis

Soil testing evaluates soil fertility, provides an index of the nutrient availability in a given soil, and is also a basis for fertilizer recommendation. The main objective of sustainable nutrient management is to reduce production cost, conserve natural resource and minimize possible negative environmental impact, while maintaining an initial soil-fertility level without build-up or depletion over years. Plant analysis, on the other hand, is used as a monitoring tool to determine sufficiency or deficiency of plant nutrients and ability of soils to supply nutrients for good growth and development of plants. Plant tissue testing also helps in achieving high degree of precision in fertilizer management. Onion-plants exhibit deficiency symptoms characteristic for each element, which are useful for diagnostic purposes. However, in many cases, the symptoms may be masked by other nutritional disorder symptoms or by those caused by unfavourable environments or stresses caused by plant pests. In such situations, plant-tissue analysis provides useful information to complement and confirm visual diagnosis. Nutritional disorders in vegetables rarely occur in well-managed crops. If a nutrient deficiency is identified during the growth period, it can be corrected by side dressing or through foliar feeding. If the deficiency appears during the late growth period, a considerable yield reduction may occur. Application of fertilizer nutrients would help reduce percentage yield losses and may guide to modify fertilization programme for the next year's crop.

Management of nutrients

In India, research conducted at different locations have shown that onion-crop required 2.10 – 2.16 kg N, 0.70–0.80 kg P_2O_5, 2.00–2.25 kg K_2O and 0.25–0.30 kg S for yielding a tonne of onion (AINRPOG, 2011). Similar studies by Dogliotti (2003) reported that onion-crop removed 1.92 kg N, 0.30 kg P and 1.30 kg K, and Zhao *et al.*, (2011) found that the crop needed 2.93, 1.16 and 2.69 kg of N, P_2O_5 and K_2, respectively. All these studies indicated that to produce a tonne of onion-bulbs, nutrient requirements were more or less similar at varied locations and also for different varieties or ecotypes, like long-day or short-day. Dry matter accumulation was very slow at the initial establishment stage, up to 20 days after transplanting (DAT), and at a faster rate after 20 DAT. Daily dry matter accumulation rate reached a maximum after 55–60 DAT. And nutrient uptake was higher from 15 to 60 DAT, followed by a sharp decrease after 60 DAT (Thangasamy, 2014). Application of plant nutrients through external sources is a must to maintain soil nutrient equilibrium, and it should match with crop nutrient demand for higher nutrient-use efficiency.

Addition of N, P, K and S through mineral fertilizers plays a major role in plant nutrition. In India, fertilizer application is mainly restricted to N, P and K; and thus fertilizer consumption is unbalanced, tilted more towards N, followed by P and K, which is the root cause of low yield and declining soil fertility in many areas (Subbarao and Sammi Reddy, 2006). Unbalanced use of chemical fertilizers for seven years caused depletion of N, P and K from the initial NPK levels (Sinha and Prasad, 1980, 1981). Addition of excess of NPK and S resulted in build-up of applied nutrients in the soil, and their deficiency reduced crop yields and further depleted plant nutrients from the soil. Balanced use of NPKS increases crop yield and contributes to carbon sequestration by favouring crop growth and crop-derived carbon inputs in the soil (Gong *et al.*, 2012).

Nitrogen

Onion has medium to high requirement for nitrogen. Mature healthy onion-leaves at pre-bulbing stage (20–45 DAT) have 3–4% N, and it reduced to 2% at the bulb initiation and development stages (45–75 DAT). Plants with less than 1% N are usually regarded as deficient (Fig. 9.1). Nitrogen is absorbed in the form of NH_4^+ and NO_3^{-1}. Normally, almost all Indian soils are deficient in nitrogen. Nitrogen deficiency usually occurs in soils with poor organic matter, and continuous depletion of soil-nitrogen owing to intensive agriculture, and N non-replenishment aggravates its deficiency. The deficiency is also caused by repeated cropping with non-leguminous crops, and due to microbial immobilization of applied and soil-nitrogen when high C : N ratio organic matter is used. Thus, there is a need to apply nitrogen through external sources. Onion yields increased with N application from 0 to 150 kg/ha, and reached plateau beyond 150 kg/ha, and after crop harvest, soil-N balance increased with additional N application (Brewster 2008). Application of locally available organic manures, such as FYM, poultry-manure or vermi-compost, equivalent to 75 kg N through broadcasting at the field preparation, is recommended for onion-crop; along with addition of 110 kg N/ha for late *kharif* and *rabi* onion and 75 kg N/ha for *kharif* season are also recommended. Nitrogen-management practices for achieving higher N-use efficiency include split application of N fertilizers; its proper incorporation into

Fig.9.1 Nitrogen deficiency

the soil to avoid volatilization losses; use of modified forms of urea fertilizers, like urea supergranules; and integrated use of organic and inorganic sources including green manures and biofertilizers. Calcium nitrate or calcium anmmonium nitrate has a positive effect on N nutrition of onion in red and light soils. Excess N in onion-plants cause thick stem (Fig. 9.2) and neck thickness (Fig. 9.3), and aggravates incidence of purple-blotch disease and attack of sucking pests. Excess N in the soil can be lost through gaseous volatilization and emission, denitrification, runoff and leaching (Raun and Johnson, 1999; Raun *et al.*, 2002), and would pollute environment and contaminate groundwater.

Fig. 9.2 Excess N leads to thick stem

Fig. 9.3 Late application of N leads to thick neck, and the encrusted soil results in bent neck

Phosphorus

Onion-crop removes 15–20% of the total P from transplanting to 20 DAT, i.e. crop-establishment stage, and 70–75% during 20–60 DAT. Only about 5–6% of the total P was removed after 60 DAT (DOGR, 2013). Phosphorus is absorbed by the plants as $H_2PO_4^-$ by an active process. In normal plants, P content varies from 0.3 to 0.4% during active vegetative growth stage (20–45 DAT) and from 0.1–0.3% during bulb initiation to developmental stages. Plants having less than 0.2 and 0.1% P during active vegetative growth stage (20–45 DAT) and bulb initiation to developmental stages (45–75 DAT), respectively, are designated as P-deficient (Fig. 9.4).

Phosphorus at 40 kg/ha is recommended for onion-crop, and full dose is applied as basal at the time of transplanting. Phosphorus applied through external sources enriches soil-available P and with time, the applied P gets fixed in soil complexes. Soil-available phosphorus remains in equilibrium with fixed phosphorus in the soil. When soil-available P is removed by plants, fixed-P would be released into the soil solution to maintain equilibrium. Available P in the soil is highly *p*H sensitive, and gets affected both in acidic as well as alkaline range. Root development is seriously hampered whenever P level in the soil is less than 10 ppm. Hence, its full recommended dose is applied at the time of transplanting. Soil application of phosphorus-solubilizing bacteria (phospho-bacteria) at 5 kg/ha is also recommended to enhance P-use efficiency. Organic manures and phosphobacteria application increased phosphorus uptake over inorganic fertilizers (DOGR, 2013). Organic manures supply plant P directly and also releases indirectly

Fig. 9.4 Phosphorus deficiency

fixed-P through chelation. Organic acids released during mineralization of organic manures form complexes with fixed-P and thus releases fixed-P. Phospho-bacteria solubilizes fixed-P and enhances efficiency of applied-P. Hence application of PSB (phosphorus-solublizing bacteria) along with organic manure is recommended in package of practices for onion-crop to increase P-efficiency. For instance, dipping seedlings in 2% P solution or slurry has been found useful in meeting P requirement in the initial establishment stages. In Karnataka, excessive use of DAP and single superphosphate in onions results in P accumulation. This situation warrants more zinc application.

Potassium

Its concentration in healthy plants varies from 3.5 to 5.5% and 2.0–4.0% during active vegetative growth stage (20–45 DAT) and bulb initiation to developmental stages (45–75 DAT), respectively. Plant tissues having level lesser than 1.0% K, develop potassium deficiency symptoms (Fig. 9.5). Potassium requirement is more or less equal to that of N. N : K ratio of 1 : 1.2 is found to give resistance to various diseases like purple-blotch. Like N and P, K is also highly mobile and is transported rapidly to younger tissues. Hence spray of sulphate of potash (0.5%) at later stages improves yield and increases disease resistance. Potassium balance in soil remains consistently negative and K supply through external sources is

Fig. 9.5 Potassium deficiency

comparatively lesser than the removal by the crop in many places in the country. Soils subjected to high cropping intensity and high K removal suffer considerable reduction in non-exchangeable content compared to soils with a low cropping intensity (Mingfang *et al.*, 1999). This negative balance results in serious soil-K depletion, which ultimately affects crop yield (World Bank Report, 2007). By balanced K application, N and P use efficiency and crop production can be enhanced. Potassium at 40 kg/ha is required at the time of planting for *kharif* onion-crop. Potassium uptake and yield of the late *kharif* and *rabi* onion is higher over *kharif* crop. Therefore, potassium at 60 kg/ha is recommended for late *kharif* and *rabi* crops. Potassium chloride (Muriate of potash) is often used as a potassium source. Most of the onion-growing areas fall in the range of medium to high category of available-K. Though soil-potassium level is high in onion-growing areas, the crop also responds well to external addition of potassium fertilizers. This indicates that replenishment of potassium removed by the crop is inevitable to maintain soil quality and sustain crop productivity. Intensive cropping without K addition in soils having high K content could lead to depletion of native soil-K. Excess K application may result in build-up in the soil, and may cause imbalance in the soil, and affect uptake of other nutrients also.

Sulphur

In addition to NPK, sulphur is an essential plant nutrient for onion-crop for improving yield and pungency of bulbs. Sulphur is absorbed as sulphate ions (SO_4^{2-}). Leaf-tissue sulphur level of 0.3 to 0.5% is required during active vegetative growth stage (20–45 DAT) and 0.2–0.3% during bulb initiation to developmental stages (45–75 DAT). Sulphur content below sufficiency level is deficient and above this level interferes with P uptake. Response to sulphur is more conspicuous in soils where *p*H is more than 7.8. Several studies were carried out on the effect of sulphur application on yield, pungency, sulphur uptake and soil-sulphur, and results indicated that potassium sulphate application gave better results over potassium chloride due to the presence of sulphur in the former. Qureshi and Lawande (2006) revealed onion yield increased with increasing sulphur nutrition up to 75 kg/ha in soils with low sulphur (<10 ppm), while in soils with sulphur level of 14 ppm, bulb yield increased significantly up to 20 kg S/ha, and increase beyond this did not improve yield. Soil application of sulphur beyond 20 kg/ha to onion successively for two years increased soil-available sulphur, slightly over the initial sulphur level (Thangasamy *et al.,* 2013). No yield increase was recorded in soils with high sulphur (Yoo *et al.,* 2006). This indicates 15 kg sulphur/ha is sufficient for growing onion-crop in soils having sulphur level above 25 kg/ha, while 30 kg sulphur/ha is needed for soils with sulphur below 25 kg/ha for the optimum onion production. Sulphur levels low enough to reduce onion yield and pungency range between 5 and 10 ppm (Yoo *et al.*, 2006). From the earlier studies it has been found that critical limit for soil available sulphur is 100 ppm, and soils with sulphur below 10 ppm are considered deficient (Parischa and Sarkar, 2002).

Micronutrients

Deficiency of micronutrients drastically affects growth, metabolism and reproductive phase in plants, animal and human-beings. Widespread deficiencies of micronutrients have been found in Indian soils. Intensive cropping with straight chemical fertilizers without micronutrients aggravates micronutrient deficiencies. World-over micronutrients are gaining much importance not only for their role in sustaining higher crop yields, but also as their increased deficiency in soil, seed/or feed, affects more animal and human health. Deficiencies of Zn, Fe, Cu, Mn, B and Mo have been noticed at 48, 12, 4, 5, 33 and 13%, respectively, in soils of India (Singh, 2009; Table 9.1). Among micronutrients, deficiency of available Zn in Indian soil is high, followed by B (Singh, 1991, 2009). Micronutrients can be applied either through soil or foliar application. When micronutrients are applied to soil, applied micronutrients are fixed in the soil and unavailable to plant growth. The availability of the micronutrients is governed by soil *p*H, calcium carbonate, soil-organic matter, sodium, calcium and magnesium. Micronutrients are so termed because their small, or micro amounts are required for crop nutrtion. Such micro amounts can be supplied adequately through foliar applications to correct temporary deficiency. Boron is highly immobile in the plant, and to correct boron deficiencies, small amounts of boron must be applied frequently to young tissues or buds. Application of recommended doses of inorganic fertilizers (110 : 40 : 60 : 30 NPKS/ha), organic manures equivalent to 75 kg N and foliar application of micronutrient mixture increased marketable bulb yield by 5–7% (DOGR, 2014). Regular application of farmyard manure (FYM) at 10–15 tonnes/ha helps mitigating deficiencies of all micronutrients in the long run (Singh, 2004).

Table 9.1 Available micronutrients content and their critical limit in Indian soils

Element	Available nutrient content (mg/kg)	Critical limit (mg/kg)
Zinc	0.1–24.6	0.6
Boron	0.08–2.6	0.5
Iron	0.36–174	4.5
Manganese	0.6–164	2.5
Copper	0.1–32	0.2

Sources: Takkar (1982), Singh (1999), Singh (2009)

Micronutrients should be applied to soil only when a specific deficiency has been clearly diagnosed (Table 9.2). There is a fine line between adequate and toxic amounts of these nutrients. Indiscriminate application of micronutrients may reduce plant growth and restrict yields because of toxicity. Francois *et al.* (1991) reported that relative yield of onions was reduced by 1.9% with each unit (mg/litre) increase in soil-solution B above 8.9 mg B/litre, which indicate that an important part of any micronutrient programme involves careful calculation of all micronutrients applied from all sources. In general, if the leaf nutrient content during active vegetative growth and bulb initiation stage is less than the lower limit, deficiency symptoms may appear. When the contents exceed

Table 9.2 The critical limit of micronutrients in onion leaves

Elements	Sufficiency ranges (mg/kg)
Zinc	15–25
Boron	30–40
Iron	400–600
Manganese	60–90
Copper	5–8

Source: Unpublished data

upper value, toxicity symptoms may be visible. Both micronutrient deficiency and toxicity affect bulb yield and quality (Figs 9.6, 9.7). It should be noted that soil and environmental factors such as temperature and rainfall may also influence plant nutrient level and sometimes make the interpretation of results difficult. Hence, both plant tissue analysis and soil-test values should be used for diagnosis and interpretation of micronutrients' deficiency and management.

Fig. 9.6 Manganese deficiency in onion-crop

Fig. 9.7 Recovered manganese deficiency plot after foliar application

Methods and time of fertilizer application

Nutrient requirement varies with the crop growth stages. Farmers are generally applying higher N fertilizers at the time of planting to get maximum bulb yield. As discussed earlier, onion has a shallow and sparse root system, concentrated mainly on the surface soil (0–30 cm). Application of fertilizers as basal at the time of planting may be moved to subsurface along with the irrigation water through leaching and may pollute groundwater. Sammis (1997) reported the need for high rates of N to onion for optimizing onion yield in New Mexico but expressed concern about leaching of NO_3–N from the root zone and low N fertilizer-use efficiency (30%) of onion.

Field experiment carried out to determine the growth and N uptake pattern of onion grown on a silty clay-loam soils showed that the greatest demand for N by onion was during bulb development, and fertilizer-N recovery by onion was about 15%. Much of the fertilizer N that remained in the upper 60-cm soil profile at the harvest leached to subsurface (Halvorson *et al.*, 2002). Application of starter N fertilizer in combination with reduced rates of supplementary N improved crop growth during initial growth stages and gave yields comparable with higher rates of basal N in onion-crop and showed that the starter fertilizer helped reducing N inputs, while maintaining yield and quality of onion (Stone, 2000). Drost and Koenig (2002) observed that application of N through polymer-coated urea to the crop reduced N losses and improved N-use efficiency compared to single or multiple applications of water soluble N sources in direct-seeded onions. Controlled release of N fertilizers is often used to reduce leaching losses from the soils (Wang and Alva, 1996) and to extend N availability throughout the growing season (Weidenfeld, 1986). In Netherlands, slow-release fertilizer N applied to onion-crop improved crop growth, bulb yield and N concentration over soluble fertilizers (Amans and Slangen, 1994). Addition of chemical fertilizers stimulates plant growth, crop yield, increases organic matter input to soil, and effect of organic fertilizers is double as this also adds organic matter to the soil (Heitkamp *et al.*, 2009). The organic manure application improves soil-organic carbon content and also supplies secondary nutrients and micronutrients.

Organic farming

Soil organic matter is a key component in maintaining soil quality (Doran and Parkin, 1994). It affects crop growth and yield either directly by supplying plant nutrients or indirectly by modifying soil physical environment that can improve root environment and stimulate plant growth (Darwish *et al.*, 1995). Application of organic manures over the years continuously enhanced soil organic matter and soil physical properties such as hydraulic conductivity, porosity and aggregate stability, lowered bulk density and increased soil biological activity than soils receiving only inorganic fertilizers (Edmeades, 2003;Diacono and Montemurro, 2010). Use of organic fertilizer with low N and high carbon as an alternative fertilizer in organic farming produced lower yields than chemical fertilizers due to slow rate of mineralization (Blatt, 1991). Although organic production provides better quality food and a balanced environment, but almost 25–40% lesser yield in the initial years. Bulb yield increased in the succeeding years. However, the yield level recorded in organic farming was comparatively less over inorganic farming (Lawande *et al.*, 2009). The production cost of organic onion was also higher than conventionally produced onion-crop. This indicates that application of organic manure improves soil-health but is not sufficient to sustain onion production. To increase production and to sustain soil-health, both chemical fertilizers and organic manures need to be applied together in a balance as per the crop requirement. The major challenge is to increase productivity through integrated use of organic manures, microbial inoculants and inorganic fertilizers as per the crop requirement at the right time.

Integrated plant nutrient system

Integrated application of 75% NPK, 10 tonnes FYM/ha and *Azotobacter* to onion-crop produced bulbs at par with 100% RDF, which was significantly higher over control without fertilizer application in sandy-loam soils of Bichpuri, Uttar Pradesh (Singh and Pandey, 2006). Similarly, combined application of 75% NPK, organic manures equivalent to 75 kg N and *Azospirillum* produced yield at par with 100% RDF (150 : 50 : 80 : 50 kg NPKS/ha) + 20 tonnes FYM/ha at Rajgurunagar, Srinagar, Udaipur, Dharwad, Samastipur, Hisar and Jabalpur (AINRPOG Annual Report, 2011). Jayathilake *et al.* (2002) found that integration of organic amendments (farmyard manure or vermi-compost) and biofertilizers with inorganic fertilizers resulted in higher yields and greater growth than inorganic fertilizers alone. Similarly, Selvakumari *et al.* (2001) found that inclusion of organic manures and biofertilizers reduced required amounts of inorganic N, P, and K. However, current integrated nutrient management practices involve just inorganic fertilizers and organic sources such as FYM or compost, which need an improvement by including all possible local sources of plant nutrients.

Inclusion of legume as a proceeding crop

Due to increased fertilizer prices and consideration for ecological sustainability, interest is focused on the intensive cropping system, especially with legume crops in a sustainable crop sequence as a supplement to chemical fertilizers. Inclusion of legume as a proceeding crop enriches soil-N and also has a synergistic effect on the succeeding crop. The potential of N fixation by legume crops varies from 26 to 300 kg, depending on the crop species. Inclusion of soybean as a proceeding crop in onion-cropping sequence, improved bulb yield and soil-health over *bajra,* followed by onion sequence (NRCOG, 2007). Substitution of nitrogen through farmyard manure, addition of bioinoculant (*Rhizobium* + phosphate-solubilizing bacteria) and *in-situ* incorporation of soybean-straw along with 75% RDF produced comparable bulb yield with 100% RDF, indicating a saving of recommended fertilizers to the extent of 25% in onion-crop in the soybean-onion cropping sequence (Tumbare and Pawar,2003). Legume-based cropping system effect was evaluated on the succeeding rice-crop at Thanjavur, Tamil Nadu. Besides, more rice yield, soil-organic carbon and available nitrogen status also improved (Porpavai *et al.,* 2011). Studies conducted at Rajgurunagar, Pune, revealed that inclusion of legume as a proceeding crop in *kharif,* followed by onion or garlic in *rabi* is ideal cropping sequence under western Maharashtra in terms of yield, soil-health and cost: benefit ratio (Sankar *et al.,* 2005).

Crop residues and green manure

Crop residues are also one of the sources of organic material and supply of carbon and nutrients to agricultural systems. Continuous incorporation of organic residues increases soil-organic matter, and also improves delivery potential of nutrient elements (Kolahchi and Jalali, 2011). About 80.12 million tonnes of crop residues are available for recycling with the total nutrient potential of 1.61 million tonnes, which can replace 0.80 Mt chemical fertilizers in India (Gill *et al.*, 2008). Recovering nutrients by reincorporating organic residues into the farming systems is a sustainable alternative that can contribute to restoring natural environmental equilibrium and also protecting environment from pollution. Incorporation of green manure crop with tender twigs planted during late summer or leaves from outside into the soil would provide plant nutrition and also improve soil architecture for achieving a good seedbed and fast emergence and early vigour of onions; each of these contribute to good crop establishment. Growing green manure crops during late summer and incorporating them into soil reduce weed menace also. The rooting depth of the onion-crop is about 0.3 m, and the crop is unable to use nitrogen of the deeper layers. However, N uptake of onion increased when green manure was grown as a proceeding crop, which was due to dual effect of green manure crop —biological N fixation and ability to concentrate available-N in the upper soil (Thorup-Kristensen, 2006).

Biofertilizers

Microbes harbouring rhizosphere benefit crops through increased nutrient availability by way of atmospheric N-fixation and/or through solubilizing fixed mineral forms of nutrients. The symbiotic and non-symbiotic N fixation is a well known phenomenon involving leguminous and non-leguminous crops. N fixing and P solubilizing bacteria help increase crop yield and nutrient-use efficiency (Hegde *et al.*, 2007). Integrated use of *Azotobacter* with 120 kg N/ha recorded highest marketable onion-bulb yield, followed by *Azospirillum* + 120 kg N/ha at Kanpur, India (Dubey and Singh, 2008). Combined application of poultry-manure and *Azotobacter* gave 64% higher bulb yield over control. Such a response of poultry-manure owing to relatively high nutrient concentration and microbial population helped mobilizing unavailable pool of nutrients in the soil, thereby triggering acquisition of optimum nutrient supply across the critical crop growth stages (Yeptho *et al.*, 2012). However, the response to microbial inoculation depends on different factors including inoculation, chances for survival, adsorption by soil particles and competition with indigenous population and soil fertility. Some soil microorganisms like *Azospirillum* sp., *Enterobacter* sp., *Azotobacter* sp. and *Pseudomonas* sp. have shown to encourage plant growth by promoting growth of secondary roots, acting as protectors against pathogenic microorganisms by release of plant hormones and siderophores (Awad *et al.*,2011).

Future Thrusts

- Fertilizer scheduling based on the nutrient uptake pattern to enhance nutrient-use efficiency.
- Quantification of nutrient losses by different means in different nutrient management options.
- Quantification of availability of nutrients in different fractions in soils to monitor build-up and/or depletion of nutrients in soils through different management practices.
- Improving productivity and nutrient-use efficiency through microbial inoculation such as vesicular arbuscular mycorrhiza.
- Enhancing productivity and nutritional and storage quality through micronutrient management.
- Screening of germplasm for higher nutrient-use efficiency through traditional breeding methods or by using biotechnological tools.

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Seed Production

10

R.P. Gupta and H.P. Sharma

Onions are normally produced from seeds, except multiplier onions, which multiply through vegetative means from bulblets. The importance of quality seed and improved varieties is well established in cereals. Quality seeds and F_1 hybrids of vegetables (tomato, cabbage, cauliflower) and some other crops have brought considerable improvement in their yields. It is high time to have an organized production and distribution of quality seeds of improved onion varieties to increase crop production for meeting domestic and export requirements.

Onion-seed production is a difficult process, as it is produced in two phases. In the first phase, bulbs are to be produced, and in the second phase, onion-seeds are produced from bulbs. It takes longer to produce quality onion-seeds compared to other annual vegetables. Further, extra precautions are to be taken from seed sowing to seed production. Details for onion-seed production such as good cultural practices for bulb production and purity of variety, seed cleaning, packing and storage need to be defined well with the latest production technologies.

Improved onion varieties and their seed production

Though there are more than 45 improved varieties of onion developed in different universities and institutes; all varieties are not popular among farmers, mainly as their seeds are not available on a commercial scale. The seeds of Pusa Red, N2-4-1, N53, Baswant 780, Agrifound Dark Red, Agrifound Light Red, NHRDF Red, NHRDF Red2, Arka Kalyan, Arka Niketan, Punjab Selection, Hissar 2, Bhima Red, Bhima Super, Bhima Kiran and Bhima Shakti in common big-onion group of red types, Agrifound Rose in common small-onion group of red types, Phule Safed, Punjab 48, Agrifound White and Bhima Shweta in white types, CO 4 and Agrifound Red in multiplier types are being produced either by universities and institutes in small quantities or by the NSC, Mahabeej, NHRDF, DOGR and some other state seed corporations and private seed companies on a commercial scale in India.

Seeds of Early Grano in short-day yellow types and Spanish Brown in intermediate day-length types are also produced and distributed locally by farmers or institutes. Bejo Sheetal and Nunhems are also producing seeds of a few F_1 hybrids and distributing them. There are many other varieties like Pusa Madhavi, Punjab Red Round, Arka Pitamber, Phule Suvarna, Pusa White Round and Pusa White Flat; seeds of them are not yet produced or distributed.

Seed Production Technology

Seed-to-seed

This method is also called *"in-situ"* method. In this, bulbs are as such left in the field and allowed for bolting and flowering in the same field. Seeds are sown in the nursery from June to August. Bolting starts in January–February and seeds are ready by mid-May. Seeds of Agrifound Dark Red, Baswant 780, Arka Kalyan, Bhima Raj and other *kharif* varieties are produced by this method. It has following merits: low-cost of seed production, early maturity and no need to store bulbs. And demerits are: it is not possible to select true-to-type bulbs and thus high quality seed production is not possible and seed yield is low. Thus, this system may be avoided.

Bulb-to-seed

In this, bulbs are lifted from the field, and after proper selection, they are replanted in the field. Following two methods are used for seed production.

Annual method

Seeds are sown in June–July and seedlings are transplanted in August–September. Bulbs are ready by November–December. Selected bulbs are replanted in another field after 10–15 days; from mid-November to mid-December. Bolting starts in January–February and seeds are ready by May. Since the method takes a year, it is called the annual method. Seeds of Agrifound Dark Red, N 53, Baswant 780, Arka Kalyan, Phule Safed, Bhima Dark Red, Bhima Raj, Bhima Super and Bhima Shubra are produced by this method. Its advantage is less cost of production as bulbs are not to be stored. The *rabi* onion varieties do not form proper bulbs, therefore this method is not being used for *rabi* onion varieties.

Biennial method

Seeds are sown in October-November, and seedlings are transplanted in December–January. Bulbs are ready by April-end to mid-May. Selected bulbs are stored up to mid-October and planted in well-prepared fields. Since this takes about one-and-a-half-year, it is called a biennial method and seeds of Agrifound Light Red, NHRDF Red, NHRDF Red 2, Pusa Red, N-2-4-1, Bhima Red, Bhima Kiran, Bhima Shakti and other *rabi* onion varieties are produced with this method, which are true-to-type. But it takes more time, losses of onion-bulbs during storage are high and thus cost of seed production is high. This is a better method for pure and quality seed production.

Storage of mother-bulbs

In the case of annual method, selected bulbs are planted in well-prepared beds after curing for 10–15 days, but under biennial method, bulbs are stored from June to October in well-ventilated godowns for planting during October–November. Onions are stored in especially designed storage structures with proper and adequate ventilation. Disinfection of storage premises for handling and storage of onions is a must to reduce post-harvest losses, particularly decay.

Cultural practices for onion seed production

Temperature and day-length set the broad limits to the areas, which are suitable for seed production. When seeds are produced from the bulbs that have been raised during the preceding year, the day-length of the growing season required for the crop is relatively short. Long days, early in the season, which are characteristic of high latitude, favour rapid bulbing rather than flowering. A fairly cool temperature over considerable time while bulbs are in storage or over wintering in the field, conditions plant for flower-stalk formation; 4.5–14°C is favourable for the conditioning, which results more flower-stalks and more flowers in each umbel. The best seed-producing areas are the ones with low humidity. Long rainy season or heavy dew and fog favour development of *Stemphylium*-blight and purple-blotch. During flowering of onions, clear and bright days are necessary to ensure insect activity for pollination. Equally important is hot and dry weather during harvesting, curing and threshing of seeds.

Selection of bulbs

Medium-sized bulbs (4.5–6.0 cm for big onions and 2.5–3.0 cm for small onions), especially single centred, should be selected for planting to get maximum yield. Though big-sized bulbs have more number of sprouts and thus give higher seed yield, they are not economical as cost increases. Medium-sized bulbs are better and economical for seed production.

Land preparation

Onion seed-crop can be grown on a wide range of soils but very light sandy soils are to be avoided. Moderately heavier soils should be preferred as they are cooler, have a high water-holding capacity and are more productive. The field is ploughed with tractor-drawn implements or *desi* plough to a fine tilth by giving four ploughings with sufficient interval between two ploughings. The planking should be done for proper levelling. The field is then divided into beds and channels. Field should be levelled to avoid waterlogging.

Time of bulb planting

Last week of October to first fortnight of November is the best time for bulb planting of *rabi* onion varieties. *Kharif* onion bulbs are available during mid-October and early November. They should be planted by 15 November from the same crop, and this way seed production can be within a year. Maharashtra, Madhya Pradesh, Karnataka, Gujarat and Rajasthan are considered better for onion-seed production. The highest seed yield is obtained from Rajkot area of Gujarat as it has dry weather during flowering and seed-setting (Pandey *et al.,* 1994a). If planting is done early, crop is damaged by rains in March/April. If late planting is done, there would be lesser vegetative growth and that would lead to lesser number of bolters and seeds.

Method of planting, spacing and bulb requirements

Planting of uncut onion-bulbs of large size with higher dose of nitrogen up to 160 kg/ha increases onion-seed yield (Sharma *et al.*, 2008). Selected bulbs of

4.5–6.0 cm are planted in a well-prepared field of normal loam to clay-loam soil at a distance of 45 cm × 30 cm (Pandey *et al.*, 1990a). If spacing is lesser, it results in lesser ventilation, and thus drying of the field is slower after irrigation, favouring diseases. In sandy soils, spacing may, however, be reduced to even 30 cm × 30 cm. The depth should be at 5–7.5 cm. Irrigation is given immediately after planting. The spacing can be reduced if seed production is under drip system. About 25–30 quintal bulbs for big and 15–18 quintal for small onions are enough to plant a hectare.

Manures and fertilizers

About 20–25 tonnes of farmyard manure per hectare is required at the time of field preparation. Nutrient requirement usually depends on the soil type, growing region, varieties and amount of major nutrients removed. Generally 80 kg of nitrogen, 60 kg of P_2O_5 and 50 kg of K_2O/ha are recommended for better seed yield (Bhonde *et al.,* 1996). If the soil is low in nitrogen, 120 kg N/ha should be applied. Whole quantity of phosphorus, potash and half of nitrogen should be mixed in the soil before planting. The rest of nitrogen should be given as top-dressing in two equal split doses, first 30 days after planting and the second 45 days after planting. Application of 150 : 75: 75 kg/ha, N, P_2O_5 and K_2O along with FYM @ 20 tonnes/ha and biofertilizers was promising for higher seed yield (Adagale *et al.,* 2010). Foliar spray of water soluble fertilizer NPK+6 trace elements (19: 19: 19+6TE) @ 1% at 60 and 75 days, and NPK (13: 0: 45) @1% at 105 and 120 days after bulb-planting should be done for higher seed yield.

Irrigation and aftercare

Irrigation in onion is given at an interval of 10 days (Bhonde *et al.,* 1996), depending on the soil type and season. Earthing-up is done after two months of planting to avoid lodging. Weeding and hoeing are done as per the requirement. Specific precautions should be taken while irrigating the crop more frequently during flowering and seed-setting. Saturating soil surface and keeping it wet should be avoided as it may cause neck-rot and other diseases, which may lead to premature dying of seed-stalks. Drip irrigation and mulching with wheat or paddy-straw is recommended for higher seed yield (Gupta *et al.,* 2005). Drip irrigation at every 3 days interval with 75% Cumulative Pan Evaporation (CPEU) is most effective for growth, yield and for production of good quality onion-seeds (Dingre *et al.*, 2012).

Weed management

The problem of weeds is inevitable, and is a serious and widespread constraint, and is one of the major causes for low productivity. Apart from the depletion of nutrients and moisture from the soil by weeds, they may also harbour insect, pests and diseases, and thus provide an ideal ecological condition to shelter them and for their proliferation. Spraying of Pendimethalin @ 3.50 litres per hectare + one hand-weeding at 60 days after planting are recommended for effective weed control and higher seed yield.

Diseases and insect-pests management

Onion-seed crop is affected by a number of diseases and insect-pests in the field. Each disease and insect-pest requires a specific management practice. The details of the most commonly occurring diseases and insect-pests, which may cause economical losses to farmers/seed producers, are given in the subsequent chapters.

Rouging

Diseased and off-type plants as follows are rouged out before flowering for quality seed production— weed plants; any other crops' plant; other varieties of onion; and diseased plants.

Mode of pollination

Onion is highly cross-pollinated crop, and bees are the main pollinating agent. So, it is necessary to have a good number of bees for proper pollination and seed-setting. Following points should be taken care of for improving pollination.

- Bee-colonies are kept in the field.
- Irrigation should be given more frequently at the time of flowering and seed-setting.
- Only safe insecticides should be sprayed during flowering. The spray should be done in evening or early morning, when there is no bee activity.

Benefits of pollination by bees

Product	% Increase
Seed	277
Seed germination	38-40
1,000 seed weight	8-10

Certification standards for seed production

Land requirement

The land to be used for onion-seed production shall be free from volunteer plants.

Field inspection

Mother-bulb production stage

- First inspection should be done after seedling transplanting to determine isolation, volunteer plants, off-types, including bolters and other relevant factors.
- The second inspection should be after the bulbs have been lifted to verify their true characteristics.

Seed production stage

- The first inspection should be done before flowering to determine isolation and off-types.

- The second and third inspection should be during flowering to check isolation and off-types and other relevant factors.
- The fourth inspection should be at maturity to verify true nature of the plant and other relevant factors.

Field standards

General requirements

Isolation : Following table gives the isolation distance.

Contaminant	Isolation distance (m)			
	Mother-bulb production		Seed production	
	Foundation seed	Certified seed	Foundation seed	Certified seed
Field of other variety	5	5	1,000	500
Field of the same variety, not conforming to varietal purity requirement for certification	5	5	1,000	500

For breeder seed production isolation distance should be 1,500 m

Specific requirements

Factor	Maximum permitted limit	
	Foundation	Certified
* Bulbs not confirming to the varietal characteristics	0.10% (by number)	0.20% (by number)
**Off-types	0.10%	0.20%

* Maximum permitted at the second inspection at mother- bulb production stage
** Maximum permitted at and after flowering at seed- production stage

Seed standards

Factor	Maximum permitted limit	
	Foundation seed	Certified seed
Pure seed (minimum)	98%	98%
Genetic purity (minimum)	98%	98%
Inert matter (maximum)	2%	2%
Other crop seed (maximum number)	5/kg	10/kg
Weed seeds (maximum number)	5/kg	10/kg
Germination (minimum)	70%	70%
Moisture (maximum)	8%	8%
For vapour-proof containers (maximum)	6%	6%

Minimum seed certification standards for onion hybrids

The general certification standards are basic, and together with the following specific standards constitute the standards for certification of hybrid onion-seed. The general standards are amplified as follows to apply specifically to hybrid onion-seeds.

Eligibility requirement for certification

- An inbred line to be eligible for certification shall be from such a source that its identity may be assured and approved by the certification agency.
- Hybrid seed to be eligible for certification shall be the progeny of two approved inbred lines, one of which shall be male sterile.

Classes and sources of seed

- An inbred line shall be relatively true breeding strain resulting from self-pollination with selection.
- The foundation class seed shall consist of an approved male-sterile line to be used as a female parent and an approved inbred line to be used as a male parent for production of hybrid seed.
- A male sterile line shall be a strain A (Smsms), carrying cytoplasmic genetic male sterility, which sheds no viable pollen, and is maintained by the normal sister strain B (Nmsms), which is used as a pollinator. For maintaining sterile line, crossing of A and B line is necessary. R line (S MS MS) crosses with A line to produce hybrid seed.
- The certified class seed shall be the hybrid seed to be planted for any use, except seed production.

Field inspection

Mother-bulb production stage

Minimum of two inspections shall be done as follows.

- The first inspection shall be made after seedling transplanting to determine isolation, volunteer plants and off-types, including bolter and other relevant factors.
- The second inspection shall be made after bulbs have been lifted to verify their true characteristics.

Seed-production stage

Minimum of four inspections shall be made as follows.

- The first inspection shall be made before flowering to determine isolation, volunteer plants, outcrosses, planting ratio, errors in planting and other relevant factors.
- The second and third inspections shall be made during flowering to check isolation, pollen-shedding umbels, off-types and other relevant factors.
- The fourth inspection shall be made at maturity to verify true nature of umbels and other relevant factors.

Field standards

General requirements

Isolation: Following table gives the details.

Crop	Isolation distance (m)			
	Mother- bulb production		Seed production	
	Foundation seed	Certified seed	Foundation seed	Certified seed
Field of other variety, including commercial hybrids of the same variety	5	5	1,200	600
Field of the same hybrids (code designation), not conforming to varietal purity requirements for certification	5	5	1,200	600
Fields of others varieties of different skin colour	5	5	1,500	750

Problems in certification

Seed-producing agencies are facing many problems while processing for certification. Mother-bulbs are produced in one state, and certified seed production programme is in another state; leading to problems in documentation and verification. This problem needs to be addressed so that certified seed of onion is produced trouble-free.

Certified seeds of *kharif* onion varieties are produced by annual method and bulbs after harvesting need to be verified immediately so that planting of bulbs for seed production is done timely, but this is generally delayed by certification agencies. Therefore, preference needs to be given for *kharif* onion bulb certification by certification agencies. Seed germination testing, especially of *kharif* varieties, is not given priority by the agencies so to distribute seeds on time to farmers.

Harvesting and curing

In onions, all seed heads do not mature at the same time, therefore, harvesting cannot be done simultaneously. When the seed inside the capsule becomes black and 10–20% black seeds are exposed, the umbel should be cut with 10–15 cm stem attached. The umbels are spread on to ground or canvas to avoid attack of mould during drying (Pandey *et al.*, 1991).

Threshing, cleaning and seed extraction

After proper drying, umbels are threshed either by rubbing manually with hands or seed umbels are treading under bullock or tractor.

- Seeds are threshed when capsules are brittle and can break readily. Threshing is done by flairing. Cleaning is done by air-screen machine by using 1/l4 × 112 as grading screen.
- Thresher with low fan speed is also used for threshing large quantities of umbels.
- Seeds are cleaned by using hand-winnowers and fans.

- Use of seed cleaners, graders and gravity separator with appropriate sequence would help obtain clean and graded seeds.
- For proper cleaning, seeds are dipped in water before putting them on air-screen cleaner. The heavier seeds at the bottom are taken out, and are spread on to the bottom trays for immediate drying.
- Dipping of seeds in water for cleaning should not be done for more than 2–3 minutes, as germination would be affected adversely. Upgrading is further done on gravity separator.

Drying, packing and storage

For safe storage, seeds are dried to a level of 6% moisture, and then packed in aluminium foil or tin, which are moisture-proof (Pandey *et al.*, 1990b). Seeds are then stored in air-conditioned and dehumidified stores at 16–20°C and relative humidity of 30–40%. Onion-seed coated with polymer @ 12 ml/kg + Thiram @ 2 g/kg seeds and stored in aluminium pouch resulted in good germination (Basavaraj *et al.,* 2008). In hot-and-humid climate, viability of onion-seed is lost within a year. Onion-seeds dried up to 5 days and packed in polythene or aluminium foil could be maintained at germination standard up to 24 months (Pandey *et al.,* 1994b). If onion-seeds are dried to 6.0% moisture level and stored in sealed containers, their life can be prolonged for 3–4 years, without loss in germination.

Production of F_1 hybrid onion-seeds

The usual ratio of male: female rows are ♂: ♀ (1: 4) or ♂: ♀ (1: 8). The pattern and the ratio depend upon the mechanization and amount of pollen-grains produced by the male parent. Male: female parent ratio of 2 : 4 is also ideal. Remove off-type male-fertile flower plants from male-sterile female parent. Seeds from ♂ sterile or ♀ lines are harvested. Seeds produced on the male parent are harvested first to avoid mixing. The other practice of raising mother-bulbs and further multiplication are the same as for seed production of open-pollinated varieties.

Seed production of multiplier onion

Since this onion type is mainly propagated vegetatively, well-grown, uniform bulbs of a particular variety should be selected. The planting details including cultural practices followed for production of planting material are the same as those for production of bulbs for consumption. The seeds of multiplier type are also produced in a way similar to that of common big onion.

Cost of Seed Production

The normal seed yield is 6–8 q/ha. When weather is favourable, 12–15 quintal seeds, especially in Gujarat, can be obtained from a hectare. Seed production cost has been estimated as ₹ 190–236/kg for Agrifound Dark Red, ₹ 163–239/kg for Agrifound Light Red and ₹ 117–140/kg for NHRDF-Red in different areas. Cost of seed production also varies due to high/low cost of mother-bulbs at the time of planting.

Seed requirement

Though no authenticated data on demand of seeds is available, NHRDF has worked out some estimates on the season-wise requirement and also based on the types of onions grown in the country. The seed requirement on the basis of the calculation is 8 kg seeds for a hectare. The details are as follows.

Certified/truthfully-labelled seeds

Season/type	Certified or truthfully labelled seed requirement (tonnes)
Kharif, including late *kharif* (big)	2,918
Rabi (big)	4,752
Small rose onion	667
Multiplier onion (bulblets)	100,000

Foundation or 2nd stage and breeder seed

Season/type	Foundation/Stock seed (q)	Breeder seed (kg)
Kharif and late *kharif* (big)	60.78	12.66
Rabi (big)	96.97	19.79
Small rose onion	25.01	9.38
Multiplier onion (bulblets)	200,000	4,000,000

Note: Multiplication ratio in the case of multiplier onion is 1 : 5

Present Position of Seed Availability

Seed production sector of onion is still not well organized. The NHRDF, NSC and MSSC are major agencies producing quality seed/certified seed in an organized manner. The total production of onion-seed by these agencies ranges between 700 and 750 tonnes, which is about 8–9% of the total requirement. The private seed companies also arrange some seed production, the quantity of which ranges between 800 and 1,000 tonnes. The DOGR is producing high quality seed to the tune of about 30 quintals per year of its own varieties.

By assessing the availability position of onion-seeds in public and private sectors, it is clear that around 80% seeds are produced by farmers and private traders without observing any standard for isolation or varietal purity, etc.

Adequate quantities of breeder and foundation seeds are available only for Agrifound Dark Red and Agrifound Light Red, NHRDF Red and NHRDF Red 2; varieties developed by the NHRDF. The breeder seeds of Bhima Red, Bhima Super, Bhima Raj, Bhima Kiran, Bhima Shakti, Bhima Shweta, B 780 and Arka Kalyan and Arka Niketan are also available with the DOGR and IIHR. However for the other varieties in demand, the basic seed material is not available. Weather vagaries also adversely affect seed-crop. Many times, it is also observed that indenters do not lift the seeds. All these factors affect seed availability.

The details of the estimated onion-seeds produced by different agencies are as follows.

Agency	Qty of truthfully labelled/ certified seed (MT)
NHRDF	400
NSC	260
MSSC	100
DOGRand SAUs	10
Private Seed Companies	900
Private Traders	1,300
Farmers	5,500
Total:	8,470

Private seed companies also distribute hybrid onion-seeds, but in a very little quantity, by producing themselves and also by importing. Though bulbs produced are uniform from hybrid seeds but they are poor in storage, and need immediate disposal. Private traders are also managing seed production through farmers in Maharashtra and Gujarat but mainly for dark red varieties where *kharif* onion bulbs are not required to be stored.

Following are the reasons for low production of onion-seeds in the organized sector.

- *Rabi* onion-seed production in India is mostly done by biennial method. Seed-producing agencies produce mother-bulbs and store them and then use them for seed production. Therefore, mother-bulbs production becomes a costly affair.
- Because of huge losses in storage of mother-bulbs, seed production becomes uneconomical.
- *Price fluctuation:* Onion seed price varies from year to year. The NSC and even private seed companies are not sure if onion-seed production would be remunerative.
- *Short viability of onion-seed:* Onion-seed is having shortest viability period, normally less than a year. Unless seeds are dried up to 6% moisture level and packed in moisture-proof containers and stored in controlled conditions, storage-life cannot be increased. Most of the agencies do not have these facilities.

Quality Seed Production— Constraints

Non-availability of statistics on variety-wise area and seed demand

As mentioned earlier, authentic data on variety-wise area are not available. In view of this, it is not possible to plan seed production programme for breeder, foundation and certified seeds; resulting in surplus in one and deficit in other.

Marketing of seed collected from premature bolters

There are many farmers who collect seeds from premature bolters and use themselves or supply the same to traders or other farmers at a very low price. Since seed produced in an organized way is costlier, it is not possible to compete with traders, and quality seed is carried over to the next year, which does not allow public sector agencies to continue seed production at the same level every year.

Isolation distance

It is experienced that seed companies are taking up seed production in areas where bulbs production is going on simultaneously. In such a situation, no care is taken in maintaining required isolation distance in the seed-production plot from premature bolters of the bulb-production plot. Further, seed companies are also taking up seed production of white, dark red and light red in the same pocket without maintaining the required isolation distance. The seeds so produced are thus of poor quality.

Lack of awareness regarding suitable seed-production pockets

Seed companies and even farmers are not aware about the suitable pockets for taking up seed production. The climatic conditions suitable for good seed production are not available in all pockets. Onion-bulbs conditioning is required to produce flower-stocks. It varies from variety to variety. Temperature of 4.5°C to 14°C is favourable for conditioning. Longer this conditioning prevails, more flower stems will each plant produce and more flowers will be in each umbel. High humid areas with long rainy period or heavy dew/fog or hailstorm favour development of downy mildew in hills and *Stemphylium*-blight in northern plains. Suitable areas for seed production of onion are Saurashtra in Gujarat; Nashik, Pune, Ahmednagar, Satara and Marathwada in Maharashtra;Khargaon, Indore and Dhar in Madhya Pradesh; Jaipur, Chittorgarh, Udaipur and Sriganganagar in Rajasthan; northern Karnataka; and Kurnool in Andhra Pradesh. The areas with good honeybee activity also yield good onion-seed.

Slow spread of improved varieties

Improved varieties are not being popularized by extension agencies at a faster rate. Seed producing agencies are also not cautious in selecting varieties for seed production according to demand and recommendation.

Inadequate bulb storage facility

Neither seed-producing agencies nor farmers have adequate bulb handling and storage facilities. This is one of the major hurdles in taking up seed production of light red varieties by seed-producing agencies.

Sub-optimal standards of seed production

Location-specific technologies are lacking for seed production of different varieties. Further, extension education on suitable seed processing including drying methods, packaging and storage conditions are also lacking.

Inadequate facility for seed storage

Onion seed looses viability very fast under ambient storage conditions. Adequate facility for grading and drying up to 6% moisture is not available. Similarly, controlled condition storage facilities are not available with many agencies, although facilities have been created by the NHRDF in Maharashtra, Gujarat, Madhya Pradesh, Delhi and Haryana.

Future Strategies

It is true that quality seed of improved varieties of onions in adequate quantities is not available. It is also true that there is no organized production of onion-seed, and non-availability of quality seed of improved varieties is one of the major hurdles in increasing productivity and production. There is sufficient scope for improvement in production and productivity if a critical assessment is made to all aspects and seed production is taken up in a well-planned strategic manner. The following strategies are suggested for improving seed production.

Demand projection and advance planning

More than 80% onion-seed is produced by farmers and traders without observing any standards for isolation or varietal purity. At present, there is no advance planning for assessing demand of quality seed; the programme is taken in an *adhoc* manner. There is, therefore, a need to assess seed demand based on the demand of onion for domestic and export markets for the next 10–20 years. There is also need to replace seeds of local old varieties with new improved varieties. Assuming that during the next 10 years it would be possible to replace old varieties with new varieties to the extent of 50%, the seed requirement should be assessed and production of all classes of seeds need to be managed accordingly, mainly by organized sector.

State Governments should give indents of seed requirement in advance so that risk in production of quality onion-seed is minimized and sufficient quantity of seed is produced.

Production of breeder, foundation and certified seed/truthfully-labelled seed

After varieties are tested, specific responsibilities for production of breeder seed will have to be given to respective universities and institutes for developing varieties or to NHRDF and DOGR. Further, NHRDF, NSC, State Seed Corporations and SFCI may be made responsible for production of foundation seed of improved varieties. For certified or truthfully-labelled seeds also NHRDF, NSC and SSC (s) and also private reputed seed companies may be made responsible by the Govt of India.

Identification of suitable seed-production pockets

The areas suitable for seed production have been described above. There is, however, a need to identify more suitable pockets for sustainable production and makeing available adequate quantity of onion-seed.

Infrastructural facilities

Before seed production is taken up on a large scale, there is a need to create necessary infrastructural facilities—bulb storage godown, seeds-processing plant with gravity separator in addition to air-screen cleaner, dehumidifier drier, air-conditioned and dehumidified packing and store-rooms. Presently, such facilities are not adequate. The assistance is although provided for this as well as for seed-village concept by the Ministry of Agriculture under its National Horticulture Programme, this needs to be revised and increased for creating facilities in different areas.

Quality control

At present mostly truthfully-labelled seeds are being sold in the market. Many traders are selling seeds without even labelling them. Quality is thus not maintained. It is necessary to take up certified seed production through adequately trained staff with certification agencies. There is a need to devise certain quality control measures by which sale of seed without labelling can be checked. Adequate training on quality control is also essential for seed production of onion.

Research and development work

Disease- and insect- pest-resistant onion varieties need to be developed. High-yielding hybrids with good storage quality also need to be developed. Location-specific technologies for production of seeds need to be developed. Also farmers need to be educated and trained with latest production and post-harvest management practices in onion. The NHRDF and DOGR should intensify their work on research and development for enhancing seed viability and seed storage. The trials on drip irrigation and mulching in onion-seed production have given very encouraging results. This technology needs to be popularized for increasing production and reducing unit cost of seed production. There is also a need to decide package of practices for different varieties of onion.

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Onion Seed Industry and Trade

11

Suresh O. Agrawal

Seed is a basic and important input in any crop-production system. In addition to climate, nutrition and production technologies, quality seed contributes 30% to yield component. Yield of the vegetable crops almost doubled due to the development of high-yielding good quality varieties and hybrids and by making available their quality seeds on time. Seed sector in crop-plants has assumed immense importance since the Green Revolution. Sustainable Green Revolution would not have been possible without quality seed developed through hard-core Research and Development. Indian seed industry handles seed worth 2 billion US$. Vegetable seeds belong to "low volume and high value" category. The National Seed Corporation, State Seeds Corporations and about 50 private sector partners' deal with the business of vegetables seeds production. Among different vegetables, onion is an important component of the seed industry.

Seed requirement scenario

Exact data on onion-seed production and requirement are not available in India. However, based on the area planted, some estimates can be gauged considering that 6–8 kg seeds are required for a hectare. Assuming that 1.0 million hectares is covered under onion every year, about 6,000–8,000 tonnes of seeds would be required for net planting. And about 20% additional seeds would be required for covering storage losses, bufferstock and poor germination. Total seed requirement, thus would be about 8,000 tonnes. *Kharif* and late *kharif* occupy 40% of the area. Approximately 3,000/3,500 tonnes of seeds would be required during June to September, and for *rabi* season, about 4,000/4,500 tonnes would be required during November to December. For multiplier onion, assuming 1,000 kg seed-bulblets would be required per hectare, around 100,000 tonnes of bulbs would be needed.

As against the requirement, supply scenario of quality seed is very dismal. The public sectors, NSC, State Seed Corporations, NHRDF, DOGR and some SAUs are producing seeds of the recommended varieties to the tune of 700–800 tonnes, which is 10% of the total requirement. The private seed companies produce around 800 to 1,000 tonnes of seed of open-pollinated varieties. Bejo Sheetal Seeds Pvt. Ltd has started producing for the first time hybrid onion-seeds in the country. In 2013–14, Bejo Sheetal produced and sold 180 tonnes of hybrid onion-seeds. This clearly indicates that 75–80% of the seeds are produced by farmers and private traders, which are actually out of scientific seed-production chain. In fact, this is a major constraint in stagnation in productivity of Indian onion. Onion production from such seed-stocks suffers from the following drawbacks—(i) variation in colour, shape, size, and maturity, (ii) high percentage of bolting and spilt bulbs or non-bulbing, (iii) less storability due to high percentage of sprouting and low TSS and dry matter and (iv) susceptibility for many diseases and pests.

There is a need to organize seed production of improved varieties, developed by research organizations, on a large scale in a scientific manner. Seed replacement ratio must be enhanced vis-à-vis other vegetables through front-line demonstrations.

Improved varieties availability

Research on onion had started in the country as early as in 1950 in Maharashtra. Department of Agriculture released cv. N 53 for *kharif* (wet) season and N 2-4-1 for *rabi* (dry) season by the selection of onion landraces from Nashik. And these very varieties are still popular by trade names: Nashik Red, Bombay Red, Poona Red and Fursungi. Later systematic onion-breeding programme had started at the MPKV, Rahuri; IARI, New Delhi; NHRDF, Nashik; IIHR, Bengaluru and DOGR, Pune. PAU, Ludhiana, TNAU, Coimbatore and HAU, Hisar, also contributed in this.

The private sectors such as Bejo Sheetal, Mahyco, Seminis (currently Monsanto) and East West Seed also started R&D in onion. The IIHR and IARI have also started developing hybrid onion (Table 11.1). In India, only short-duration onions are grown. Internationally, onion varieties are classified in 4 categories (Table 11.2). Bejo Zaden, Nunhems, the Netherlands and Takii Seeds, Japan, are the big partners and deal mostly with long-day onion hybrids.

Table 11.1 Hybrid onion developed and marketed by private and public organizations

Organization	Hybrids
Bejo Sheetal Seeds Pvt. Ltd, Jalna	Lucifer, Orient, Flair, BSS 441, White, and Grano 858
Indian Institute of Horticultural Research, Bengaluru	Arka Kirtiman and Arka Lalima

Table 11.2 Classification of onions according to day-length

Type	Duration	Varieties
Very long-day	160–180 days	Rignburger
American long-day (good for storage)	160 days (popular in the USA and Canada)	T 400, Tamera (Bejo)
Intermediate	150 days (good for storage)	Spanish Brown, Legend Brown, Leony
Short-day	140–150 days	Grano, Indian Bombay, Cruel

Seed quality

Onion-seeds are smaller in size with irregular shape and black seed-coat. Seed viability and vigour is retained up to one year, and afterwards it reduces drastically. Seed-coat is very thin and endosperm is too little. During storage, if not packed properly, seed-coat absorbs moisture and seed germinates and thus looses viability. Seeds when not dried properly to appropriate moisture level (6–8%), fail to germinate. The quality standards for onion-seed are given in Chapter 10.

Constraints in seed production

Isolation distance

Onion is 100% cross-pollinated crop, being protandrous in nature. It requires more than 800 metres isolation distance for truthful seeds and more than 1,500 metres for breeder seed production. Maintaining such an isolation distance in the main seed-production area is a problem. In known and potential seed-production areas, many agencies organize seed-production programmes with more than 3 or 4 varieties of different colours and seasonal suitability. Thus, maintenance of purity is a big challenge. Any good variety if multiplied under such a situation is likely to get 100% contaminated.

Suitable seed-production areas

For onion-seed production, moderate sunny days with 4–14°C night and 18–25°C day temperature are required during flowering and seed-setting. After seed-set, seed maturity and seed drying requires higher day temperature. Pollination is mostly by honey-bees alone, which are active at 18 to 30°C. Therefore, all-over India, onion-seed production is restricted to winter only. Highly humid and warm areas are also not suitable for onion-seed production. Further areas likely to suffer from hailstorms and rains during March–April are also not suitable. These regions pose problem of *Stemphyllium*-blight and downy mildew. Best suited areas for onion-seed production are: Saurashtra in Gujarat; Nashik, Pune, Ahmednagar, Satara and Marathwada in Maharashtra; Khargone, Indore, Dhar in Madhya Pradesh; Jaipur, Chittargadh, Udaipur and Sriganganagar in Rajasthan; northern Karnataka; and Kurnool in Andhra Pradesh. These areas are cool and dry with good honey-bees activity, and seed yields are comparatively high.

Inadequate storage facilities

Onion-seeds loose viability quickly under ordinary packing and storage. But, neither seed-producing agencies nor farmers have adequate and suitable bulb handling and storage facilities. Seeds remain in good conditions up to 3–4 years in cold storage. However, cold storage facilities in strategic seed-production areas are not available. Seed drying at very low moisture (6–8%) and storage at low temperature with CO_2 and good quality packing improves storage of onion-seeds. Studies indicated that cold storage at 15°C and 45% humidity enhanced storage life of seeds up to three years. Packing in 400-gauge polythene bags and cold storage are recommended for long-term storage. Onion-seed production is always affected by hailstorms and untimely rains in major production areas. So, there is a need to have bufferstock at least with public sector undertakings. This will keep spurious seeds away from production chain.

Lack of awareness about seed-production technologies

Farmers produce seed on their own without following proper isolation distance. Seed-production practices followed are also sub-standard, which result in poor quality seed production. Identification of new seed-production areas and a whole package of practices for seed production are required.

Reduction in bee activities

Honeybees are the main pollinators of onion. Due to pollution, over use of pesticides, and sudden change in temperature, their activity is reducing day by day. This reduces seed yield by almost 50%, despite good agronomy practices and production technologies.

Poor seed replacement rate

Country's 80% seed is being produced by farmers and small traders, who organize their seed-production programme with farmers' help. Farmers and traders produce seed of their own genetic-stock maintained without scientific upgradation and improvement. Many times small traders purchase seed bulbs from the market and supply to farmers for seed production. These bulbs are available at cheaper rate than breeder or certified bulbs, produced by research organization. Seed production at a lower cost of local genotypes is the main reason for slow replacement. Further, onion-bulbs are planted for seed production in November and December, when price of onions is very high in the market. And farmers opt out for selling their best bulbs at higher premium, and thus small and rejected bulbs are used for seed production. There is high cost involved in storage of bulbs from April to December, especially of *rabi* varieties. Any seed company or a public sector, who is involved in seed production over thousands of acres, needs to store huge bulb-stock nearly for six months. This would definitely increase overheads and thus cause an impediment in faster seed replacement of new varieties.

Research organizations do not have infrastructure to produce enough breeder seed of released varieties; besides strict regulations delay proposals for notification by central as well as state governments. There is a time lag of 5 to 10 years between identification for release and notification of varieties. Research institutes lose their interest and the release of a variety ends up only an academic record. Private seed dealers many times purchase breeder seed and change variety nomenclature; this affects realization of the impact of the varieties released by research organizations. In short, seed-production chain is not being monitored in a holistic manner by all stakeholders, resulting into slow rate of replacement of varieties. The notification for registration under the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) for the onion would solve this problem.

Hybrid onion, far from reality

Heterosis for onion was reported much earlier than many other vegetables. Yet its exploitation in onion is lagging behind tomato, cole-crops, melon and many other vegetables. Onion research workers are divided on this issue. Many researchers think that hybrids do not excel in yield and other characters than open-pollinated varieties. However, the supporters are of the opinion that there is good amount of heterosis in onion for yield, uniformity in colour, shape, size and maturity. Private sector is promoting hybrids; whereas public sector is still with open-pollinated varieties. For quality seed supply chain management, hybrids can play a significant and an important role, and therefore hybrids should be promoted. Non-availability of male sterility in different backgrounds of colour and maturity groups and their maintainers is the main impediment for production of hybrid onions. Maintenance of three parental stocks and slightly higher technique involved in hybrid onion-seed production is also an important reason for non-spread of hybrids. However, there is much scope for promotion of this technology to produce potential hybrids for increasing yield, quality and earliness.

Export of onion-seed

Many countries in the world, especially South-East Asian and African countries, grow onions on a commercial scale, but they are not able to produce quality seed owing to climatic unsuitability. India is at advantage in this regard. India exports about 500–700 tonnes of onion-seed annually. There is increasing demand for onion-seed but in the absence of definite policy, spurious seed and unfair trade are increasing. In fact, we can take up the customized seed production of varieties and hybrids for many international seed companies; where Indian farmers show no interest.

Policy issues

Central Government becomes sensitive about onions only when their prices shoot up in the domestic market. Under, such a situation only and easiest way appears to ban export, whether effective exports are happening or not. Following issues need to be addressed with proper perspective.

1. There should be a regular national policy on production plan, storage and export of onion-bulbs and seed. There is a need to assess demand of seeds based on the demand of onions for domestic as well as export market. There is a need to set-up policy for phasing out old varieties and their replacement with new varieties by 50% during next 10 years. Advance planning for breeder, foundation and truthful seed production should be done as is done for cereal crops.
2. There is a need for creation of cold storage facilities for seed bulbs as well as onion-seed in strategic production areas. Seed processing and packing units are also important.
3. Ministry of Agriculture, research organizations and seed production companies should join hands for identifying variety specific seed production areas to do away with the burning problem of isolation distance vis-à-vis quality seed production.
4. Seed-village concept needs to be developed and implemented under the NHM programme. One village one variety will help in quality seed production.
5. Activating and enforcing quality control mechanism from every State Government is highly essential in production and supply of quality seed. Many traders sell seed without labelling. All district seed officers and quality control officers need rigorous training in this regard.
6. There should be a regular mechanism for training farmers and seed-production agency personnel for quality seed production.
7. Bee-keeping and maintenance of beehives during the seed production must

be an integral part of onion-seed production. There should be a subsidy component in the seed-production programme.

8. Export of onion-seed should be well thought of, and an official channel should be opened by the Government to cut down supply of sub-standard and spurious seed. Otherwise this will cut-down export of seed in the long run. The licensing policy should encourage quality seed production for domestic as well as export markets.

Future Strategies

Availability of onion-seeds with good genetic and physical qualities is a big problem, which is resulting in yield reduction and unavailability of quality onion-bulbs in India. Government has to solve these problems and needs to formulate strategies to improve availability of good quality seeds. In general, onion prices are highly fluctuating, sometimes very high and sometimes very low. Role of Government becomes very important to balance onion prices with good strategy and policies for stable pricing round-the-year. This can be achieved by establishing good onion-bulb storage facilities in onion-growing areas. Ban on export needs to be minimized, and if possible removed.

Fungal Diseases

12

S.J. Gawande

Onion (*Allium cepa* L.) is known to be affected by 66 diseases that include 14 bacterial, 40 fungal, 6 nematode, 3 viral, 1 phytoplasmal disease and 1 parasitic plant, and 7 miscellaneous diseases and disorders (Schwartz and Mohan, 2008). From India, 29 fungal, 3 viral and 4 bacterial pathogens were recorded on the onion-crop (Gupta *et al.*, 1994). These diseases cause production and storage losses up to 50% annually depending upon the location, environment, host cultivar and pathogen involved (Srinivas *et al.*, 2007). Apart from the direct production losses, these pathogens reduce marketable quality significantly. Anthracnose, purple-blotch and *Stemphylium*-blight cause extensive crop losses, and are important throughout the onion-producing areas. Fungal diseases such as purple-blotch cause yield reduction up to 50% in seed-crop of onion (Anonymous 1986). There are a few diseases of local importance such as downy mildew in temperate zones, Jammu and Kashmir and Uttarakhand in India. Pink-root and *Fusarium* basal-rot have significant impact on reducing onion yield in the country.

Economic losses due to diseases vary significantly across three seasons. *Kharif* onion suffers heavily, and losses reach as high as 50–60%, followed by 20–30% in *rabi* and losses are least in late *kharif*. Although, *kharif* onion share in the total onion production is lesser (up to 20%) still this has significant impact on market stabilization as it fills the gap during October to December when supply from *rabi* stored onions depletes. Thus disease management in *kharif* onion is very important to ensure continuous supply of onions in the market. Disease management during late *kharif* and *rabi* seasons is important to maximize yield potential. Precise knowledge about pathogens infecting the crop is the key to devise effective management strategies. No stable source of host resistance in Indian short-day onions against major diseases has been recorded or reported. It compels to resort only to chemical methods of disease control. However, disease management through chemicals is not only costly but also it is hazardous besides polluting environment.

Purple-blotch (*Alternaria porri* (Ellis) Cif.)

It is a pandemic disease, known to cause up to 80% yield losses in India (Yadav *et al.*, 2013). The disease has been observed throughout the world, but is most serious in hot-humid climates. Apart from onion, the pathogen attacks other members of *Allium* family including Egyptian onion (*A. proliferum*), Welsh onion (*A. fistulosum*) and leek (A. *ampeloprasum* var. *porrum*) (Shref and MacNab, 1986). The name 'Purple-blotch' was proposed by Nolla (1927), who named its causal fungus as *Alternaria allii* sp. nov., which was later changed to *Alternaria porri* (Ellis) Cif. In India, it was first reported by Ajrekar (1921) from Bombay (now Mumbai) as *Macrosporium* sp. In the following years, he further studied the disease, and reported causal organism as *Alternaria* sp., which was later confirmed to be *Alternaria porri* (Pandotra, 1964).

Symptoms: They are prominently seen on leaves, scape and pseudostem as small, white, oval sunken spots/lesions with well-defined margins between the infected tissue and healthy part of the leaf/scape (Fig.12.1b). The lesions expand to become zonate and turn brown to purple surrounded by a broad chlorotic spot that extends upwards and downwards for some distance. The lesion margins have often shade of purple to reddish brown colour (Fig.12.1a, c). Under humid conditions, surface of the lesion gets covered with brown to dark grey fungal sporulation. In advanced stage, lesions may coalesce to form larger spots, leading to girdling of leaf/scape, which results in necrosis or death of plant. There is a significant reduction in yield and quality of produce in the infected plants. Severe disease symptoms on the older leaves were attributed to their low sugar content (Horsefall and Diamond, 1957).

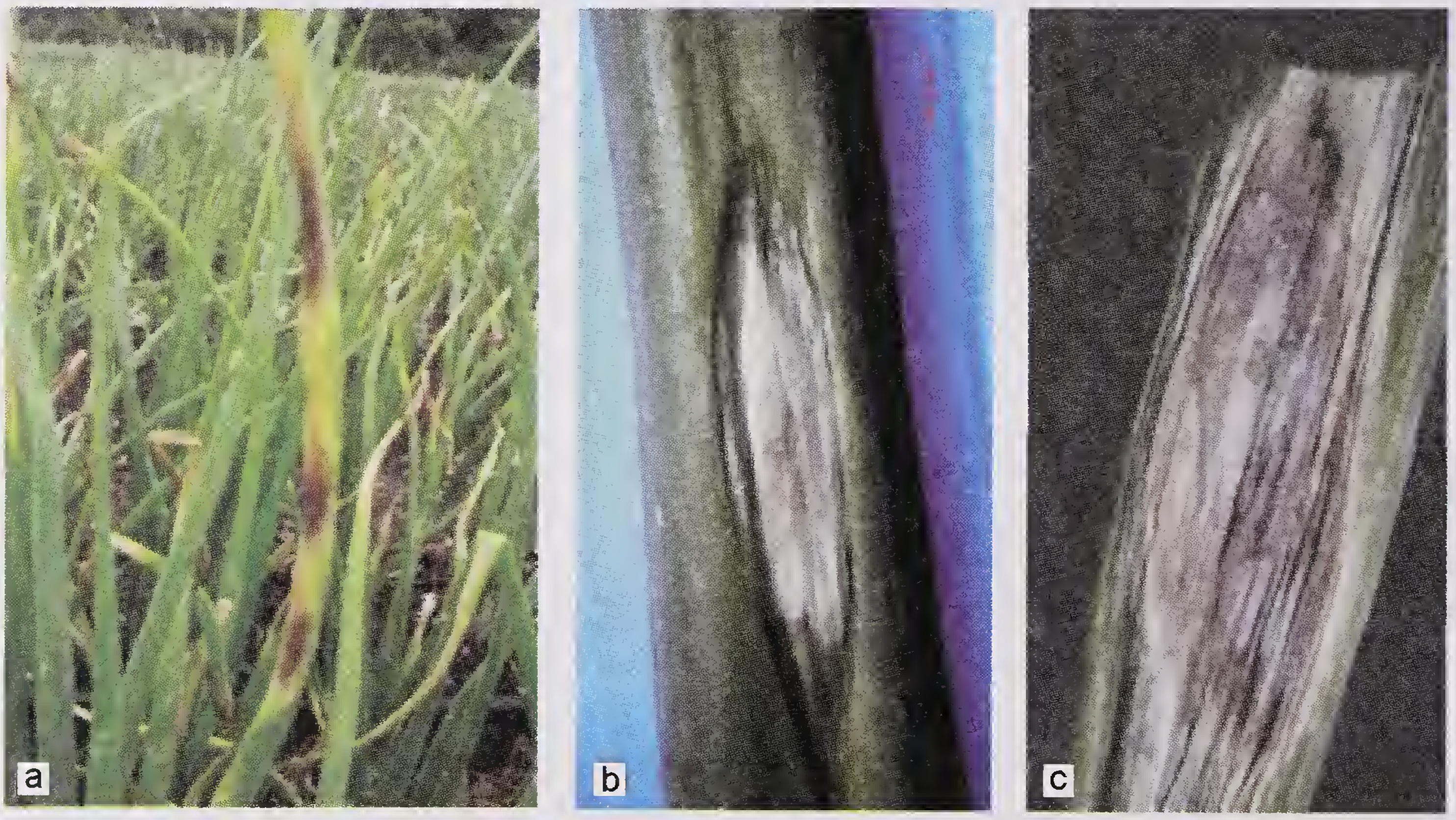

Fig.12.1 (a) Symptoms of purple-blotch. (b) Initial white oval sunken spot with well-defined margins. (c) Purple-blotch in later stage when lesions turn purple

In most of the cases, fungus invades through neck, but sometimes it may enter into bulbs through wounds on fleshy scales. Purple-blotch on bulbs are characterized by semi-watery rotting of bulb-neck, which later turns yellow to red. The fungus secretes pigments profusely through scales in the advanced stages. Because of it, bulb tissues become desiccated and eventually dry and become papery.

Causal organism and pathogen biology: *Alternaria porri* (Ellis) Cif. is a dematiaceous fungus, of class Hypomycetes. Its conidiophores arise singly or in group and are straight or flexuous, sometimes geniculate, septate and pale to medium brown (Aveling *et al.,* 1994), 120 μm long and 5–10 μm thick with one or several well-defined conidial scars. Conidium borne singly is straight or curved, obclavate (the body of the conidium may be ellipsoidal), and it tapers to a beak that is commonly about the same length as or slightly larger than the body of the conidium. Conidia are pale to golden-brown, are smooth or minutely varicose, overall length measures about 100–300 µm, and thickness in the centre is 15–20 µm. Conidia contain 8–12 transverse and zero to several longitudinal or oblique septae, and a pale, tapering beak of 2–4 µm thick. Till date no sexual stage is known. Conidiophores are borne singly or in groups on lesions. Dark olivaceous, long, multicellular conidia are produced at conidiophore tips. Conidia may repeatedly form on lesions with alternating cycles of low and high relative humidity. The fungus can grow at a temperature range of 6–34°C. But, the optimum temperature for growth is 25°C, and the growth is slower below 13°C. For sporulation, relative humidity of 90% or higher is required. Conidial initials are formed after 9 hr, septa develop after 12 hr, and fully mature conidia appear after 15 h of dew (Ellis, 1971). Conidia formed during dew period of 12 hr or less cause flecks and typical lesions are formed when dew duration is 16 hr or more.

Normally, sporulation takes place during night under high relative humidity. Since during day, humidity decreases, hygroscopic movement in the conidial apparatus causes detachment of mature conidia. Secondary spread of disease is through rain, sprinkler irrigation, spraying, or wind, which increase the release and spread of conidia.

When conidia land on susceptible onion tissues and germinate, germ tubes can invade tissues through wounds or stomata or can directly penetrate epidermis (Skiles, 1953). Susceptibility of onion-leaves to infection by *A. porri* is influenced by plant age, season, foliage architecture, and injuries caused through thrips and mites. Other factors that aggravate purple-blotch are moisture stress and excess moisture in the soil. Disease incidence and severity varies with year and season. At Pune, India, the peak incidence of purple-blotch was observed during October to January.

Management strategy: Follow clean cultivation and long crop rotation with non-host crops to break disease cycle. Preferably use raised bed for growing onion for proper drainage. Avoid sprinkler irrigation as it may help spore dispersal. Reduce plant density by using 15 cm × 10 cm spacing, which helps reduce infection. Hot-water soaking of onion-seed (50°C for 20 min) is also advised. High rates of calcium, phosphorus and potassium fertilizers reduce possibility of infection but increased nitrogen fertilizers enhance disease infestation. Application of *Trichoderma viride* (1,000 spores/ml) helps manage the disease. Onion-leaves are increasingly susceptible to *A. porri* as they age, and emerging leaves at the bulb maturity stage are more susceptible. Purple-blotch is increasingly difficult to be managed as bulb approaches maturity. Foliar sprays of Mancozeb @ 0.25%, Tricyclazole @ 0.1% and Hexaconazole @ 0.1% at 30,45 and 60 days, respectively, after transplanting help checking disease incidence/spread. Varieties such as Red Creole and Kaharda were reported resistant to purple-blotch in Nigeria (Abubaker and Ado, 2013). In India, onion line PBR 287 was reported to be resistant and genotypes, Arka Kalyan 704 and MS 65-268 from the IIHR, Bengaluru, were moderately resistant to purple-blotch.

Stemphylium leaf-blight

This disease has come to prominence throughout the world since the last 20 years. Its outbreak caused significant losses in Texas and New York in North America (Miller *et al.,* 1978; Lorbeer 1993). The disease was also recorded from Europe, Africa, North and South America (Ellis, 1971). It is a major disease of onion in South-east Asia and India. It was first reported in India from Varanasi by Rao and Pavagi (1973) and later has been reported all-over India (AINRPOG Report, 2013). It occurs frequently at the same time and on the same plants as *A. porri,* the cause of purple-blotch, forming disease complex.

Symptoms: Small, light yellow to brown to purple, water-soaked lesions appear. These lesions elongate, become spindle-shaped to ovate-elongate, and turn into diffusive spots, often extending to leaf tips. The spots frequently coalesce into patches blighting leaves. As conidiophores and conidia develop on the lesions, they turn light brown to tan purple at the centre, and later to dark olive-brown to black (Miller *et al.,* 1978). Similar symptoms may also occur on the scape of onion (Fig. 12.2a,b). Perithecia may appear in blighted areas of leaves and scape as small, black, pinhead like raised bodies.

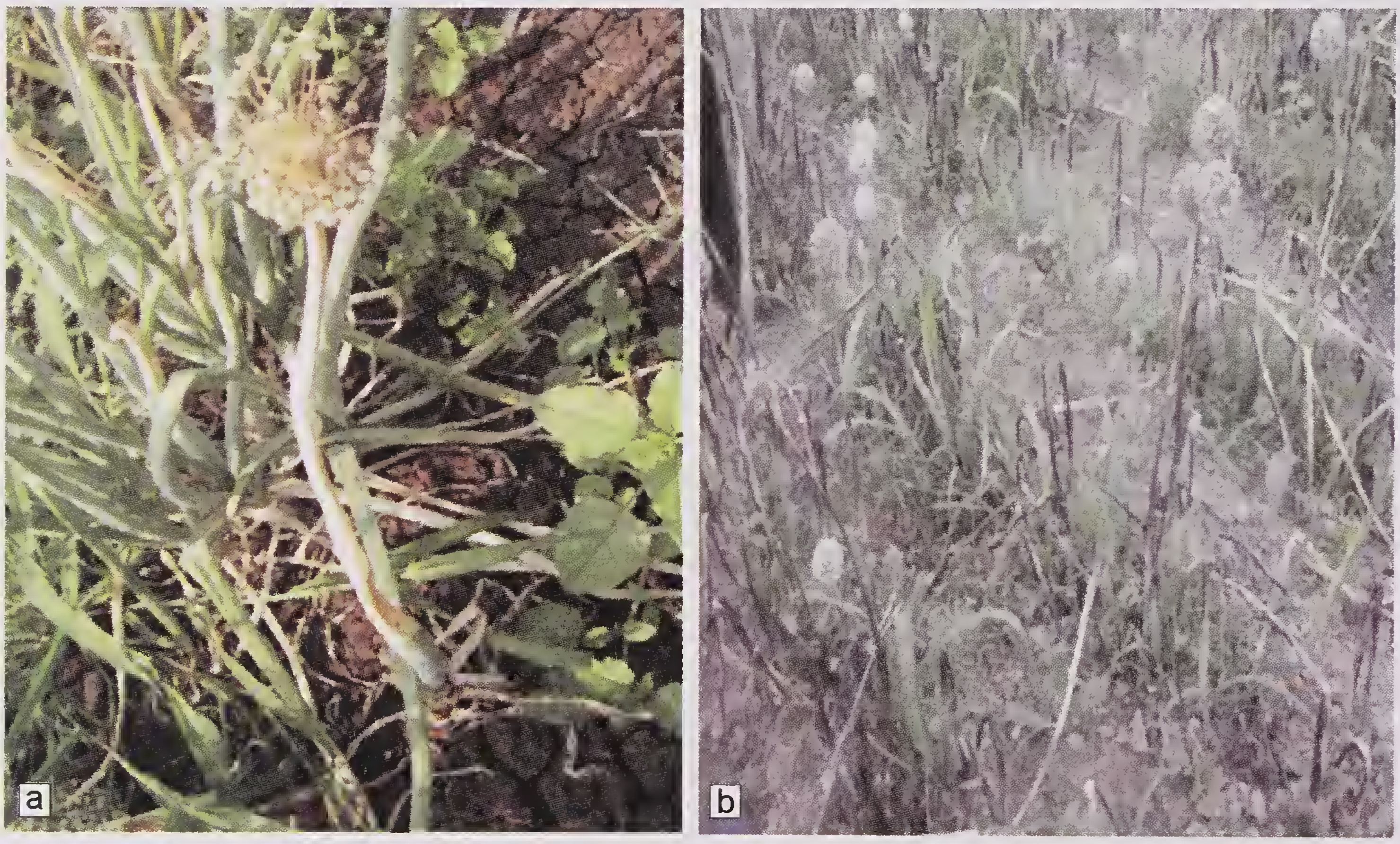

Fig.12.2 (a) Symptoms of *Stemphylium*-blight on scape of onion. (b) Severely affected onion-seed production plot by the blight

Besides, above symptoms, the pathogen also forms yellow mottle lesions (Misawa, 2008a), characterized by bright yellow mosaic-like symptoms, ranging from 0.5 to 4 cm in diameter on the inner leaves (Misawa, 2008). These symptoms are distinct, and there are no intergrades between them.

Perithecial stage appears in isolated locations, and is more prominent on the onion scape. The pathogen enters normally through dead or dying tissue like leaf tips, purple-blotch lesions and insect injuries, causing minimal foliage damage. Under wet conditions for about more than 24 hr, conidial inocula multiply and cause minute lesions, which later coalesce and may cover entire leaf.

Causal organism and disease biology: *Stemphylium vesicarium* (Wallr.) Simmons causes *Stemphylium* leaf-blight in onion. The perfect stage of fungus is *Pleospora allii* (Rab.) Ces and de Not. Its conidia are oblong or broadly oval and sometimes are equilateral. Conidium has 1–6 transverse septa, measures about 12–22 × 25–42 μm and is light or medium golden brown to olive brown. It has conspicuous basal scar-like zone up to 7 μm in diameter surrounding small spore. Its external walls are conspicuous and densely verrucose at all ages.

Conidiophores measure 5–8 × 33–47 μm; are straight to variously curved; are simple and occasionally branched; are cylindrical but enlarging apically to the site of conidia production; are light yellow-brown or olive-brown, dark to medium golden-brown at the swollen apex; and are smooth throughout, except sparsely punctuate roughened on the apical cell. They have one to four septa, and their apical cells are swollen or distinctly flared to 7–9 μm in diameter (Fig.12.3). Apical sporiferous cells have a single pore (4–7 μm in diameter) and as many as five apical proliferations (Ellis, 1971).

Fig.12.3 Conidia of *Stemphylium vesicarium*

Perithecia of *S. vesicarium* mature in 3–6 months. Mature asci are 25–170 μm, narrowly cylindrical to clavate, tapering to knob-like base. Ascospores are ellipsoidal initially with upper part tapering narrowly. They become distinctly constricted at the three transverse septa by the time longitudinal septa are produced. The base of the ascospore becomes broadly rounded and remains so in maturity; the apex of the spore develops an obtusely pointed appearance that is maintained in maturity. Mature ascopore measures 18 μm × 38 μm, and has seven transverse septa. Its wall colour deepens from an initial pale-yellow to a final translucent yellow-brown.

Infection usually remains confined to leaves and does not extend down to scales of the bulbs. Lesions generally occur on the side of the leaf facing the prevailing wind. The pathogen is necrotrophic in nature, and normally invades dead and dying onion tissues—necrotic leaf tips, purple-blotch and downy-mildew lesions, injured tissues and senescent tissues. The fungus can be isolated from necrotic leaf tissues at most growth stages; however, serious leaf damage is apparent only after long, warm periods of leaf wetness. If rains continue for more than 24 hr, population on leaf surface may reach 200 conidia per square centimetre, and the minute lesion caused by each conidium coalesces to form larger lesion, ranging from 1 cm in diameter to that covering entire leaf (Maude, 1990).

Management strategy: The disease can be effectively minimized by following practices.

- Follow crop rotation with the non-host crops such as cabbage, cauliflower and mustard.

- Clean the cultivation by destroying plant debris of the previous season.
- Provide good field drainage by using raised beds, and reduce plant density, as stress triggered oxidative process attracts *Stemphylium*-blight incidence.
- Drip irrigation should be used over conventional irrigation to avoid spore dispersal and resultant disease outbreak.
- Hot-water soaking of onion-seed (50°C for 20 min) is recommended (Aveling *et al*., 1993).
- Welsh onion lines, TA104, TA108, TA198, AF468 and TA204, are moderately resistant to *Stemphylium* leaf-blight (Pathak *et al.,* 2001).
- Bioagents such as *Bacillus subtilis* at 10^8cfu/ml and *Saccharomyces cerevisiae* at 4×10^4 cfu/ml could effectively control *Stemphylium* blight to 53.49 and 51.23%, respectively, as compared to chemical fungicide Ridomil, which had 69.87% efficacy (Hussein *et al*., 2007).
- Application of salicylic acid (5mM) reduced disease up to 40% under controlled conditions (Kamal Abo-Elyousr *et al.,* 2009).
- Foliar sprays of Mancozeb @ 0.25%, Tricyclazole @ 0.1% and Hexaconazole @ 0.1% at 30, 45 and 60 days after transplanting effectively managed disease.

Anthracnose/Twister (*Colletotrichum gloeosporioides* (Penz.) Penz.& Sacc.)

The disease was first recorded during 1924–1925 in the eastern and northern part of Puerto Rico (Nolla, 1926). It has been reported from Africa, Brazil and Asian countries. Aquino and Wanderley (1966) reported anthracnose as "Seven Curls", a serious disease in Brazil. Due to this disease, 50–100% losses in yield were reported (Ebenebe, 1980).

In India, it is predominantly observed in *kharif* onion-crop. It was recorded for the first time in 1981 from Lonand area of Satara district in Maharashtra. It was observed during 1982 and 1983 on crops grown in Nashik and Pune districts, and was reported from Karnataka in1987 (Qadri and Shrivastava, 1985; Quadri, 1988).

In the past, there was controversy regarding etiology of twister disease symptoms. Asif *et al*. (1976) and Viets (1967) reported that symptoms were due to zinc deficiency or virus/mycoplasma infection. Robbs *et al*. (1972) reported *Fusarim oxysporum* f. *cepae* as the causal organism for these symptoms. Finally, Ebenebe (1980) conclusively proved *Colletotrichum gloeosporioides* as the causal organism of twister disease.

Symptoms: Initially white sunken-oval lesions appear, which turn into pale-yellow water soaked spots in the later stages. Spots expand to cover whole leaf as the disease progresses. Besides lesions on the leaves; abnormal elongation and twisting of the pseudostem, i.e. neck of bulb is noticed (Fig.12.4 a, b) (Chawda and Rajasab, 1996). In the advanced stages of disease, plant bends from the pseudostem.

Water-soaked spots extend up to bulb as disease advances. On these spots, numerous black coloured raised structures of acervuli are produced in concentric rings—characteristic morphological symptoms (Fig.12.4 d,e) (Nolla, 1926). Tiny oval whitish spots grow on the leaves and extend to bulb scales.

The symptoms appear initially in patches in the field where water stagnates—

low laying area in the field, near field trenches, near drip and sprinkler irrigation points. These patches grow, and finally cover the whole field. The progress of the disease depends upon the frequency and intensity of rainfall; the intensity is higher in heavy soils than light soils.

There is a secondary infection of saprophytes in bulbs of affected crop, which gives rise to rotting and substantial reduction in quality of bulbs. In the severely affected crop, there is no bulb formation (Fig. 12.4c). In India, since seed production is carried out during *rabi* season (Nov–Mar), anthracnose symptoms are not recorded on the onion-seed crop. But, incidence on the seed crop was observed in many other countries (Ebenebe, 1980; Chawda, 1992).

Fig.12.4 (a,b) Long neck and twisting symptoms of anthracnose. (c) Severely affected onion plot by anthracnose/twister. (d,e) Concentric rings formed by acervuli of *Colletotrichum gloeosporioides*

Causal organism and pathogen biology: *Colletotrichum gloeosporioides* (Penz.) Penz.& Sacc. (Teleomorph: *Glomeralla cingulata* (Stonem) Spauld. & Von Schrenk) causes anthracnose in onion. The fungus survives in plant debris and spreads through seedlings and onion-bulbs. However, seed-borne nature of the pathogen has also been reported (Boff *et al.,* 1995). The progress of the disease depends upon the intensity, quantity and frequency of rainfall. Dispersal of conidia occurs from soil to lower leaves to the neck of the onion-bulb by rain splashes (Rajasab and Chawda, 1994). The pathogen normally infects plant from the inoculum in the soil. Conidia germinate and infect onion tissues under high humidity and temperature of 23 to 30°C.

The secondary spread of inoculum is through rains and wind, which results in a more uniform distribution of infected plants in the field. The fungus may persist on seeds, debris and alternative host. Insects and irrigation water can also spread the pathogen. In the perfect state, dark brown to black perithecia (85–300 μm in diameter) bear eight spored asci (8–14 μm ×35-80 μm). Ascospores are hyaline oval to cylindrical, unicellular and sometimes slightly curved (Fig. 12.5). They may become faintly brown and unisepted prior to germination. In imperfect state or telomorphic stage, acervuli may form on the necrotic areas of the host. The hyaline conidia (3–6 µm × 9–24 µm) are cylindrical with obtuse ends, aseptate and uninucleate. Conidia are formed on the unicellular, hyaline or faintly brown, cylindrical, phialidic conidiophores. Grayish white to dark gray colonies develop on potato dextrose agar. Perithecia may form in culture.

Fig. 12.5 Ascospores of *Colletotrichum gloeosporioides*

The peak incidence of anthracnose at Rajgurunagar (Pune, India) was observed during August–September, when humidity is around 75–90% and rainfall averages 36 mm/week (Fig. 12.6).

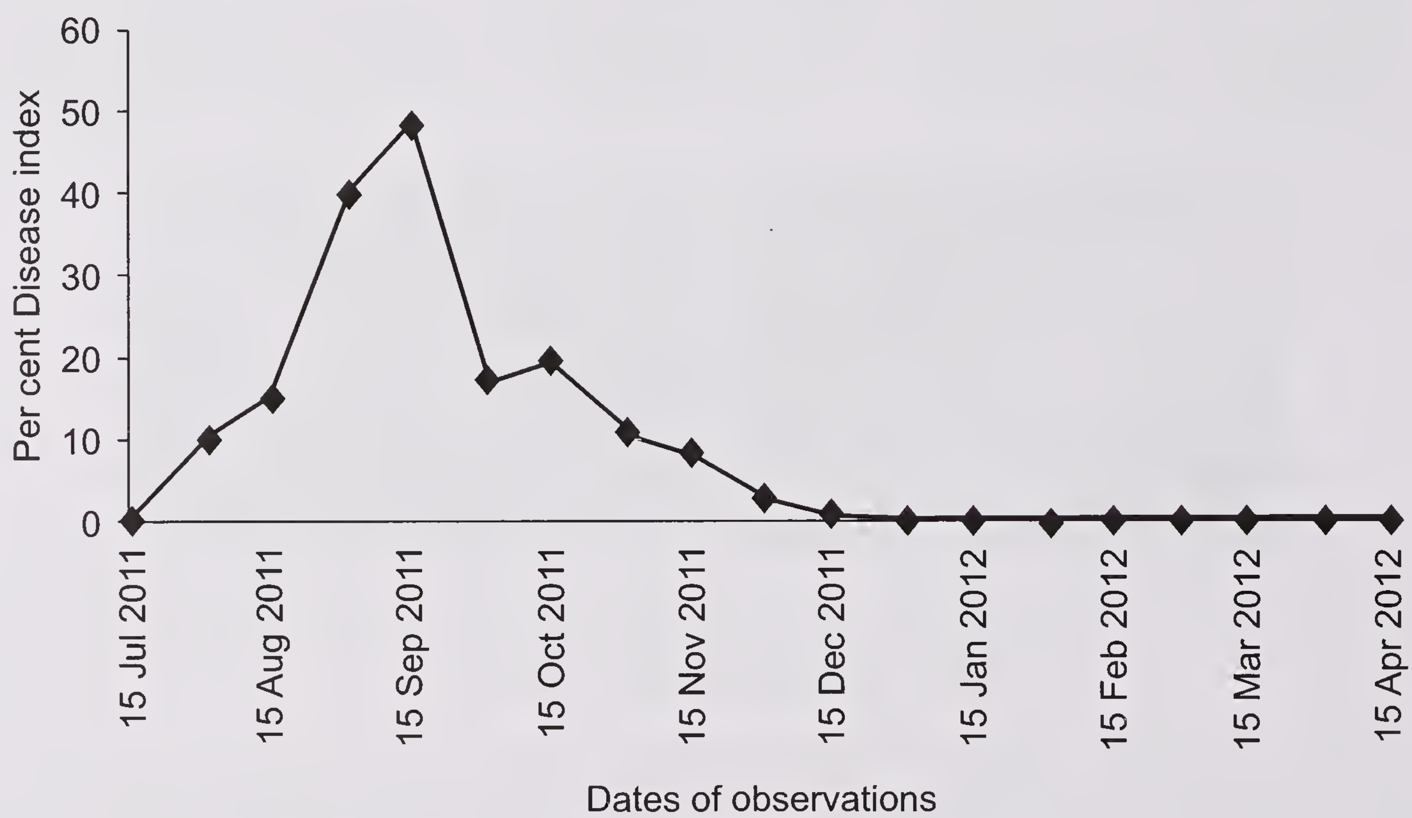

Fig. 12.6 Severity of anthracnose on onion at different dates in 2011–12

Management strategy: The control measures usually adopted are as follows.

- Clean cultivation, removal of debris from the previous crop, and 3–4 years crop rotations to minimize inoculum load in the soil.
- Growing of onion on the raised beds drains out excess water in the field and thereby avoids water stagnation, which ultimately results in checking disease incidence.
- Cultivation of disease-tolerant cultivars like Bhima Raj and Red Creole is recommended.
- Biological control agents such as *Trichoderma viride* @ 1,000 spores/ml can be effective to some extent.
- Application of Benomyl at 0.2% as soil treatment is recommended.
- Seed treatment with Bavistin @ 0.1% is recommended.

- Foliar sprays of Mancozeb @ 0.25%, Tricyclazole @ 0.1% and Hexaconazole @ 0.1% at 30, 45 and 60 days, respectively, after transplanting checks disease incidence/spread.

Downy mildew (*Perenospora destructor* (Berk.) Casp.)

This disease is widely distributed on all continents, particularly temperate areas of the world. The pathogen was first described by Berkeley in the later half of the 19^{th} century from the UK. Downy mildew is reported from most onion-producing regions of America, Africa, China, Europe, and Japan. In cool and humid weather, the disease can be highly destructive, causing losses in both yield and quality. This disease affects many wild and cultivated species of *Allium*, including onion, chive and shallot. In India, downy mildew was first reported by Mir (1977), and it is still limited to Jammu and Kashmir and Uttarakhand, where considerable losses were recorded.

Symptoms: The disease commonly starts in patches in the field, and spreads to the surrounding areas. Symptoms are found most readily by examining older leaves in the morning, while dew is still present. Elongate patches (3–30-cm long) may appear on leaves, which are slightly paler than the rest of the leaf area or which have turned light tan to brown, and may be confused with initial lesions of purple-blotch. A grayish-violet, furry growth may be visible on the surface of the leaf or seed-stem during moist periods.

Affected leaves gradually become pale-green, and later yellow, and diseased parts, such as leaf tip, folds over and collapse. Sporulation on these lesions produces thick grey to purple belt of conidiophores. Under unfavourable climate, lesions are restricted to non-sporulating white-spots on the foliage. Lesions on the seed stems are circular or elongate, often affecting only one side of the stalk. They weaken stalk and it breaks over with the weight of the seed-umbel, thereby resulting in shrivelled seeds. The pathogen also may infect flower parts and may be carried with seeds. After a period of storage, infected bulbs become soft and shrivelled, and their outer fleshy scales become partly or wholly amber in colour, wrinkled and watery. Other infected bulbs may remain firm and sprout prematurely. Plants developing from such bulbs can be detected by their light-green foliage.

Pathogen and disease biology: Downy mildew is caused by *Perenospora destructor* (Berk.) Casp. The fungus is a phycomycete with aseptate mycelium and asexual monopodially branched sporangiophores, which bear fusiform to pyriform sporangia. Sporangia germinate by one or two germ tubes. Sporangia are pyriform to fusiform, attached to sterigmata by their pointed end and measure 40 to 72 μm × 18 to 20 μm. The sporangiophores are aseptate, 122 to 820 μm in length; swollen at the base to a diameter of 7 to 8 μm. Branching is dichotomous. Sterigmata are sub-acute or acute. The coenocytic mycelium is intercellular with filamentous haustoria. Oogonia are formed in intercellular spaces.

The main infection source for seed-production crop is systemically affected onion-bulbs. Leaves of overwintering plants also carry the disease, on which sporangia are produced, and these spread to infect spring-sown onions. The fungus may also over-winter as oospores, and decaying onion tissues may release oospores into the soil thereby increasing inoculum potential. It is reported that mycelium may invade onion-seeds. However, seed does not seem to be a significant source of pathogen.

The pathogen overwinters in volunteer onion-plants as oospores and also persists from one year to another as mycelium in infected bulbs (in storage) and seeds. The oomycetes possess both asexual (lemon-shaped sporangia) and sexual stage (think-walled oospores), both of which can infect growing plants by being blown or splashed from the soil, respectively.

Pathogen requires cool conditions (less than 22°C) to infect along with water film on the leaf surface or relative humidity greater than 95%. A few hours of dry, sunny weather can dramatically impede disease progress. The infection cycle is characterized by long latent periods of 9–16 days and 1 to 2 days of sporulation, dispersal and infection. Spores are produced at night and dispersed during the day responding to varying environment conditions. Dispersed spores survive on the host leaves for 1–3 days. Duration of spore survival depends on the temperature, relative humidity and absence of intense radiations. The fungus may destroy the onion-foliage in the field almost completely within four infection cycles.

Management strategy: Mildew contaminated onion-sets should not be planted. Rotation schedules that exclude *Allium* crops for more than 3–4 years should be followed. Well-drained land should be used. Rows should be planted in the same direction as the prevailing wind. Dense population of plants and wind-breaks or other protection should be avoided. Surface and drip irrigation rather than sprinkler irrigation are to be preferred. Various disease forecasts systems of sporulation and infection period are available internationally, and include DOWNCAST, ONIMIL, and MILIONCAST (De Visser, 1998; Battilani *et al.,* 1996; Gilles *et al.,* 2004). Infected crop debris should be destroyed after harvest to eliminate inocula, and refuse heaps of onions culled from storage should be removed. *A. roylei* possesses resistance for downy mildew (Kofoet and Zinkernagel 1990). Onion lines, IC 48045, IC 32149, IC 49371 and DOP 2 have been reported to be resistant to downy mildew. For eradication of mycelium in bulb destined for seed production, direct heat treatment for 4 hr at 41°C was proposed (Yarwood, 1943).

Foliar application of diathiocarbamate fungicides, Zineb, Mancozeb and Maneb/ Zineb mixtures control onion downy mildew (Newhall and Rawlin, 1952). Spraying Mancozeb @ 0.25% and Ziram @ 0.1% at 10–12 days interval is recommended. Bulb and seedling dip in Ridomil MZ @ 0.25% for 12 h, followed by 2 foliar sprays of the same gives effective disease control.

Other Diseases of Minor Importance

Damping-off

This is a serious disease in nurseries and in areas of intensive production of direct-seeded onions.

Symptoms: This disease results in seed-rotting, pre-emergence damping-off and post-emergence damping-off. In pre-emergence damping-off, younger seedlings are killed before their emergence from the soil. They may, in fact, be killed even before hypocotyl has come out of the seed-coat. Radicle and plumule, when come out of the seed, completely rot. Post-emergence damping-off is characterized by toppling over of the infected seedlings any time after their emergence. It usually occurs at or below the ground level, and infected tissues appear soft and water-soaked. As the disease advances, stem becomes constricted at the base and plant collapses. The disease may appear in the field in roughly circular areas in which plants are killed. Later stunting and root-rot may occur.

Causal organism and disease biology: Many fungi are known to cause damping-off. *Pythium* species, *Fusarium* spp. and *Rhizoctonia solani* are pathogenic to onion seedlings. *F. oxysporum* and *F. oxysporum* f.sp. *cepae* cause delayed seedling emergence and damping-off (Davis and Reddy, 1932). *Colletotrichum circinans* causes damping-off in warm humid conditions (Shref and MacNab, 1986).

This disease is seed and soil borne. The pathogens persist in the soil in areas which are constantly under production of transplants. It is most severe under high soil moisture and temperature.

Management strategy: Soil solarization of nursery-beds with transparent polyethylene sheet for 30 days before sowing provides a good control (Srivastava and Tiwari, 2000). Agricultural practices that minimize periods of excessive soil moisture (crop rotation and land leveling, installing drains, sowing of clean and healthy seed on raised beds) are used to reduce infection. Overcrowding of plants or dense sowing of onion-seeds should be avoided. Well-decomposed farmyard manure should be used in the nursery.

Seed treatment with *Trichoderma viride* @ 4 g/kg of seeds, followed by soil application of *T. viride* mixed with farmyard manure at 500 g in 50 kg of the FYM/ha provides good control of damping-off (Srivastava and Tiwari 2000).

Damping-off disease can be effectively controlled by using protectant fungicides such as Thiram or Captan @ 0.35% as seed-dressing before sowing. Drenching of the nursery-beds should be done with Benomyl @ 0.25% in the standing crop.

Fusarium basal-rot (*Fusarium oxysporum* f.sp. *cepae*)

The disease is prevalent in almost all parts of the world. This also causes damping-off and wilting at seedling stage and bulb-rot in mature crop, accounting for 30–40% losses in storage.

Symptoms: Initially, there is progressive yellowing and dying back from tips of the leaves; aerial part may die in 1–2 weeks or decay may extend over much longer period. When disease appears above the ground level, decay has already taken place at the base. The roots may turn pink and gradually decay until the entire root system disappears. A semi-watery decay affecting fleshy scales starts from the base and progresses upwards with early infection and may be almost complete by the harvest time. White mycelium appears on the stem plate, and the later may show a brown discolouration.

Causal organism and disease biology: The basal-rot is caused by *Fusarium oxysporum* f.sp. *cepae*. The pathogen is commonly found in the soil, and its long-term survival is by means of chlamydospores. Incidence of disease appears to increase with injury of roots, stem plate or bulb by onion maggot (*Delia antique*) or other insects. Stress due to high temperature and drought leading to tissue damage, also increases disease incidence.

Management strategy: Crop rotation with non-host crops has been found effective in eliminating disease. Mixed cropping with tobacco and sorghum was effective in reducing the disease (Srivastava and Pandey, 1995). Good drainage, deep ploughing in hot summer and avoiding injury during cultural practices reduce disease incidence. Satisfactory control of basal-rot can be achieved by flooding soil in fallow season (Tanaka *et al.,* 1996).

Hybrid onion Spanish and Mustang showed resistance to bulb rotting after harvest. Girija *et al.* (1998) found three lines (IIHR 141, IIHR 506 and Sel 13-1-1) consistently resistant to *F. oxysporum* in field in different growing seasons. Stadnik and Dhingra (1997) reported Bola Precoce, Roxa de Barreiro, Crioula, Texas Grano 502, Roxa IPA3, Monte Alegre and Pera IPA1 as resistant.

Trichoderma spp., *Pseudomonas fluroscence* and *Bacillus subtilis* have been found effective against *F. oxysporum* under *in-vitro* conditions (Rajendran and Ranganathan, 1996). Combined seed treatment of *T. viride + P. fluroscence* reduced onion basal-rot in pot and field conditions.

Dipping onion-sets in Benomyl, Carbendazim, Thiram and Dofolatan @ 0.2% controls pink root, basal-rot and neck-rot of onion. Spraying Carbendazim @ 0.1% at 30, 20 and 10 days before harvest gave lowest yield loss owing to decay after 5 months of storage (Srivastava and Tiwari, 1997).

Pink root [*Phoma* (*Pyrenochaeta*) *terrestris*]

It is mainly a field disease, affecting mainly growing plant but losses occur during transport and storage. Pink root often occurs in association with *Fusarium* basal-rot.

Symptoms: The affected roots turn yellow, shrivel and die, meanwhile taking on distinct pink colour. The new roots, which grow from the infected plants, are infected and become functionless. The disease is confined to roots only. The affected plants are generally not killed but bulb growth is retarded.

Causal organism and disease biology: The fungus *Phoma* (*Pyrenochaeta*) *terrestris* causes pink root. *F. solani* has also been reported to be associated with pink root rot (Mathur *et al.*, 2005). The pathogen persists in the soil and is distributed on onion seedlings, sets and garlic cloves. Dissemination also results from movement of spores, infected soil and plant residue by agricultural tools, wind and surface irrigation or through drainage water.

Management strategy: Some garlic lines and *A. fistulosum* are resistant to pink root. Cultivars reported to be pink-root resistant may not be resistant in all situations. Soil solarization reduces pink-root incidence. It has been observed that early sowing resulted in higher disease incidence than late sowing (Robinowitch *et al.,* 1981). Long rotations with non-host crops should be followed.

Many workers have reported soil fumigation and use of fungicides but it is uneconomical at the field level. After chemical control in field conditions, pathogen population gets reduced early in the season but reappears.

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Viral Diseases

13

K. S. Ravi, Muktha Raghuram and Mahesh Shekar

Viruses are one of the major constraints in onion production. A number of viruses, Iris yellow spot virus, Groundnut bud necrosis virus, Tobacco streak virus, Onion yellow dwarf virus, Allexivirus and Rymovirus, have been reported and among them, Iris yellow spot virus and Onion yellow dwarf virus are the common and the prevalent ones in major onion-growing regions across the world.

Iris yellow spot virus

The Iris yellow spot virus (IYSV) is an emerging onion disease, which was first reported from Treasure Valley, Idaho, USA, in 1989 (Hall *et al.*, 1993). Since then, it has also been reported from the Netherlands, Australia, Brazil, Chile, India, Israel, Japan, Peru, Spain and eastern and western parts of the USA. The widespread incidence of IYSV in seed and bulb production areas of the USA might have been by the natural infection of the wild relatives of the cultivated onion (Pappu *et al.*, 2006). In India, IYSV-infected onions were first reported in Jalna and Nashik regions of Maharashtra by Ravi *et al.* (2005).

Distribution: IYSV is widely prevalent in most of the onion-growing regions of the country—Maharashtra, Punjab, Haryana and others. High incidence of the virus was found in Maharashtra; it was up to 100% in Aurangabad, 90 to 100% in Chinchipur, Sangamner districts. In Tamil Nadu, its incidence was 80–100% in Dindigul and 12–20% in Viralapatti districts (Sivamani 2009 – Unpublished).

Causal organism: Iris yellow spot virus

Virus morphology: Genus: Tospovirus; Family: Bunyaviridae.It consists of enveloped quasi spherical particle, measuring approximately 80-120 nm in diameter.

Symptomatology: The disease has the following characteristics.

- Spindle/diamond-shaped chlorotic lesions on the leaves and the scapes (Fig. 13.1a).
- In advanced stage, chlorotic lesions coalesce and result in withering of leaves and scapes (Fig. 13.1b).
- Twisting or bending of flower-bearing stalks (Fig. 13.1c).
- Bulbs are affected with hay-coloured spots in advanced stage.

Symptoms on different host-plants: Kumar and Dhawan (2013) described its symptoms as follows.

- The IYSV produced local chlorotic ringspots; 3–6 days post-inoculation in *Nicotiana tabaccum* L. and *N. clevelandii* A. Gray.
- The chlorotic local lesions were produced on the inoculated leaves of

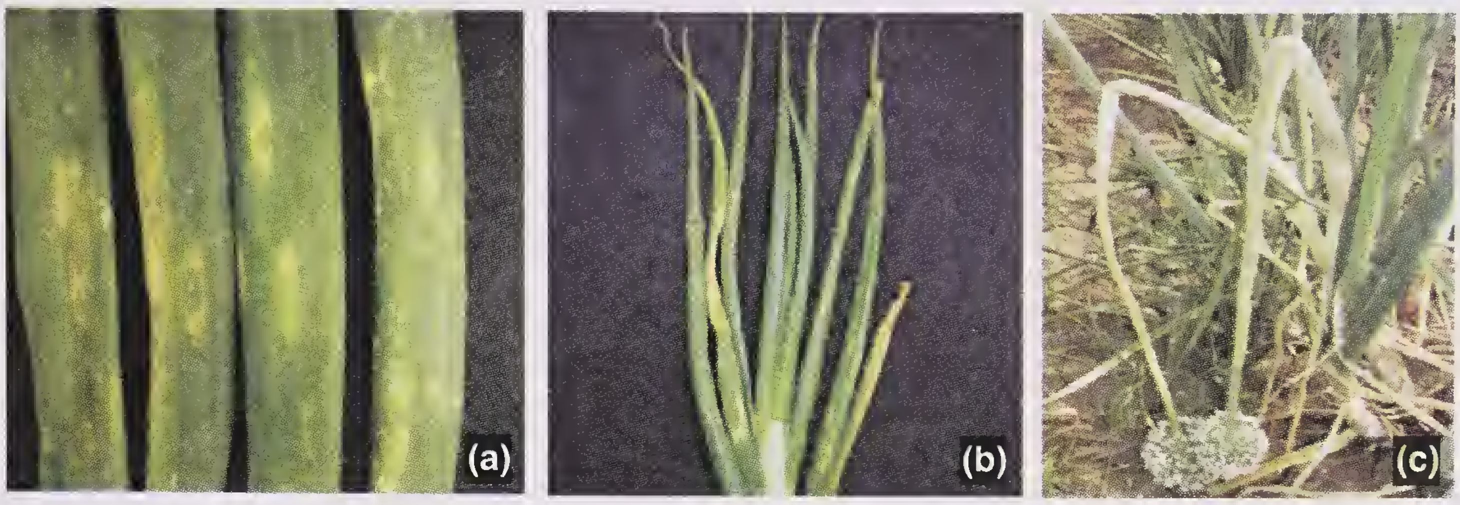

Fig.13.1 Symptoms of IYSV on onion. (a) Diamond/spindle shaped chlorotic lesions on leaves. (b) Withering of leaves and scapes. (c) Bending/twisting of flower-bearing stalks

Amaranthus retroflexus L., *Chenopodium album* L., *C. amaranticolor* L., *C. muralae* L., *Nicotiana benthamiana* Domin., *Physalis floridana* Rydb. *Zinnia elegans* Jacq. and *Iris hollandica* L.

- The necrotic local lesions developed in *Vigna unguiculata* 3–4 days post-inoculation

Transmission: The virus is transmitted as follows.

- The virus is transmitted by mechanical sap inoculation under greenhouse conditions and produce typical symptoms.
- Nymphs of onion thrips (*Thrips tabaci* L.) are known to transmit the virus under laboratory conditions, and percentage infliction was up to 54.17% (Kumar and Rawal, 1999). *Thrips tabaci* L. is involved in virus spread under field conditions.
- The presence of virus in bulbs was detected and diagnosed by many workers, and its transmission across generations is yet to be confirmed.

Virus diagnosis: Following are the means of diagnosis of the disease.

(a) The disease can be characterized by spindle or diamond-shaped spots on the scapes and on the flower-bearing stalks. The symptoms are more prominent on flower-bearing stalks.

(b) The virus can be detected by serological and PCR-based techniques. Tissue Immuno Blot Assay was used to detect the virus from infected plants and bulbs, using polyclonal antibody prepared against recombinant nucleocapsid protein (NP) of IYSV (Sivamani *et al.*, 2012) (Fig.13.2).

(c) Double Antibody Sandwich Enzyme Linked Immunosorbent Assay (DAS-ELISA) was also used to detect the virus from infected plants. The ELISA kit (Loewe Biochemica GmbH Company, Germany) of IYSV was used for

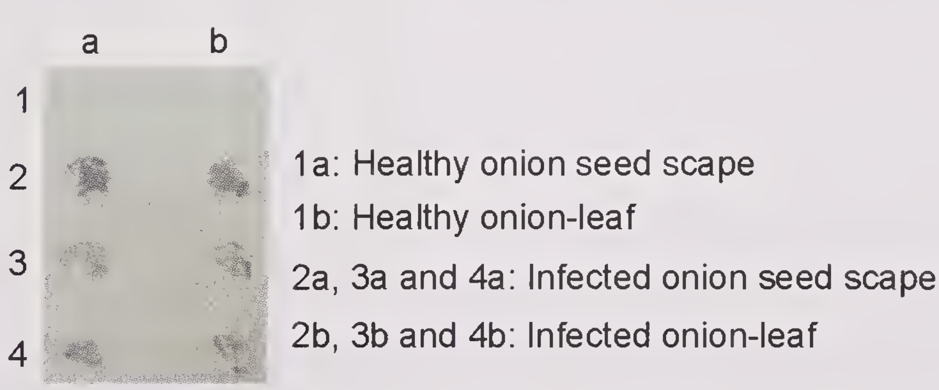

Fig. 13.2 Tissue Immuno Blot Assay to detect IYSV from the infected onion

detection, diagnosis and confirmation of the virus causing the disease (Kumar and Dhawan, 2013).

(d) The virus was detected from infected onion plants and bulbs by Reverse Transcriptase Polymerase Chain Reaction (RT-PCR) using primer specific for *Nucleocapsid* gene of IYSV (Ravi *et al.*, 2005).

Host range: The virus is known to infect different plant species—*Chenopodium amaranticolor* L., *Chenopodium quinoa* L., *Datura stramonium* L., *Gomphrena globosa* L., *Portulaca oleracea* L., *Nicotiana benthamiana* L. and *Nicotiana rustica* L.

Some of the weed-hosts which harbour the virus are—Redroot lettuce (*Lactuca serriola* L.), Common lamb squarters (*Chenopodium album* L.), Redroot pigweed (*Amáranthus retroflexus* L.), Spiny sowthistle (*Sonchus asper L.*), Green foxtail (*Setaria viridis* L.) and Two-scale salt brush (*Atriplex micrantha* L.) (Kumar and Dhawan, 2013).

Dissemination: The disease spreads by onion thrips (*Thrips tabaci* L.) under field conditions (Kumar and Rawal, 1999).

Management: The disease management is as follows.

(a) Use healthy and virus-free bulbs for planting.

(b) Removal of virus-infected plants at the early stage of crop growth to reduce source of inoculum.

(c) *Vector control:* (i) Management of thrips by spraying systemic insecticides: Confidor (Imidacloprid) at 0.2 ml/litre, Regent (Fipronil) at 1–2 ml/litre, Tracer (Spinosad) at 0.1 ml/litre, Pride (Acetamiprid) at 0.2 g/litre for three times at 20 days interval; (ii) Spray crop with neem oil (3.5 litres/ha) for managing onion thrips; (iii) Apply Trumpet (Dimethyl phosphate) three times at 5 days interval, followed by two sprays of Orthene (Acephate) at 1.5 g/litre or Decis (Deltamethrin) at 1.5 ml/litre at 10 to 14 days interval.

Groundnut bud necrosis virus

The first report of natural occurrence of this disease (Serogroup IV of Tospovirus) in onion-crop was given by Sujitha *et al.* (2012) from Andhra Pradesh.

Distribution: The disease is widely prevalent in the commercial onion fields of Kadapa district of Andhra Pradesh.

Causal organism: Groundnut bud necrosis virus (GBNV)

Virus morphology: Genus: Tospovirus; Family: Bunyaviridae .It consists of enveloped quasi spherical particle, approximately 80–120 nm in diameter.

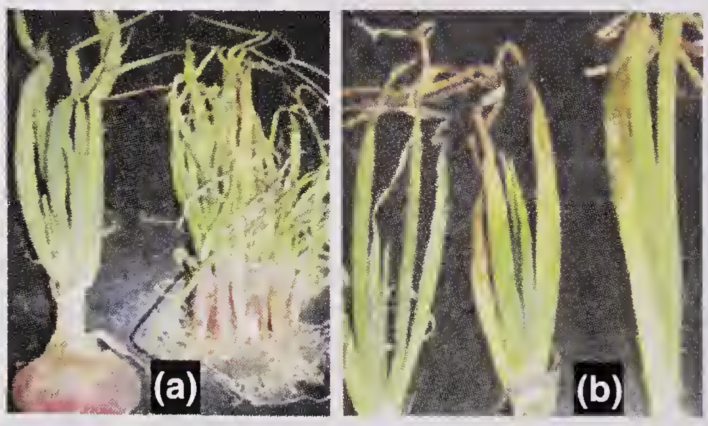

Fig.13.3 Symptoms of GBNV on onion. (a) Chlorosis and mosaic mottling symptoms on leaves. (b) Necrosis and tip dying symptoms

Symptomatology: The host-plant shows the following symptoms.

- Straw coloured, mosaic and necrotic lesions are observed on the young leaves (Fig.13.3a).
- The necrosis starts with apical portion of young leaves and finally

die-back of plants (Fig.13.3b).

- In severe stage, necrosis on flower-stalks is observed and eventually the flower aborts.

Transmission: The virus is transmitted through onion thrips (*Thrips tabaci* L.) and *Scritothrips dorsalis* Hood. (Meena *et al.*, 2005).

Virus diagnosis: To detect the virus, the following methods are used.

(a) Direct Antigen Coating Enzyme Linked Immunosorbent Assay (DAC-ELISA) using GBNV polyclonal antibodies to detect virus from leaves (Sujitha *et al.*, 2012) (Fig. 13.4).

(b) Reverse Transcriptase Polymerase Chain Reaction of leaf tissue from onion-plants using specific primer against *Nucleocapsid* gene of GBNV (Sujitha *et al.*, 2012).

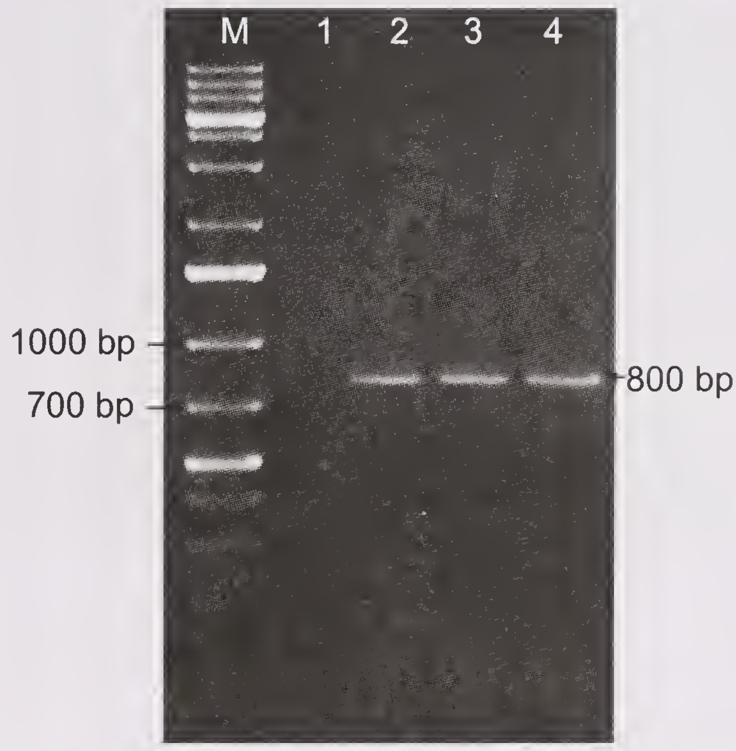

Fig. 13.4 Detection of the virus with specific amplification of *GBNV N*-gene (~800 bp) fragment. [Lane M: 1 kb DNA ladder; Lane 1: Uninfected onion sample; Lanes 2-4: Infected onion samples]

Host range: GBNV is known to have a wide host range. It infects legumes, oilseeds, vegetables, ornamentals, weeds and other hosts (Reddy, 1991).

Dissemination: The virus is known to spread in fields by onion thrips—*Thrips tabaci* L. and *Scritothrips dorsalis* Hood.

Management: This disease is managed as follows.

(a) Use healthy and virus-free bulbs for planting.

(b) Removal of infected plants at an early stage to reduce source of inoculum.

(c) *Vector control:* (i) Management of thrips by spraying systemic insecticides: Confidor (Imidacloprid) at 0.2 ml/litre, Regent (Fipronil) at 1–2 ml/litre, Tracer (Spinosad) at 1 ml/litre, Pride (Acetamiprid) at 0.2 g/litre for three times at 20 days interval; (ii) Spray the crop with neem oil (3.5 litres/ha) for managing onion thrips; (iii) Apply Trumpet (Dimethyl phosphate) three times at 5 days interval, followed by two sprays of Orthene (Acephate) at 1.5 g/litre/Decis (Deltamethrin) at 1.5 ml/litre at 10 to 14 days interval.

Tobacco streak virus

This virus in onion was first reported by Sivaprasad and co-workers during 2010 from Kurnool district of Andhra Pradesh.

Distribution: Kurnool district of Andhra Pradesh.

Causal organism: Tobacco streak virus (TSV).

Virus morphology: Genus: Ilarvirus; Family: Bromoviridae. It consists of non-enveloped, quasi-isometric particle, approximately 25–28 nm in diameter with tripartite positive sense single stranded RNA (RNA1, RNA2 and RNA3).

Symptomatology: Host-plants show the following symptoms.

- Irregular straw-coloured necrotic lesions on the leaves (Fig.13.5a).

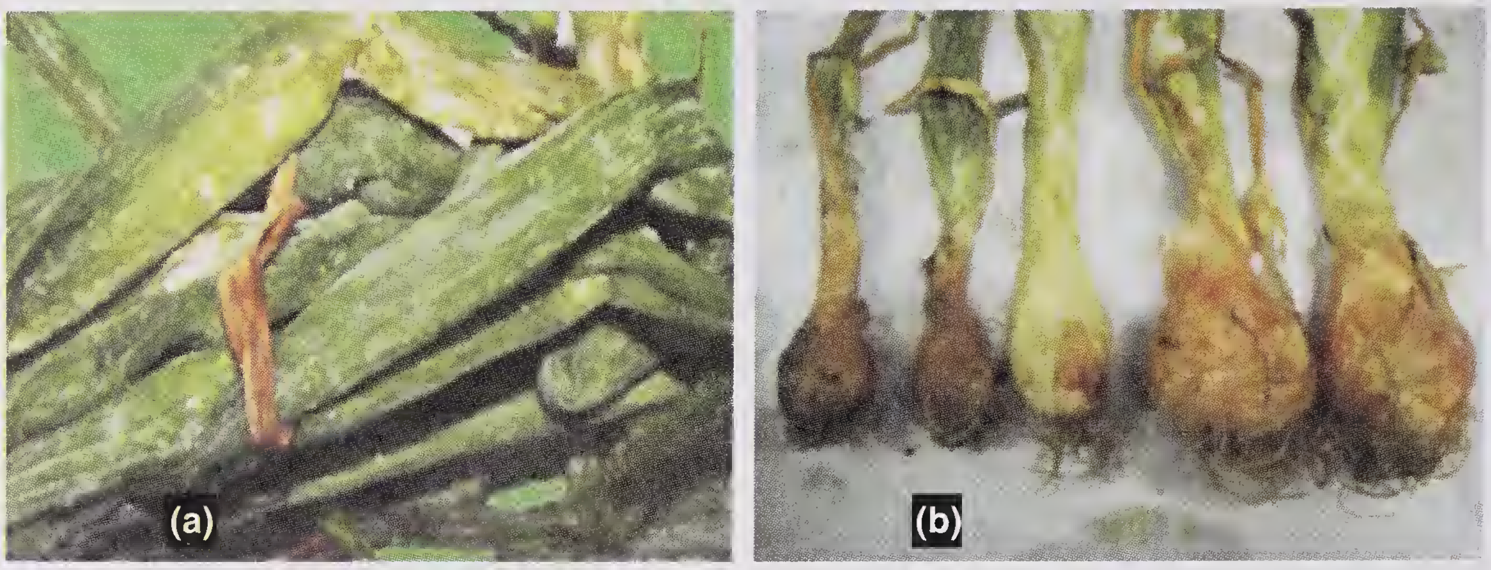

Fig.13.5 Symptoms of TSV on onion. (a) Infected onion-plants showing necrotic lesions on leaves. (b) Virus infected bulbs with various abnormalities

- Early infection aborts flowers.
- Reduction in bulb size and necrosis of bulbs (Fig.13.5b).
- Wilting and necrosis of plants, leading to yield reduction.

Transmission: The virus is transmitted as follows.

- Through mechanical sap inoculation under laboratory conditions.
- This virus spreads through pollen-assisted transmission by thrips—*Megalurothrips usitatus* (Bagnall), *Frankiniella schultzei* (Trybom) and *Scritothrips dorsalis* Hood. (Prasad Rao *et al.*, 2003).

Virus diagnosis: Its presence is diagnosed as follows.

(a) Detection of the virus from leaves is by DAC-ELISA using TSV polyclonal antibodies (Sivaprasad *et al.*, 2010).

(b) RT-PCR checks the virus from leaf tissue of diseased onion-plants using specific primers for the *Coat Protein* gene of tobacco streak virus (Sivaprasad *et al.*, 2010) (Fig.13.6).

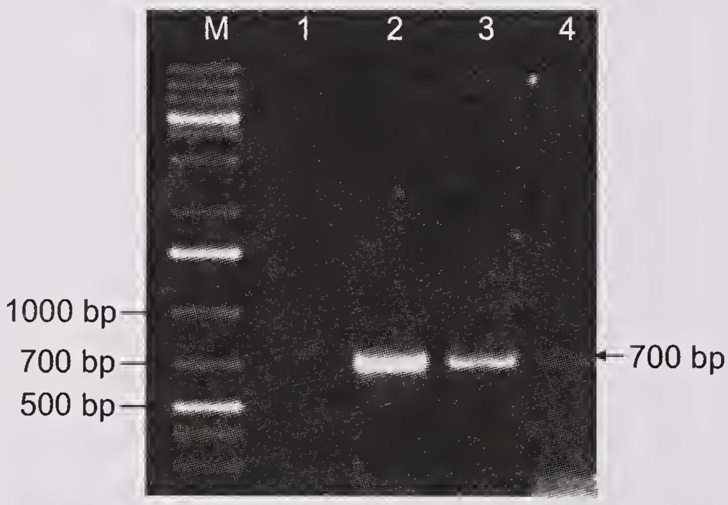

Fig.13.6 Detection of virus by amplification of ~700bp fragment of *TSV-Coat Protein* gene by RT-PCR. [Lane M: 1 kb DNA ladder; Lane 1: Uninfected onion leaf; Lanes 2-4: Infected onion leaves]

Host range: The virus is known to infect a large number of host-plants, and some commonly infected plants are groundnut, sunflower, cotton, mungbean, soybean, sunnhemp, okra, cucumber, gherkin, safflower, chilli the as well as several weeds and ornamentals (Kumar *et al.*, 2006).

Dissemination: The virus spreads in the fields through thrips—*Megalurothrips usitatus* (Bagnall), *Frankiniella schultzei* (Trybom) and *Scritothrips dorsalis* Hood. (Prasad Rao *et al.*, 2003).

Management: This disease is controlled as follows.

(a) Removal of infected plants at an early stage to reduce source of inoculum.

(b) Intercropping of onion with groundnut, chilli and other vegetable crops to stop virus spread.

(c) *Vector control:* (i) Management of thrips by spraying systemic insecticides, Confidor (Imidacloprid) at 0.2 ml/litre, Regent (Fipronil) at 1–2 ml/litre, Tracer (Spinosad) at 1 ml/litre, Pride (Acetamiprid) at 0.2 g/litre, three times at 20 days interval; (ii) Spray crop with neem oil (3.5 litres/ha) for managing onion thrips; (iii) Apply Trumpet (Dimethyl phosphate) three times at 5 days interval, followed by two sprays of Orthene (Acephate) at 1.5 g/litre/ Decis (Deltamethrin) at 1.5 ml/litre at 10 to 14 days interval.

Onion yellow dwarf

This is the most common virus in onion. Bulb and seed yield can be drastically reduced in virus infected onion-plants. OYDV occurs in epiphytotic proportion and has been implicated in reduced onion-seed production. It was first reported from onion in Iowa, USA (Melhus *et al.*, 1929), and occurs worldwide; its incidence was recorded up to 52% in Europe and 86% in Asian countries (Van Dijk, 1993). Since then, it has also been reported in Egypt, India, Serbia and Sudan. In India, it was first reported by Dhingra and Nariani in 1963 from the Indian Agricultural Research Institute (IARI), New Delhi.

Distribution: The disease was recorded from commercial fields in Haryana, Delhi, Rajasthan and Maharashtra. In 1995–1997, the disease similar to onion yellow dwarf was recorded in seed-crop at the IARI, New Delhi. Subsequently, its epiphytotic form was recorded in and around Delhi in onion-seeds (Ahlawat and Varma, 1997). Incidence of this disease up to 90% was recorded in 1998–99 on seed crop of commercial varieties at the IARI farm.

Causal organism: Onion yellow dwarf virus (OYDV)

Virus morphology: The virus belongs to Family: Potyvirus. It is non-enveloped, rod-shaped/flexuous virus particle, ranging from 650 to 900 nm.

Symptomatology: The disease is recognized by following.

- Short chlorotic streaks are on the leaves, which eventually become yellow throughout.
- Infected onion-plants show irregular yellow stripes on leaves (Fig13.7a).
- In severe cases, yellowing of the entire plant is observed.
- The leaves become crinkled and somewhat flat.
- Infected plants become highly stunted and distorted (Fig.13.7b).
- In severe infections, older leaves fall, and plants appear abnormal.

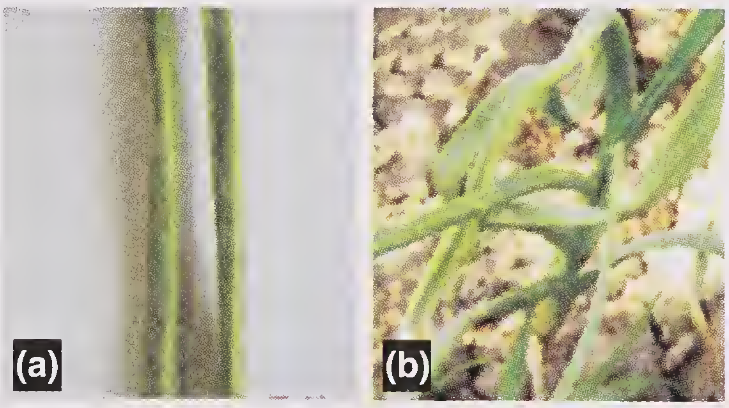

Fig.13.7 Symptoms of OYDV. (a) Infected leaves showing discontinued yellow stripes on leaves. (b) Severely infected plants showing stunting and leaf distortion

- Flower-stalks of infected plants show yellow streaks extending upward from the base. The streaks coalesce, stalks become dwarf, yellow and twisted in a characteristic manner and bear a fewer flowers.
- Bulbs produced from the infected onion-plants are underdeveloped, deformed and of little commercial value.

• Immature sprouting results in infected bulbs under storage.
• OYDV develops local lesions in *Chenopodium murale* L. and *C. quinoa* L.

Transmission: The virus transmission is by following means.

(a) The virus is transmitted onto onion by mechanical inoculation on leaves and bulb injections under the laboratory condition.
(b) In fields, virus is known to spread by 50 aphid species (Tate, 1940) such as *Aphis craccivora* Koch, *A. gossypi* Glover and *Myzus persicae* Sulzer. The maximum transmission of virus up to 20% was by *A. gossypi* Glover (Hoa *et al.*, 2003).

Virus diagnosis: This virus can be detected by the following methods.

(a) Virus detection is by DAC-ELISA using OYDV specific polyclonal antibodies from the infected plants (Hoa *et al.*, 2003).
(b) Immunosorbent electron microscopy was used to detect virus presence in infected leaf tissues (Hoa *et al.*, 2003).
(c) The virus was also detected in onion-plants by RT-PCR, which is 10–100 times more sensitive than ELISA, using specific primer designed for the conserved region of RNA dependant *RNA polymerase* gene and 3' UTR regions (Meenakshi *et al.*, 2006) (Fig.13.8).

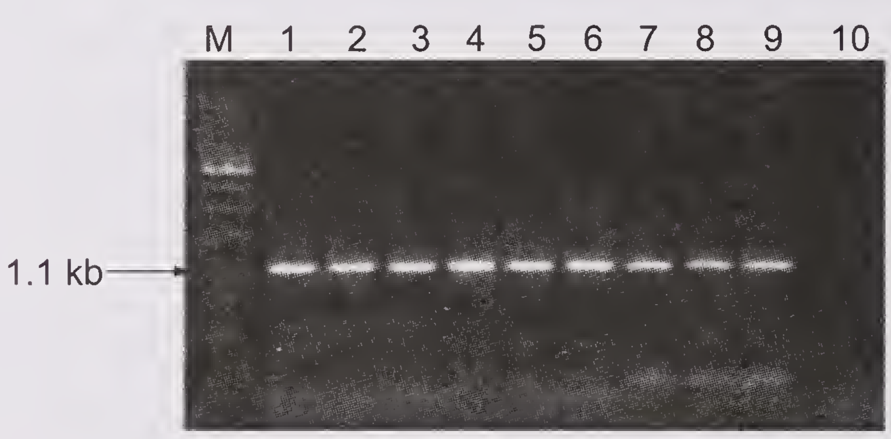

Fig.13.8 Detection of virus by amplification of 1.1kb RNA dependent *RNA polymerase* gene fragment of OYDV using RT-PCR. [Lane M: 1 kb DNA marker; Lanes 1-4: Garlic leaf samples; Lanes 5–8: Garlic bulb samples; Lane 9: Onion leaf sample; Lane 10: Negative control]

(d) The primer used was OYDVVKBF- 5'-ATAGCAGAAACAGCTCTTA-3' (forward) OYDVVKBR- 5'-GTCTCYGTAATTCACGC-3' (Reverse), which produced an amplicon of 1.1kb indicating OYDV presence.

The techniques mentioned above developed for viral diagnosis would be useful for developing healthy planting material of onion-seed crops, and thus, primary spread of virus from seed-crop to main crop would be avoided.

Host range: The virus is known to infect *A. cepa* L. and *A. satium* L.

Dissemination: Under field conditions, the virus spreads by different species of aphids—*Aphis craccivora* Koch, *A. gossypi* Glover and *Myzus persicae* Sulzer.

Management: To save plants, following methods are applied.

(a) Use virus-free bulbs for planting.
(b) Corn is recommended as the barrier crop to stop influx of insect-vectors (aphids), and spray the crop with systemic insecticide, like Confidor (Imidacloprid) (0.2 ml/litre).

(c) Apply Furadon @ of 1 kg a.i./ha at the time of transplanting seedlings, followed by 3–4 foliar sprays of Monocrotophos (0.05%) or Dimecron (0.05%) at 10 days interval.
(d) Control aphid vector by spraying systemic insecticides: Carbosulfan (Marshal) 1.5 ml/litre, Asataf (Acephate) (1.5 g/litre) for 4–5 times at 10 days interval.

Mixed Infections in Onions

Mixed infection of onion yellow dwarf virus and allexivirus

This was reported from Delhi and its adjoining regions. Ahlawat and Varma (1997) reported presence of OYDV mixed infection in garlic and onion.

Distribution: Onion yellow dwarf virus and allexivirus are common flexuous virus particles, which infect onion in Delhi region. Allexivirus is known to cause significant yield losses in garlic and also affect onion-crop in mixed infection with onion yellow dwarf virus.

Causal organism: Onion Yellow Dwarf Virus and Allexivirus

Virus morphology: Onion yellow dwarf virus belongs to Family: Potyvirus.It is non-enveloped, rod-shaped/flexuous virus particle, ranging from 650 to 900 nm.Allexivirus is also non-enveloped, flexuous, filamentous, 800 nm long and 12 nm in diameter.

Symptomatology: The symptoms for infection are as follows.

- Yellow stripes on the leaves are with diffused chlorotic spots.
- Twisting of leaves and distortions are noticed.

Transmission: Onion yellow dwarf virus is transmitted in fields by different aphid species—*Aphis craccivora* Koch, *A. gossypi* Glover and *Myzus persicae* Sulzer, and Allexivirus transmission is by mites.

Virus diagnosis: Detection of this mixed infection is done as follows.

(a) Onion yellow dwarf virus and Allexivirus were detected by Duplex RT-PCR using specific primers having conserved regions of nuclear inclusion protein (NIB), coat protein (CP) and 3' untranslated region (Fig. 13.9). The primer set details used for the Duplex RT-PCR for OYDV and Allexivirus are detailed in Table 13.1 (Sandeep *et al.*, 2010).
(b) OYDV could be detected by Primer set 3 in leaves and bulbs of five cultivars of *rabi* onion— Pusa Red, Pusa Madhavi, Early Grannow, Pusa White Flat and Pusa White Round (Fig. 13.10). Similarly, allexivirus was detected both in bulb and leaf tissues but was more in bulb tissues (Fig. 13.11).

Table 13.1 Primer-sets for the duplex RT-PCR for OYDV and Allexivirus

	Primers	Base pairs	Virus
1.	Primer- set 3:OYDV.VKB3F-5' ATAGCAGAAACAGCTCTTA 3' OYDV.VKB3R-5' TCCATCATAGTCCAATTTCC 3'	~500bp	OYDV
2.	Primer -set 4: Allexi1F-5' CYGCTAAGCTATATGCTGAARGG 3' Allexi2R-5' TGTTRCAARGTAAGTTTAGYAATATCAACA 3'	~200bp	Allexi

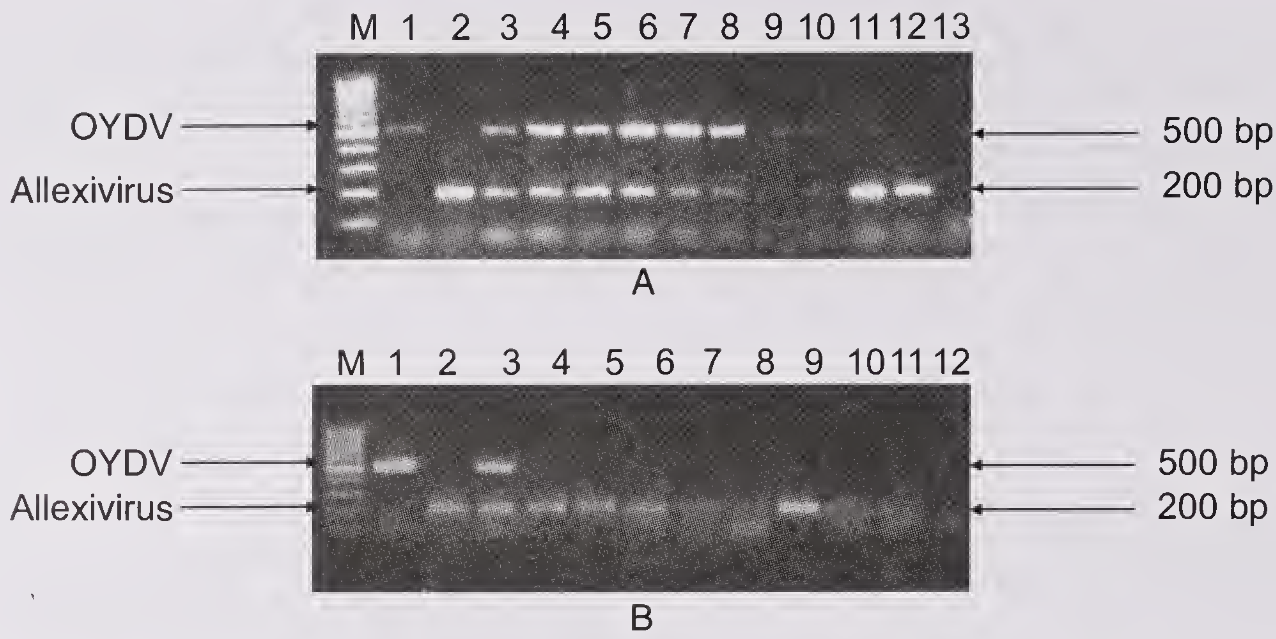

Fig.13.9 Amplification of OYDV and Allexivirus by Duplex RT-PCR. [Lane M: 100 bp marker; Lane 1: OYDV by RT-PCR; Lane 2: Allexivirus by RT-PCR; Lanes 3-12: Amplification of OYDV and Allexivirus by Duplex RT-PCR; Lane 13: Healthy control]
(A) Detection of OYDV and Allexivirus in *rabi* onion. (B) Detection of OYDV and Allexivirus in *kharif* onion.

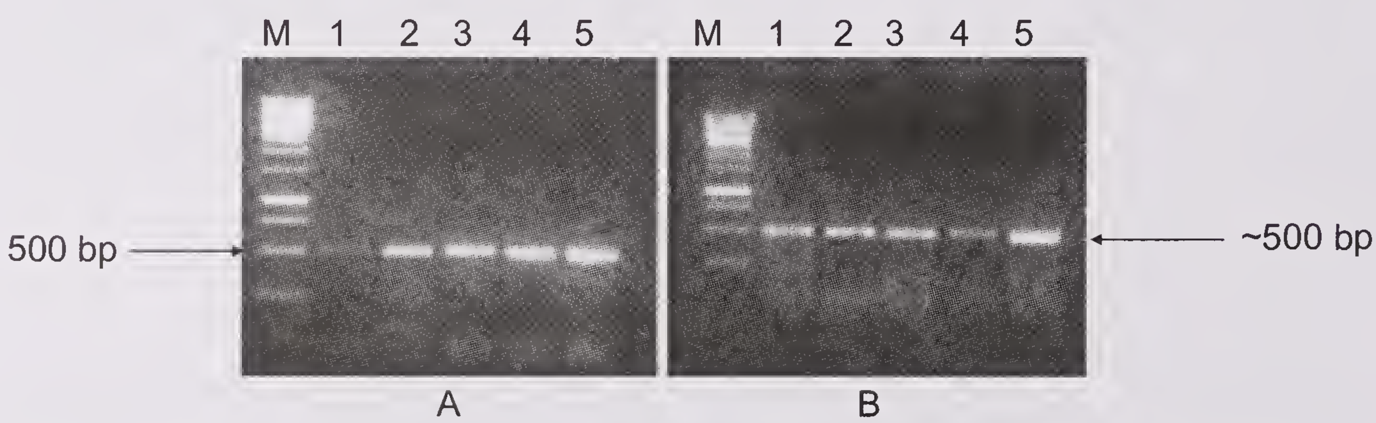

Fig. 13.10 Detection of OYDV using primer set 3 producing amplicons of ~500 bp. (A) in leaves. (B) in bulbs. Lane M 100 bp ladder; Lanes 1-5 PR, PM, EG, PWF and PWR accessions]

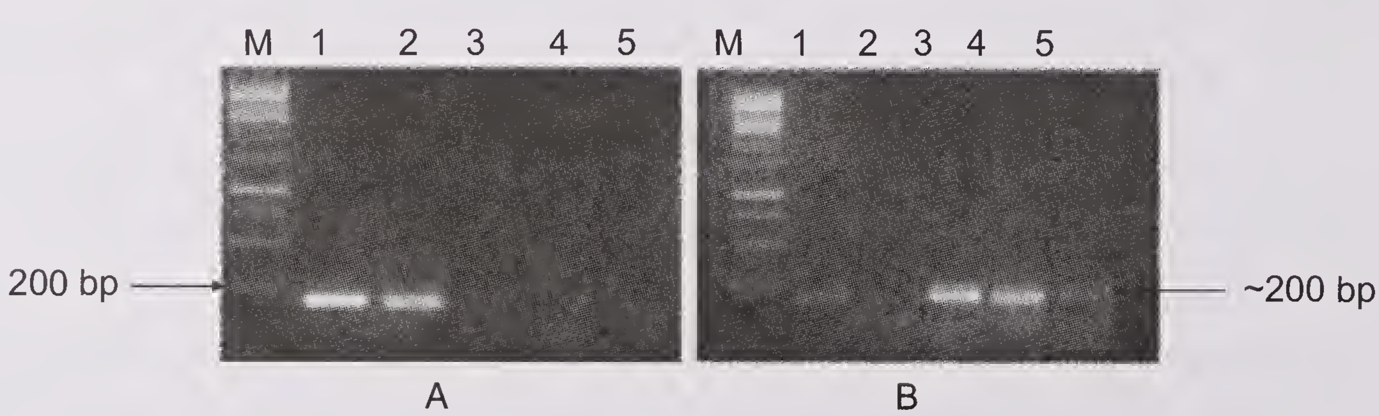

Fig.13.11 Detection of an Allexivirus: (A) in leaves. (B) in bulbs
[Lane M: 100 bp ladder; Lanes 1-5: PR, PM, EF, PWF, PWR accessions]

(c) Immunosorbent electron microscopy was used to detect presence of virus in leaf tissue (Hoa *et al*., 2003).

Management: Following care needs to done.

(a) Seed-crop should be grown away from the main crop to avoid infection of main crop by aphid and mite vectors.

(b) Select seeds/bulbs from healthy explants.

(c) Roguing of infected plants from the seed-crop is a must to prevent source of virus inoculum, and further spread of virus by insect-vectors.

(d) Manage aphid vectors by spraying systemic insecticides: Carbosulfan (Marshal) at 1.5 ml/litre Asataf (Acephate) at 1.5 g/litre for 4–5 times at 10 days interval.

(f) Mites can be managed by spraying Acaricides: Kelthane (Dicofol) 2 ml/litre, Omite (Propargite) 2 ml/litre and Karathane (Dinocap) 1ml/litre once in 5–7 days interval.

Mixed infection of onion yellow dwarf virus and rymovirus

In 1997, Ahlawat and Anupam first reported the presence of onion yellow dwarf virus (OYDV) and mite transmitted Rymovirus at the Indian Agricultural Research Institute, New Delhi.

Distribution: The mixed infection of OYDV and Rymovirus was observed in onion-seed crop in villages around Delhi and at Nazafgarh in Haryana.

Causal organism: Onion yellow dwarf virus (OYDV) and mite transmitted rymovirus

Virus morphology: Onion yellow dwarf virus belongs to Family Potyvirus. It is non-enveloped, rod-shaped/flexuous virus particle, ranging from 650 to 900 nm. Rymovirus is also non-enveloped, flexuous/filamentous, approximately 690–700 nm long and 12–15 nm in diameter.

Symptomatology: The infection leads to following symptoms.

- The leaves and flower-stalks showed mosaic mottling, short chlorotic streaks, yellowing and stunted growth of infected plants.
- Crinkling and drooping of older leaves was observed.
- Severely infected plants did not develop flower-buds, resulting in severe losses in seed production.

Transmission: Onion yellow dwarf virus is transmitted in fields by*Aphis craccivora* Koch, *A. gossypi* Glover and *Myzus persicae* Sulzer, and Rymovirus transmission is by mites.

Virus diagnosis: Presence of viruses is detected as follows.

(a) Electron microscopic investigations were conducted to determine the cause of the disease.

(b) Immunosorbent electron microscopy was used for presence of virus in leaf tissue. Leaf-dip preparations were made and stained with uranyl acetate.

Management: The mixed infection is controlled as follows.

(a) Seed-crop should be grown away from the main crop to avoid infection of the main crop by aphid and mite vectors.

(b) Mother-bulb for seed crop should be harvested from healthy plants.

(c) Indexing for the presence of viruses in the mother-bulb should be done.

(d) Roguing infected-plants from seed-crop to reduce source of virus inoculum and to prevent further spread of virus.

(e) Control aphid vector by spraying systemic insecticides like Carbosulfan (Marshal) 1.5 ml/litre, Asataf (Acephate) (1.5 g/litre) for 4–5 times at 10 days interval.

(f) Mite vector can be managed by spraying Acaricides like Kelthane (Dicofol) 2 ml/litre, Omite (Propargite) 2 ml/litre and Karathane (Dinocap) 1 ml/litre once in 5–7 days interval.

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Insect and Nematode Pests

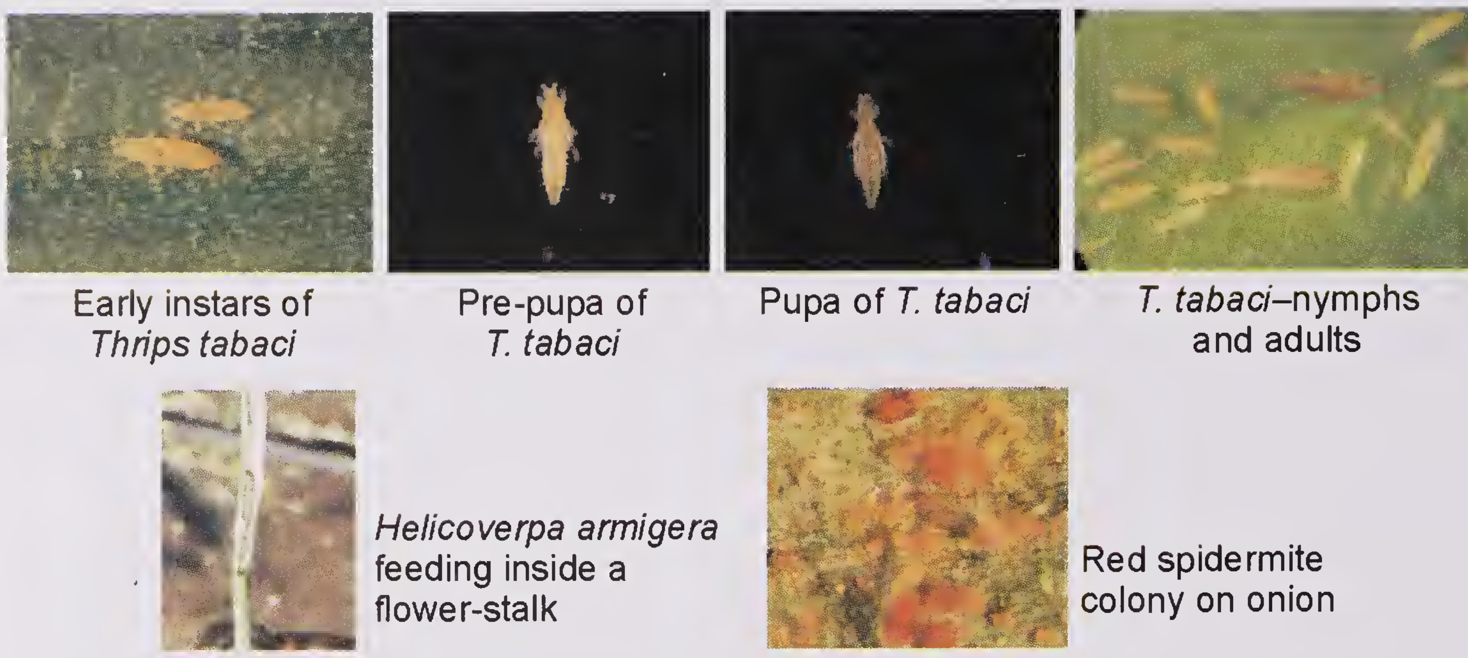
14

P. S. Srinivas and N. K. Krishna Kumar

Several insect-pests cause serious damage to onion leaves, bulbs, flowers and developing seeds. In addition, mites and nematodes are also known to cause considerable damage and yield loss to the onion. Around 10 to 25% of world's onion production loss is due to pests (Soni and Ellis, 1990). Pests, like onion thrips, are cosmopolitan and distributed worldwide. Onion-fly is more of a specialized type of pest; and other lepidopteran pests invade onion-crop sporadically and feed on the leaves. Nematodes are soil-borne and slow moving; they have been reported to have reduced onion-bulb yield significantly in many countries. In this chapter, major insect- and non-insect pests that infest onion-crop and their management have been discussed (Table 14.1; Figs 14.1, 14.2).

Table 14.1 Pests of onion-crop in India and other parts of the world

Pest	Scientific name	Taxonomy
Leaf-feeding insect-pests		
Thrips	*Thrips tabaci*	Thysanoptera: Thripidae
	Frankliniella occidentalis	
Leaf miner	*Liriomyza trifoli*	Agromyzidae: Diptera
	L.sativae	
	L. nietzkei	
Aster leafhopper	*Macrosteles quadrilineatus*	Hemiptera: Cicadellidae
Psyllid	*Bactericera tremblayi*	Psyllidae: Hemiptera
Beet army worm	*Spodoptera exigua*	Noctuidae: Lepidoptera
Cut worm	*Agrotis ipsilon*	Noctuidae: Lepidoptera
Gram borer	*Helicoverpa armigera* Hubner	Noctuidae: Lepidoptera
Red spidermite	*Tetranychus urticae*	Acari: Tetranychidae
Insect-pests infesting bulb		
Onion maggot	*Delia antique*	Anthomyiidae: Diptera
	D.platura	
Bulb mite	*Rhizoglyphus robini*	Acaridae: Acari
	R. setosus	
	Tyrophagus sp.	
Nematode pests		
Stem and bulb nematode	*Ditylenchus dipsaci*	Tylenchida: Anguinidae
Root knot nematode	*Meloidogye incognita*	Tylenchida: Heteroderidae
	M. hapla	
Needle nematode	*Longidorus elongatus*	Dorylaimidae: Longidoridae
Root lesion nematode	*Pratylenchus penetrans*	Tylenchida: Pratylenchidae
Stubby root nematode	*Paratrichodorus allius*	Triplonchida: Trichodoridae
	P. minor	



Early instars of *Thrips tabaci*

Pre-pupa of *T. tabaci*

Pupa of *T. tabaci*

T. tabaci–nymphs and adults

Helicoverpa armigera feeding inside a flower-stalk

Red spidermite colony on onion

Fig. 14.1 Onion pests

Thrips damage on the plant

Curling and twisting of onion-leaves due to thrips attack

Thrips damage on dry onion-bulb

Thrips damage on bulbs in the field

Webbing white specs on onion-leaves by red spidermite

Webbing of umbel by red spidermite

Helicoverpa damage to umbles and flower-stalk

Fig. 14.2 Symptoms of different pests

Thrips

Thrips are minute, soft-bodied insects with fringed wings belonging to order Thysanoptera. A total of 5,500 thrips species identified, so far, are distributed in 8 families belonging to 2 suborders. Many pests of Thysanoptera are members of family Thripidae, a group of 1,700 species worldwide. Thrips cause damage with their piercing and sucking mouth parts through direct feeding or by many indirect means as vectors.

Onion thrips

Only 1% of the total thrip species act as crop pests. Onion thrips, *Thrips tabaci,* is an important pest found in different parts of the world. Thrips feed on leaves and flowers and cause quantitative damage, while on bulbs damage is mostly qualitative in nature. This most diversified group of insect-pest differs greatly between crops and geographical areas. Apart from *T. tabaci*, another species, *Frankliniella occidentalis,* has also been reported on onion-crop in many countries. In India, only *T. tabaci* is predominant in all onion-growing areas (Srinivas *et al.*, 2011c).

Thrips damage plants through not only feeding and by oviposition, but they have a great ability to act as vectors, particularly tospoviruses. Of more than 5,500 species of thrips, it is a interesting fact to note that only 10 species act as a vector. Recent studies have proved *T. tabaci* a non-vector of tomato spotted wilt virus (TSWV); it was earlier considered its vector. It transmits effectively other viruses; the most recent one is onion Iris yellow spot virus, which is spreading worldwide on the crop. Transmission is successful only when first or early second instar larva of thrips acquire virus; adults cannot acquire and transmit tospoviruses.

Apart from acting as a virus vector, thrips are known to be associated with the spread of fungal diseases. Population of onion thrips, *T. tabaci,* is positively correlated with purple-blotch disease, caused by *Alterneria porri* (Thind and Jhooty, 1982; Bhangale and Joi, 1983). In general, *A. porri* infection is more on the older leaves but shifts to younger leaves in the presence of thrips injury. *A. porri* enters leaf tissue through stomata or directly through epidermal cell layer. Leaf tissue turns more necrotic when thrips and purple-blotch occur simultaneously. *A. porri* uses thrips damaged tissues as alternative penetration sites and the disease aggravates (Mc Kenzie *et al.*, 1993). Thrips also increase *Botrytis allii* infection in storage (Mayer *et al.,* 1987).

Damage and symptoms: It was earlier believed that thrips feed by rasping and sucking mouth parts but lately this has been proved wrong. Recent studies have suggested their mouth parts of piercing and sucking type. Adults and larvae puncture food substrate (leaves, flowers and bulbs) and suck the sap. Some of the common symptoms caused by thrips are curling, twisting, silvering of leaves, drying of flowers and scarring of bulbs. Onion thrips congregate at the innermost leaves. As the leaf grows, silver blotches are more visible and shine in the sun light. Under severe infestation, whole plant turns white. A highly infected onion-plant harbours more than 600 thrips. High infestation sometimes kills the seedlings. Bulb yield losses can be as high as 50% during *rabi* season.

T. tabaci is a polyphagous pest and survives on many vegetable crops and flower-plants but its most preferred crops are onion, garlic, leek and cabbage. It overwinters as the adult and lays eggs when suitable temperature is reached (Lewis, 1973). Volunteer plants, weeds like *Amaranthus hybridis* and *Chenopodium album,* and soil are important overwintering sites for thrips (Larentzaki *et al.*, 2007). In India, off-season survival of thrips was observed on cotton, brinjal, bottlegourd, *bhindi* and sunhemp (Lall and Singh, 1960).

Thrips also cause damage to onion-bulbs; the damage starts in the field itself, and they are carried to storage with bulbs. They continue feeding but do not multiply in bulbs. They penetrate into inner scales but not beyond 3rd scale. The damage affects bulb quality in storage. Though the damage is cosmetic, it may reduce onion export especially in countries like New Zealand.

Biology and life-cycle: Thrips measure about 1–2 mm in length, and are with dorso-ventrally flattened bodies, which help them hide under small-and-tight spaces. The colour of the adult may be pale or black, depending on the temperature; high temperature results in darker colour. Thrips complete their life-cycle by passing through egg, two larval, prepupa, pupa and adult stages. Their different stages occupy different niches—an adult female lays 50 to 80 eggs inside the leaf tissue, which are not visible; nymphs and adults are seen on the plants and pupal stage occurs in soil or plant debris. Their life-cycle completes in 13–24 days, depending on the temperature, the shortest was at around 30°C (Lall and Singh, 1960). Males are rare; and females lay eggs parthenogenetically. In onion thrip, *thelytoky* (female produced from unfertilized egg) is the predominant mode of reproduction, and the other two are, *arrhenotoky* (male produced from unfertilized egg and female produced from fertilized egg) and *deuterotoky* (female and male produced from unfertilized egg).

Weather and thrips: Knowledge about pest–host-plant relationship and their interaction with other biotic and abiotic factors would help in understanding pest abundance as well as population dynamics to decide strategies for effective management programmes. Generally, it is considered that thrips population increase during hot and dry climates. Many workers across the world studied relationship between weather factors like maximum and minimum temperature, mean temperature, morning RH, evening RH, rainfall, evaporation rate, sunshine hours and wind velocity with thrips populations on onions and other host-crops (Panickar and Patel, 2001; Duraimurugan and Jagadish, 2002; Gahukar, 2003; Chhatrola *et al.*, 2003). Dry weather (30.3 mm rainfall) with moderately high temperature (15.6–28.2°C) increased number of thrips, while wet season (391-mm rainfall) with moderately high relative humidity was negatively correlated with thrips number (Waiganjo *et al.,* 2008).

Temperature, rainfall, relative humidity and wind have been reported as important factors affecting number of thrips (Kirk, 1997). Maximum temperature showed positive (Hamdy and Salem, 1994), negative or no (El-Gendi 1998) correlation with thrips populations. Heavy rains proved to be detrimental as thrips were washed off the plants. Relative humidity and rainfall were negatively related to thrips population (Waiganjo *et al.,* 2007). Thrips multiplication was high during hot and dry years as more generations were produced, and there was decrease in mortality rate due to no rains. In Maharashtra, two population peaks occurred (Fig.14.3)—a smaller one in *kharif* during August and the large one in *rabi* during January–February (Srinivas and Lawande, 2004). Hot and relatively dry climate that prevails during January–February conditions are ideal for thrips to reach to harmful proportions in a short span of time (Table 14.2). Due to these factors, geographical variations were evident in population fluctuations, abundance and time of population peaks (Hayder and Sheriff, 1990; Torres *et al.,* 1994; Gonclaves, 1997; El-Gendi, 1998).

In *T. tabaci*, 63% of the total variation in flight capture of adults was explained by degree-days, number of rainy days and total precipitation. A commonly used model for predicting effects of weather factors on thrips is degree-day model. This model was developed to predict development in the field (Edelson, 1988). During low and fluctuating temperatures, development took 228.2 day-degrees against 191.1 day-degrees at high temperatures.

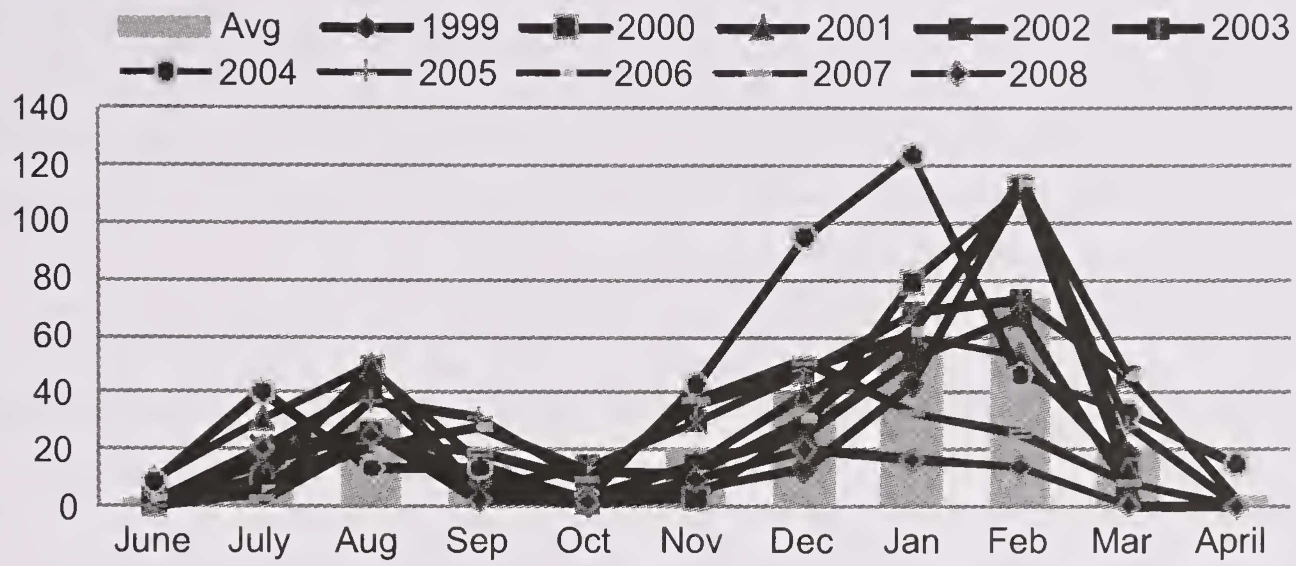


Fig. 14.3 Seasonal incidence of onion thrips at Rajgurunagar, Maharashtra

In India, prediction models were developed using regression analysis. The results varied, and were mostly derived from a very few years' data. A forewarning system for *T. tabaci* based mainly on the temperature sums was developed in Belgium that claims to be reliable in leek. Mathematics models may help understand host-pest relation and may be used as prediction tools in decision support system. Using these models, thrips population prediction was attempted in glasshouse chrysanthemum. A GIS-based modelling developed in the Netherlands suggested that population dynamics of *T. tabaci* was dependent on the interplay of different sources at small or large scale but not totally on weather and susceptibility of the crop (Anonymous, 1978). In Cuba, a logarithmic model, which was based on phenology and climatic variables, estimated efficiently population densities of thrips in garlic (Cortinus Abrahantes *et al.*, 2003). In India,

Table 14.2 Thrips abundance and impact of planting dates in different parts of India

Location	Occurrence of thrips (Standard weeks)	Peak occurrence (Standard weeks)	Planting date with higher infestation of thrips	Thrips number/ plant under different dates of planting
North				
Srinagar	15 -30	24–25	15-Dec	11.1–18.7
Durgapura	–	–	01-Jan	4.2–24.3
Kanpur	46 -19	10	15-Jan	8.5–27.3
East				
Samastipur	–	–	15-Dec	21.1–32.6
Imphal	40 –13	6	Nov	16.2–21.2
Chiplima	37–15	11	01-Dec	3.4–40.0
Central				
Jabalpur	28–05	Dec	15Oct/1 Nov	2.6–34.0
West				
Junagarh	40–06	3	01-Nov	7.2–25.5
Rajgurunagar	33–14	7	15Nov/1 Dec	3.2–64.2
South				
Coimbatore	25–04	44	01-Dec	4.6–28.1
Dharwad	25–14	32, 12	Nov-Dec	25.5–54.2

Source: AINRP *Onion Reports* 2010–13

statistical models based on weather indices and through artificial neural networks forecasting models, developed by the Directorate of Onion and Garlic Research (DOGR), Pune, and the Indian Agricultural Statistics Research Institute (IASRI), New Delhi, are used for forecasting first appearance of thrips, time (crop age) of peak population and maximum population of thrips.

Climate change and impact: Significant predictable changes are projected for temperature and CO_2. Insects being cold blooded in nature, temperature would have a direct and maximum impact on their development, survival and number of generations. Developmental dynamics of onion thrips depends strongly on temperature thresholds, which are usually represented in the models as degree-days. Potential climatic change would affect temperature, and thus the development of onion thrips. Through simple degree-day models, it has been demonstrated that expected increases in temperature would result in faster development of thrips, and there would be more number of generations in a year (Bergant *et al.*, 2003).

In countries like Slovenia, it is expected to have larger increase in degree-days, and thus more number of generations with warmer climate. As a result, damage would probably be more in areas that are exposed more to thrips (Klemen Bergant *et al.,* 2005). There is a chance of change in sex ratio between the male and the female. At the same time, changes that are taking place in host-plant and nutritional quality may also indirectly affect the pest. Climate change is a long-term process, and therefore, adaptations in both plants and in thrips need to be considered.

Integrated management: Monitoring and scouting of thrips is of prime importance to initiate programmes. Sticky traps with various colours and hues have been reported to be effective in attracting thrips of great geographical and species variations. The most commonly and widely used traps are yellow and bright blue in open as well as in greenhouse (Fernandez and Lucena, 1990; Diraviam and Uthamasamy, 1992; Cho *et al.,* 1995). Even regular scouting is a must to identify invasions of new thrips species into a new locality. In recent times, some semio-chemicals are commercially available abroad with the trade names such as Thripline$_{\text{amsTM}}$ and Lurem-TR. These are not attracting *T. tabaci* but are effective in trapping to other thrips species (Broughton and Harrison, 2012). Lures with ethyl isonicotinate, methyl isonicotinate and ethyl nicotinate captured a number of thrips in white-water traps in an onion-crop in New Zealand (Davidson *et al.*, 2009; Wogin *et al.,* 2010).

In some countries, cumulative thrips days (CTD) are used to monitor abundance and damage of thrips in onion. Presence of thrips on an onion-plant is difficult to detect. Even damage caused by them becomes visible only with plant growth due to plant's cryptic habit and small size. The better way to detect them is to check randomly 20–25 plants, particularly at the inner most whorl of the leaves.

Cultural methods: Commonly practised cultural methods include time of planting, crop rotation, irrigation, fertilization, intercropping, clean management etc. In general, crop rotation is useful for thrips species surviving in the soil but it needs to be practised on larger areas. Peak flights of thrips in the cabbage fields were recorded during maturations and senescence (North and Shelton, 1986). Therefore, in onion-growing areas, care should be taken to avoid cabbage, cotton, garlic, celery, leek, beans and tomato crops in the vicinity. Thrips from the adjacent fields and old plantings of onion can migrate to new plantings. By planting new crop in upwind direction to old ones may slow down thrips migrations to a great extent. Crop rotation as such has little impact as migrations and infestations are from external sources. Deep ploughing destroys soil-dwelling stages, like pupae and overwintering adults. Top 2-cm soil bears more thrips, and they are negligible at 8–10 cm (Deligeorgidis and Ipsilandis, 2004).

Planting date can also have a significant effect on thrips damage. Dramatic impact on thrips densities and amount of damage thrips cause was noticed with the planting date (Stoner and Shelten, 1988). In onion, plantings in the month of September and October were less prone to thrips, whereas November plantings were more prone to thrips (Srinivas and Lawande, 2004). Well established crops can withstand thrips density and damage; so early plantings are desirable (Table 14.2).

Thrips survive on many weeds as they have a wide host range, which act as a green bridge between seasons. Many of the weeds harbour viruses also, and *T. tabaci* is a potential virus vector for diseases like Iris yellow spot.

Intercropping helps reduce thrips abundance on many vegetable crops compared to monocropping. In Kenya, coriander, maize and marigold as intercrops reduced thrips population on Frenchbean (Kasina *et al.*, 2006). In Egypt, intercropping onion and garlic with tomato reduced infestation of *T. tabaci* by 80% but with declined yields (Afifi and Hayder, 1990). Infestation of *T. tabaci* on onion was reduced to half in England when it was grown with carrots (Uvah and Coaker, 1984). This was attributed to masking of onion by carrot foliage. Thrips were low on onions with companion crops, like *Rasmarinus* and *Ocimum sanctum* (Cabrera Asencio and Velez, 2006).

Wind plays a major role in spread of adult thrips from one location to other. Therefore, live-barriers around onion fields may block thrips. Maize and wheat as a live-barrier in two rows effectively blocked adult thrips by 80% and decreased nymphal population, besides reducing pesticide use to half on the onion-crop (Srinivas and Lawande, 2006). Care should be taken to avoid long maize varieties, as this would impose shading effect and reduce onion bulb yield.

In onions, reflective silver mulch repelled adult thrips but only during early stages of the crop growth. Shadow caused by fully grown plants reduced effect of reflection later in the season. In seed-crop, bulb rotting occurs when plastic mulches are used. Aluminium painted (Scott *et al.*, 1989) reflective mulch repelled 33–68% of thrips, and was found very effective at the seedling stage than at the mature plant stage (Lu, 1990), but was not effective in New Zealand (Toor *et al.*, 2004). Spreading of mulches is labour-intensive, and their disposal after use is of environmental concern. Organic mulches were also found effective in reducing thrips and increasing predatory ground beetles (Jenson, 2003; Larentzaki *et al.*, 2008b). In India, application of FYM, vermi-compost and oil-cakes was effective in reducing thrips population in onions (Ali *et al.*, 2002).

In onion, flood irrigation has been a common practice. At present, microirrigation systems, like drip and sprinklers, are gaining popularity. Overhead sprinkler irrigation systems simulate rains and wash-off thrips from onion-plants.

While using drip system, soil should be kept moist for longer period; this would help reduce thrips damage. In addition, moist soil may be detrimental to pupal stages of thrips dwelling in the soil.

Host resistance: This plays a vital role in suppressing thrips to a safer level (Table 14.3). However, so far no variety with stable resistance exists in India. Among the released varieties Baswant 780 is found moderately resistant. Many sweet Spanish onion varieties were found resistant to *T. tabaci* (Davis *et al.*, 1995). Resistant genotypes were also reported from Brazil (Loges *et al.,* 2004), Iran (Alimousavi *et al.,* 2007; Yousefi *et al.,* 2011) and Pakistan (Muhammad Shakeel *et al.,* 2006). Many germplasm sources were also reported as resistant to thrips in India (Anitha *et al.,* 2011). Some of the wild species, *A. gallanthum, A. ampeloprasum,* and some accessions of *A. fistulosum* showed resistance to thrips (Srinivas *et al.,* 2007). But bottlenecks in breeding with cultivated *A. cepa* are discouraging their use. Crosses with wild species often gave sterile plants. However, advanced breeding and molecular techniques may help removing these hurdles. Understanding resistance mechanism of thrips would also give proper direction for selection of physical or biochemical property associated with the resistance. Genotypes with wide angled leaves and open types are less prone to thrips. Genotypes with glossy foliage were resistant to thrips, while non-glossy ones were susceptible (Alimousavi *et al.*, 2007; Molenaar, 1984). It is also believed that white onions are relatively resistant than red, while yellow are intermittent, yet with no clear-cut evidence.

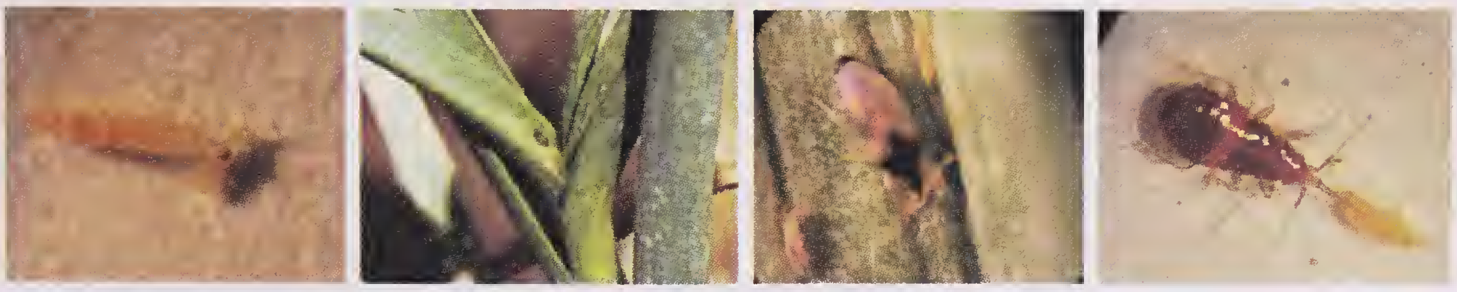
Table 14.3 Some of the resistant sources identified for thrips in onion

Meshkat, Sefid-e-Kurdistan, Sefid-e-Qom, Eghlid.	Alimousava *et al.*, 2007
Giza 6, Giza 20	El Khayat *et al.*, 1997
Valeouro, IPA11, Roxa IPA3, Belem IPA9, Texas Grano 502, Brownville, Daquesa	Loges *et al.*, 2004
Chiltan89, Phulkara, Sariab red, Swal1	Muhammad Shakeel *et al.*, 2006
544, Kalyanpur Red round, Udaipur 103, N 53	Pawar *et al.*, 1987
N 2-4-1, Sello 04Ratnar, Sel 71, Hissar brown, Sel 202	Darshan Singh *et al.*, 1986
Pusa Red, N 53	Sinha *et al.*, 1993
Sefid-e-Kashan, Sefid-e-Qom, Sefid-e- Khomein	Youseffi *et al.*, 2011

Protease inhibitors have shown significant effects on oviposition rate restricting build-up of thrips population. Therefore, the concept of enhancing cystein protease inhibition activity may be utilized through suitable approaches in species like *F. occidentalis,* where cystein proteases are more prodominent.

Biological control: This was successful against *T. tabaci* under greenhouse conditions. In fields, not much control was observed, even though, 90 predators, parasites and pathogen, have been listed worldwide (Waterhouse and Norris, 1989). Most commonly reported predators in greenhouses belong to mirid bug, *Orius* sp., and predatory mite *Amblyseius;* and entomopathogens, fungi, *Verticillium, Metarrhizium* and *Beauveria;* nematodes, *Steinernema feltiae Thripinema* and *Heterorhabditis.*

In many cases, predators were found active in protected cultivation. They consumed 23.2–96 thrips per day (Saxena, 1981). However, in the open fields,



Predatory thrips, *Aeolothrips* sp | Mirid bug, *Orius tantillus* | Mirid bug, *Orius tantillus* predating *T. tabaci* | *Orius* nymph predating *T. tabaci*

Fig.14.4 Predators of onion thrips

their incidence was very low. The main parasitoid on *T. tabaci* was endoparasitoid wasp (Loomans, 1995). One such parasite recorded in India, *Ceranisus menes* Walker, showed very low incidence in fields but was effective in Japan with 34% parasitism (Sakimura, 1937; cited by Kirk, 1997). Thrips escape from natural enemies by hiding in the inner whorl leaves. Predatory mite, *Amblyseius*, controlled thrips in the greenhouses but not in open fields. In India, *Orius tantillus* occurs naturally on onion thrips. It is a good predator on thrips (Fig. 14.4). But because of its poor reproductive potential, field releases on a large scale may not be possible with this bug. It is commonly noticed feeding on sunflower-heads. Therefore, raising sunflower plants near onion fields helps augmenting these predators in the onion ecosystem. In Maharashtra, *Orius* population increased only in February and March, and by that time thrips number declined. Another mirid bug, *Blaptostethus,* also proved effective under laboratory and caged released conditions, but could not be established in fields. Maize pollen also supports *Blaptostethus*. A predatory thrips, *Aelothrips mongolicus* Pelikan was recorded on *T. tabaci* in onion fields in Maharashtra (Satya Srinivas *et al.,* 2011c).

Under laboratory conditions, mortality of *T. tabaci* was more with entomopathogens, like *Metarrhizium anisopliae, Paecilomyces fumosoroseus* and *Verticillium lecani* (Bradley *et al.,* 1998; Kubota, 1999). *M. anisopliae* was reported to be effective in fields also (Ganga Visalakshi and Krishna Moorthy, 2012). *Beauveria bassiana* caused highest mortality at 26°C and 75% RH (Murphy *et al.,* 1998). However, such high level of humidity seldom occur in fields for a longer period during *rabi*; hence cannot be employed as a stand-alone method. *V. lecani* and *B. bassiana* reduced thrips up to 35% in fields.

Entomopathogens in combination with entomopathogenic nematode, *Steinernema feltia,* was evaluated against onion thrips (Elad *et al.,* 2004). For entomopathogenic nematode, *T. tabaci* was also a suitable host with equal reproduction rate for *Thripinema nicklewoodi* Siddiqi, which is an obligate parasite of *F. occidentalis* Pergande, (Un Taek Lim and Van Driesche, 2005). Soil application of *Heterorhabditis indicus* caused 70% mortality in *T. tabaci* (Al-Siyabi *et al.,* 2006).

In fields, bringing in plant diversity by using cover crops like buckwheat and sunflower that bloom most of the growing season would support large number of predators and enhance their population; as was done in California vineyards. Use of biological control for thrips is still far from reality where potential viruses are associated with the crop.

Alternative to insecticides: Most widely used alternatives for insecticides are botanicals that are considered safer to environment, and result in pesticide-residue-free produce. Among them, neem has gained much popularity in many IPM programmes.

Even though some studies have shown that neem stops development of early instars of thrips (Klein *et al.,* 1993), many of the Azadirachtin-based formulations could not suppress *T. tabaci* populations to the desired level in onion fields. Neem, Karanj and Annona proved inferior to insecticides in reducing thrips (Gupta and Sharma, 1998; Altaf Hussain *et al.*, 1999; Srinivas and Lawande, 2000a). Plant extracts of eucalyptus and other *in-situ* growth regulators did not prove effective against thrips and were not economically viable (Sujay Pandey *et al.,* 2012). Sole application of mineral oil sprays @ 2.0% reduced thrips population up to 48% only. But their efficacy improved when mixed with insecticides like Profenofos and Carbosulfan even at half the dose. A non-chemical, kaolin-particle film reduced oviposition of thrips and increased their mortality in laboratory (Larentzaki *et al.*, 2008a).

Chemical control: Use of chemical insecticides still remains the sole and dependable method of thrips control, particularly in warm regions. Different insecticides belonging to organophosphate, carbamate and pyrethroid groups are widely used for pest control.

In India, onions are planted in a staggered manner till the month of January. Therefore, late planting in *rabi* (winter) season, results in poor establishment of the crop owing to high attack of thrips. Seedling root-dip with Carbosulfan (0.025%) or Imidacloprid (0.04%) solution for 2h before planting protects young plants up to 30 days (Srinivas and Lawande, 2007). Economic threshold levels (ETLs) in many locations ranged as low as 1 to 35 thrips/plant (Shelton *et al.*, 1987; Fournier *et al.,* 1995; Srinivas and Lawande, 2000b; Rueda *et al.,* 2007). It depends largely on location, season, input costs and market price of bulbs; hence, it is not possible to have one prescribed ETL across all situations. Thrips control is critical during bulb initiation stage, beginning with the seventh week after planting. Farmers had highest benefit : cost ratio when insecticides were sprayed on 45–75 days old crop (Srinivas *et al.,* 2008).

Many of conventional insecticides vary in their efficacy due to long-term and indiscriminate use. With reduced effectiveness of insecticides, growers often are forced to increase spray frequency. Farmers in Indonesia, spray insecticides up to 16 times to control thrips on chilli, onion and potato throughout the growing season (Sastrosiswojo, 1991). Same is the case in the Philippines with Carbamate compounds (Bernardo, 1991). Insecticides like Lambda Cyhalothrin, Imidacloprid, Abamectin, Spinosad, Thiamethoxam, Fipronil, Clothianidin are found promising in minimizing thrips population (Gupta *et al.*, 2002;Zezlina and Blazic, 2003; Sule *et al.;* 2008). As on today, in India, only two insecticides, Dimethoate and Lambda Cyhalothrin are registered for use against onion thrips. In most of the western countries, Lambda Cyhalothrin and Methomyl are extensively used (Shelton *et al.,* 2003; Allen *et al.,* 2005). Others like Spinosad and Acetamiprid are also used on a large scale. Use of Spinosad and Acibenzolar-S-Methyl was suggested in Italy (Mautino *et al.,* 2012).

Thrips insert eggs into plant tissues while prepupal and pupal stages occur in soil or plant debris; only nymph and adults are visible on plants. Whenever foliar sprays are given, larvae and adults are exposed and killed, but other stages escape. This results in re-infestation of thrips soon from freshly hatched eggs or newly emerged adults. High volume sprays with good pressure would reach the base of the leaves where majority of the thrips feed. Addition of a spreader to spray fluid is useful for retention and spread on erect leaves of onions. Onion-plants are more vulnerable to thrips at bulb initiation and development stage, foliar application at this stage gives better yields (Srinivas *et al.*, 2008). Thrips management in seed-crop is more challenging. Foliar sprays even wash out pollen and prove fatal to bees.

Over reliance and frequent usage of pesticides cause intense selection pressure, and encourages development of resistant populations. Thrips resistance is reported for Deltamethrin in England and New Zealand (Stephen *et al.,* 2010). Differential resistance of thrips against some insecticides under field conditions has also been reported (Davis *et al.,* 1995; Gangloff, 1999). Lambda cyhalothrin had shown large temporal spatial variations in the susceptibility of thrips. No resistance was developed in thrips with Acetamaprid and Spinosad (Shelton *et al.*, 2006). In Maharashtra, susceptibility of thrips was reduced to 40% against Cypermethrin in areas where its usage was more (Satya Srinivas *et al.,* 2011a). It is always advisable to use insecticides belonging to different groups to reduce chances of development of resistance.

Pesticide residues and scope for organic farming: Onions are widely used as salad, besides being used for culinary preparations. Therefore, pesticide residues are a threat to consumers and farmers as well. Bulbs should be free from harmful pesticides. Pyrethroids like Cypermethrin, Permethrin, Fenvalerate and organo phosphorus compounds, Fenitrothion, Methyl Demeton and Dimethoate left no residues on onion-bulbs (Sinha *et al.,* 1992). Monocrotophos residues on onion-leaves and bulbs reached undetectable levels in 15-20 days after application. A minimum waiting period of 14–20 days for onion-tops and 6–13 days for bulbs has been suggested (Srinivasan and Lingappa, 1986). Insecticide residues were found in onion-bulbs collected from different markets of Maharashtra, Gujarat, Andhra Pradesh and Tamil Nadu (Satya Srinivas *et al.,* 2011b). Application of insecticides at the recommended doses up to 75 days after planting did not leave any residues on bulbs at harvest. Onion-tops are used as a vegetable in many parts of the country, and only Spinosad has been found safest to be sprayed 2 days pre-harvest (Satya Srinivas *et al.,* 2012).

Organic farming is gaining importance in many crops, particularly those with export potential. With increased awareness of non-insecticide-based cultivation, the demand for such products is increasing, particularly among the urban population. Growing onions in an organic way is a big challenge in warm countries, including India. Biological and cultural controls as well as sprays of Spinosad are acceptable for use on organically certified crops. In India, thrips were managed on a special type of onion called rose onion that is grown organically with manures and neem seed kernel extract (Krishna Kumar *et al.,* 2008). Still some more alternatives should be available to growers to manage pests like thrips to take up onion cultivation organically.

Onion fly (maggot)

There are three important species—*Delia antiqua*, *D. platura* (seed-corn maggot or bean-seed fly) and *D. allaria*—in different parts of the world. Onion maggots infest onion-crop in cooler coastal climates, and heavy organic soils are ideal for them. In India, their incidence is not widespread and it is restricted to only a very few areas. Adults are small grey flies with hunch back. Onion fly completes several generations in a year. Female lays eggs in groups on the soil surface nearer to plants. Maggots are creamy-white. Seed-corn maggots are present during early stages of the crop growth and feed on the developing seedlings, and onion maggot infests at the later stage of crop, and feed on the developing bulbs. Pupation occurs in the soil.

It can cause losses up to 90% in the plant stand (Eckenrode *et al.,* 1994). This is not a major pest in India. But, in Kargil district of Jammu and Kashmir, infestation up to 17.0–37.5% was observed (Pandey and Namgayal, 2010).

D. antiqua lays 4–8 times more eggs on older plants. Temperature of 15°C and RH of 90% are ideal for egg-laying. Soil temperature of 20°C is more congenial for survival and development of eggs. Plant chemical, n-dipropyl disulphide, present in the onion attracts both mated and gravid females than males (Romeis and Ebbinghaus, 2003). *D. antiqua* prefers internal sections of the onion-bulbs for faster development and survival (Schneider *et al.,* 1985).

Management: This pest can be monitored by erecting yellow sticky traps. Delayed onion planting reduces its damage by 35–95%. Delaying planting up to mid-May reduced *D. antiqua* damage without affecting crop period (Nault *et al.,* 2011).

Organic and animal manure applied to soil is allowed to be decomposed completely before crop sowing. Egg-laying of the fly increases with seedling density (Chiang and Perron, 1980). Integration of plant resistance and insecticide application was better alternative in situations where crop rotation is difficult (Walters and Eckenrode, 1996). *Allium fistulosum* was reported to be resistant to onion fly (Ellis *et al.,* 1979). Resistant cultivars produce alkyl thio compounds while it is not so in susceptible cultivars (Ikeshoji *et al.,* 1981). Plants with basal diameter of 1–4 mm and height of 100–350 mm had significantly lesser oviposition (Harris *et al.,* 1987).

Seven insect species were confirmed as parasites on onion fly. Only *Aphaereta pallipes* (Family: Braconidae) and *Aleochara bilineata* (Family: Staphylinidae) caused mortality of onion fly (Tomlin *et al.*, 1985) but performance was poor in the field. Grassy refuge stripes in onion-crop enhance ground beetle population which reduces maggot population. Adults were more prone to entomopathogens than maggots. *Entomophthora muscae* (Tu and Harris, 1988) and *Metarrhizium anisopliae* (Davidson and Chandler, 2005) were found effective in managing the pest. Entomopathogenic nematodes, *Steinernema feltiae* and *Heterorhabditis,* could cause 50–100% mortality of *D. antiqua* (Choo *et al.,* 1988; Ellis and Scatcherd, 2007). No biological agent has been found promising at the field level.

Insecticide application in the soil or on the seed at the time of planting was very effective. Commonly registered insecticides in the USA for onion fly are Diazinon and chlorpyriphos. In-furrow application of granular formulations of Dichlorofenthion, Ethion, Carbofuran and Chlorfenvinfos or Chlorpyriphos or Pirimiphos Methyl or Deltamethrin (Ritcey and Mc Ewen 1984, Finch *et al.*, 1986, Paulauskyte 1999) was used conventionally for its control. But susceptibility to these insecticides decreased by 45%. Seed treatment is widely practised. New chemicals like Fipronil 80 WG (25 g a.i./kg) and Cyromazine (50 g a.i./kg), an insect growth regulator, or Spinosad (25 g a.i./kg) and Clothianidin (50 g a.i./kg) or Tefluthrin (Hoepting *et al.,* 2000; Nault *et al.,* 2006; Ellis and Scatcherd, 2007) are recommended as seed treatment. Film coating or pelleting of Cyromazine was very effective in reducing crop stand damage (Taylor *et al.,* 2001). A strategy known as Stimulo-deterrent-diversion (SDD), where attractants and deterrents are used simultaneously, has been suggested along with soil insecticides that might reverse selection for physiological resistance of *D. antiqua* to insecticides (Miller and Cowles, 1991).

Lepidopteran pests

Beet armyworm, *Spodoptera exigua* and common armyworm, *S. litura,* are reported in Taiwan and India. In Guntur district of Andhra Pradesh, they were found active during November–February with peak activity in December and January (Rao and Subbaratnam, 1999). Leaves are eaten away, and sometimes larvae bore into cylindrical leaf. Sex pheromones are used for monitoring and disruption of mating in these pests by placing pheromone trap at 125-cm height. Resistant varieties are not known, and research in this area is being carried out at the AVRDC, Taiwan, and elsewhere. Insecticides like Cypermethrin, Methomyl, Quinolphos, Acephate etc., are commonly used for their management.

Helicoverpa armigera occurs sporadically and infests the seed-crop. Larvae feed inside the flower-stalk and move on upwards, and feed on the developing seed at later stages. This results in complete drying of flowers and thus seed losses. Although no resistant varieties are available; Arka Niketan was least attacked in India (Brar *et al.,* 1993). Sex pheromones can be used for monitoring. Ha NPV and *Bacillus thuringiensis* formulations can be used for killing larvae on the seed-crop.

Cutworm, *Agrotis* sp., is a localized pest in areas where sugarcane, potato and other related crops are grown. Eggs are laid on leaves. After hatching, larvae settle in soil. Cutworms attack seedlings in nursery and in the transplanted fields as well. Larvae hide in the soil and damage onion-plant at night. They feed on the plant at the ground level, and as a result plant gets cut-off at the ground level. A single larva can damage more plants. Early instars are yellowish-grey, which turn brown later on, greasy to touch, and larvae coil if disturbed. Incorporation of Carbofuran (1 kg a.i./ha) granules or Chlorpyriphos into the soil at the time of planting is recommended.

Bulb mite

Bulb mites (*Rhizoglyphus robini* Claparede, *Tyrophagus* sp.) attack bulbs of

Allium sp. These tiny mites are shiny, creamy-white, 0.5- to 1-mm long and are visible to naked eye. They occur in clusters under the root plate of onion bulb. Therefore, onion bulbs sown for seed purpose should be properly monitored. Mites are carried to storage also, and easily penetrate bulbs that are infected by *Fusarium* and multiply rapidly. They are attracted to alcohol released from fungus, *F. oxysporum* (Okabe and Amano 1990). Root plate of the infested plant detaches, leading to death of the plant.

R. setosus, has been reported in Taiwan. The mite enters the bulb through the neck and later penetrates to outer scales. Neck of the damaged bulb shows brown rotting and leaves appear abnormal. Damaged tissue hosts thousands of mites and eggs. Infected plants have a few roots and plant becomes stunted. Sometimes, mites aggregate on roots, causing collapse of the plant (Chen *et al.,* 2002).

Management: Onion, garlic, species of *Lilium* and *Gladiolus* should not be grown in succession. Decaying cauliflower is a good source for bulb-mite multiplication. Use clean cloves for sowing. Drenching soil with dicofol at 2 ml/litre is a better method of control. Even soil application of powdered sulphur is effective for 3–4 weeks (Kassab and Hafez, 1990). For stored bulbs, fumigation with methyl bromide @ 16 g/m^3 for 3 h or 10 g/m^3 for 6 h is recommended, and this practice did not affect germination (Perez *et al.,* 1989). Use of methyl bromide is put under 'restricted use' for fumigation, so other options need to be explored.

Red spidermite

Tetranychid mite [*Tetranychus cinnabarinus* (*urticae*)] is found throughout the world on major food crops, like beans, okra, cucumber, amaranth, cassava, tomato, potato, chillies; fruits, like papaya and some flower-plants, like rose, chrysanthemum, gerbera, etc. This mite prefers garlic than onion but at maturity stage only. Mites develop colonies under webbing. Because of continuous feeding, small white specs develop on the leaves. Infestation can occur on both old and new leaves. In case of onion, along with foliage, flower-stalks are also infested. Fine silk webbing is spun around the umbel (Srinivas and Lawande, 2004a). Their population was found more in plots where synthetic pyrethroid, Cypermethrin was repeatedly applied.

Management: Miticides like Dicofol and Ethion are commonly applied to control this pest. Many insecticides or miticides were found effective against this pest on various crops, but have not been evaluated on onion. But reinfestation by it is faster as larval stages and eggs survive owing to protection by silk webs produced by mites. Even a thorough water spray during the initial stages of infestation washes off mites from the plant.

Nematodes

Nematodes are microscopic creatures that dwell in the soil and infest crop-plants. They move very slowly and may move a few centimetres in a year. The most commonly found plant-parasitic nematodes in onion fields in many parts of the world are: Stem and bulb nematode, (*Ditylenchus dipsaci*), root-knot nematode (*Meloidogyne* sp.) and root lesion nematode (*Pratylenchus penetrans*). The most common symptoms associated with nematode infections are stunted plant growth, poor plant stand, yellowing of leaves, stem swelling and deformation of bulbs.

Stem and bulb nematode: This nematode is not reported from India but occurs in many parts of the world. Due to its infection, seedlings become stunted and turn pale. Yellowish-brown spots develop on leaves, and stems are swollen. Gradually neck and scales become soft and gray. Bulbs are malformed and lose weight. Infected bulbs emit characteristic foul smell due to fungal and bacterial invasion. The nematode is seed borne in nature and spread through onion sets; migrate through infected soil, water and farm machinery. A chemical attractant from onion root exudates with a molecular mass <700 kDa that was stable to heat and proteolytic enzymes was identified (Spiegel *et al.,* 2003). Soil temperature around 20°C is favourable for nematode spread and development of symptoms.

Regulatory methods are the best to prevent this in newer areas. Soil and seed stock should be thoroughly inspected for its presence. Once the field is infected, it is better to go for long rotations and avoid growing host and related crops. Soil fumigation with methyl bromide is recommended. Hot-water treatment of onion-bulbs at 43.5°C for 2 hr is also suggested for its management. However, proper care should be taken, otherwise it may affect germination. Crop rotation with non-hosts like carrots, beet, crucifers, spinach etc. has proved effective.

Root-knot nematode: It infects many of the vegetable crops. Characteristic small galls can be found on the roots of the infected plants. The shape and size of galls vary with the species. Egg mass is many a time visible on the infected roots. Infected onion fields show poor crop stand, with stunted yellow plants. Three *Meloidogyne* spp.—*M. incognita*, *M. javanica* and *M. arenari*—are the most common species infecting onions. In direct-seeded onion-crop, *M. incognita* considerably reduced yields and economic returns. Transplanted onions did not suffer economic losses. This disease was found widespread in all onion-growing areas of Allahabad with an average incidence at 82.04% (Anamika *et al.,* 2010). Temperature at 10–35°C is congenial for infection. This nematode spreads through infected bulbs, and in fields through irrigation water and farm implements.

Management: It is a soil-borne pest with a wide host range. Once infected, this pest cannot be easily controlled. Cultural method like crop rotation with non-host crops like wheat, maize and other grain crops offers a better control. In India, it was reported lately, hence strict measures like restricting soil movement through farm equipment and irrigation may prove promising. Seed material and soil needs to be tested for infection of this nematode before growing onion-crop, particularly in areas where it has been reported. Cover crops like Sudan grass and marigolds are used in some countries which showed negative effects on nematodes. Soil fumigation and nematicides like Oxamyl are recommended in many countries.

Lesion nematode: This results in stunting of plants and poor root development. Small, round to elongated yellow lesions develop on roots. The yellow lesions may turn dark brown as disease develops. Depending on the disease severity, infected plants will grow poorly, produce low yield and will show symptoms of water and nutrient deficiencies. Moderate soil moisture and temperatures (20–30°C) favour growth and development. Crop rotation and field sanitation are better management practices to contain this pest.

Future Prospects

IPM is an evolutionary process and already many effective thrips management practices have been developed in different crops. Biocontrol methods, which were not effective in the fields, were successful in greenhouses, particularly for cucumbers, sweet-peppers and chrysanthemums in temperate conditions. In India, no such success has been reported. Only promise in thrips control is through mirid bugs. Efforts shall be made to improve reproductive potential and rearing methods. Conservation of natural enemies in open fields and their enhancement by growing plants to which they attack or through habitat manipulations may help their establishment in the fields for a long term. More emphasis needs to be given on taxonomy and biosystematics of thrips in India. Molecular tools can be standardized to make species identification easier and error-free.

Development and incorporation of resistant cultivars in the IPM programmes for thrips control is still in its infancy; resistant varieties will play a vital role. In the absence of highly resistant sources, accessions with tolerance can be identified and developed so that frequency of insecticides use can be considerably reduced. Overcoming breeding hurdles in crossing with wild species will open a great source of resistance incorporation. Resistant varieties also gain significance in reducing tospoviruses. Search for sources of resistance should be increased with more focus on wild species where resistance is not found in existing germplasm.

Climate change is another area of concern. Implications of global warming are more visible now. Anticipated increase in global temperature favours thrips and other similar insects. Besides thrips, threat from mites may be expected with more economic damage to onions in future. Looking into the current status,it is evident that cultural control methods are more effective. Undisputedly use of chemicals is inevitable. Insecticide resistance is being reported in India against Cypermethrin. There is a need to rationalize its use and awareness should be created among growers. As onion is an export-oriented commodity, pesticide residues should be within the prescribed limits.

Other insect-pests and their management practices should be compatible with those of thrips. Pheromones can be integrated into the existing thrips management to make it more holistic. Mite problems are on the rise not only in onion but in many other crops. Management tactics need to be formulated for mites. Increasing temperatures may be a reason for such outbreaks. Nematode is not a major problem in India, however, changing climate may influence their importance. Free trade and movement of onions through imports may pose a threat of introducing nematodes in India. Regulatory measures should be implemented strictly to avoid any entry of these nematodes. Consolidation of available individual components of thrips management practices is necessary. A multi-faceted approach that effectively exploits weak links in the life-cycle of the thrips would strengthen IPM programmes.

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Post-harvest Management and Processing

15

A.A. Murkute and Kalyani Gorrepati

Onion, being an essential commodity of the daily diet, creates relatively constant year-round demand. Across the globe, huge post-harvest losses to the tune of 40–50% have been reported. Attempts are being made to reduce the losses through pre- and post-harvest management practices (Adamicki, 2004; Kassali and Idowu, 2007; Hyde *et al.*, 2011; Magomedov, 2006; Sabaragamuwa *et al.*, 2011). The post-harvest losses mainly consist of physiological weight loss (20–25%), sprouting (8–10%) and decay (10–12%). The losses during transit deteriorate the scenario further. Apart from the physiological processes that culminate into post-harvest losses, pre-harvest factors causing losses include cultivation practices. Successful storage depends on the cultivar or the variety, cropping season, cultural practices, maturity of the crop at the harvest and post-harvest handling (Sidhu, 2008; Murkute, 2012). To reduce post-harvest losses, different pre- and post-harvest management practices need to be standardized.

Onion is known to have natural health-promoting properties due to its rich nutritional composition. With increase in consumer awareness regarding its attributes, onion consumption is increasing day by day. This vegetable is not very convenient to cut and prepare owing to its pungency and tear-inducing effects (Siddiq *et al.*, 2013). Its processing into ready-to-eat and ready-to-use forms would increase its consumption further. Processing of onions into different products (Fig.15.1) would allow even effective utilization of those onions that fail to meet quality standards required for the marketing (Horiuchi *et al.*, 1999). It is utmost important to standardize and evaluate different processes for value-addition and producing processed products to improve utilization of onions, reduce their losses and stabilize market fluctuations.

Pre-harvest practices

They have been reported to be crucial for affecting storage life of onions. Sowing time, fertilizer dosage and method of application, irrigation, use of phytohormones, including growth suppressants, desiccants and metal salts, all can contribute to losses in storage. In storage, when leaf primordium develops into a green sprout, which eventually protrudes from the bulb-neck, is the principal cause of loss (Chope *et al.*, 2006). Extended suppression of sprout growth could be achieved using Maleic Hydrazide (MH), a synthetic sprout suppressant. However, due to carcinogenic activity of MH (Epstein *et al.*, 1967), its use has been banned.

Pre-harvest application of ethephon was reported to reduce sprouting during storage (Thomas and Rankin, 1982). While fixing critical limit for minimizing storage losses, it has been concluded that sulphur (S) has a major role in reducing weight loss, followed by nitrogen (N) and phosphorus (P). N : S ratio during crop growth (6.5–8.1) in harvested leaves (5.3) and bulbs (4.1–6.0) was found critical to reduce losses in storage. Similarly, S : P ratio in leaves of 2.4 at 63 days after transplanting was found ideal for curtailing sprouting losses (Jaggi, 2009). Lately, it has been noticed that applied sulphur did not affect sprouting, root formation, decay or development of surface discolouration or mould in storage (Forney and Jordan, 2010); rather it increased onion pungency and pyruvate content (35%). The content of propenyl cysteine sulfoxide, the precursor of the tear-inducing lachrymatory factor, increased 10-folds higher in S-fertilized onion during storage.

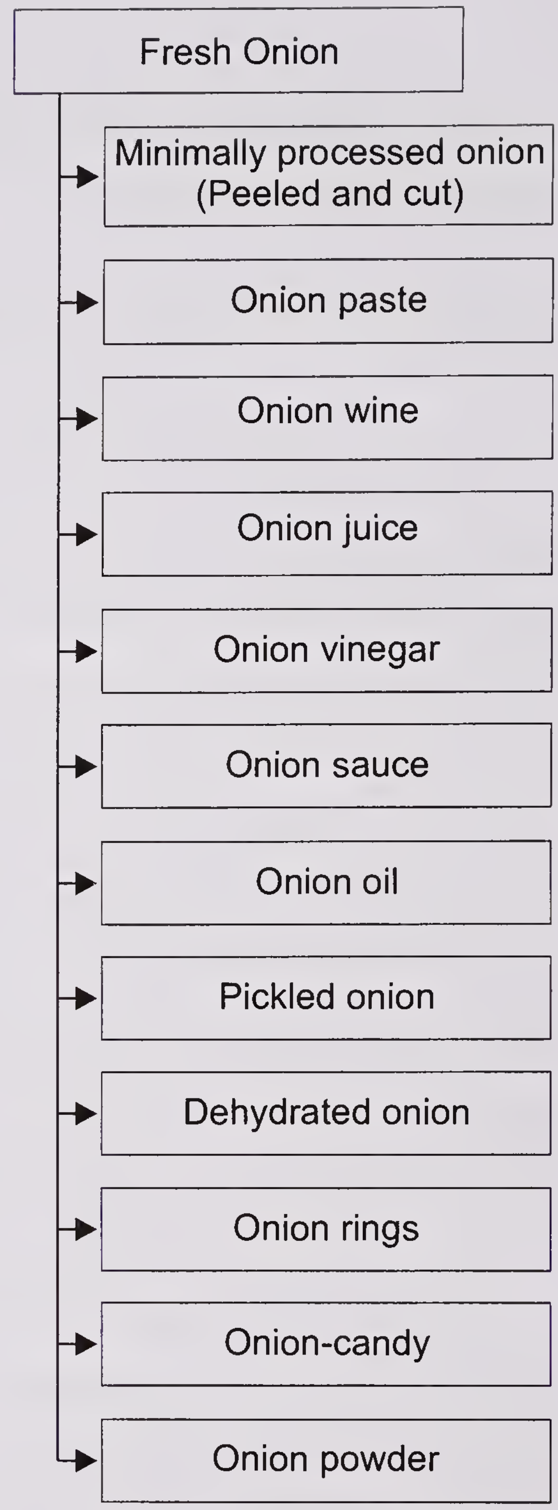

Fig.15.1 Onions— Some processed products

Application of Zn (10 kg/ha as Zn-EDTA) lowered rotting (13.7%), sprouting (2.1%) and physiological weight loss (7.71%)of onions stored up to 120 days in a perforated paper packet compared with other treatments (Zn (0 and 20 kg/ha) and three levels of S (0, 30 and 60 kg/ha)) (Kumar *et al.*, 2000). The foliar spray of 0.5% calcium nitrate ($Ca(NO_3)_2$) resulted in lowest sprouting loss (14.38%) and foliar spray of 0.5% $Ca(NO_3)_2$ + 0.5% $ZnSO_4$ lowered rotting loss (19.18%) after 150 days storage. Foliar spray of 0.5% $ZnSO_4$ resulted in lowest physiological weight loss (24.78%) and total loss (60.1%) of bulbs at the end of 150 days of storage under ambient conditions (Shrinath *et al.*, 2007). Organic manures, vermi-compost, poultry-manure and sheep-manure reduced post-harvest losses compared to urea application (Dhotre and Allolli, 2012).

Timely and appropriate irrigation has been strongly recommended to reduce post-harvest losses of onions. Extended irrigation before harvest results in skin splitting and promotes rotting by different fungi (Shock *et al.*, 1998), and water deficit results in accelerated sprouting and water loss at a higher rate during storage (Rattin *et al.*, 2011). Bulbs grown under low-soil moisture regime resulted in higher physiological weight loss and more sprouting. Maximum sprouting percentage of 25.49% was recorded in bulbs stored on the cemented floor when water applied (IW)/cumulative pan evaporation (CPE) ratio was 1.20. Application of last irrigation five days before harvesting reduced losses in storage significantly over irrigation applied just before the harvesting (Sharma *et al.*, 2007).

Microirrigation affects storage life significantly. Losses were lower in the crop grown with drip irrigation than that grown with surface irrigation (Tripathi *et al.*, 2010). Under microsprinkler irrigation regime, the crop should be irrigated on the basis of pan evaporation replenishment at 1.0 Ep for better post-harvest attributes. Physiological weight loss at 45 days of storage was 8.42 and 9.51% in 0.60 and 1.2 Ep of irrigation, respectively, which increased to 42.80 and 29.03% after 120 days of storage with the same treatments (Kumar *et al.*, 2007). However, physiological weight loss at 1.0 and 1.2 was Ep not significant. Highest sprouting and physiological weight losses were with (NPK) fertigation @ 100 : 50 : 50 kg/ha (Kumar *et al.*, 2006). Fertigation at 150 kg/ha was found most desirable for micro-sprinkler irrigated onion-crop under semi-arid climate; and at 200 kg/ha, highest physiological weight loss was noticed at the end of 120 days of storage (Kumar *et al.*, 2007). Pre-harvest applications (seedling-dip and pre-harvest spray of two calcium forms, i.e. calcium nitrate or calcium chelate) have also been found to reduce microbial decay during storage. There was significant reduction in storage-rot, i.e. black-rot (*Aspergillus niger*), neck-rot (*Botrytis allii*) and basal-rot (*Fusarium oxysporim*) with the pre-harvest application of calcium (El-Neshawy *et al.*, 2004). Improved cell-wall structure integrity observed under scanning electron microscope (SEM) was attributed to reduction in rotting due to calcium application. Different leaf desiccants as pre-harvest treatments (carfentrazone, diquat and paracquat) desiccated onion foliage well but increased bulb-rot in storage (Arboleya *et al.*, 2005). Although, copper sulphate and pelargonic acid increased desiccation of onion-foliage; they were not sufficiently effective for field use. Pre-harvest treatment with metal-salts—calcium and potassium—also influences storage of onion (Ghoname *et al.*, 2007). Exogenous treatment of abscisic acid (ABA) (10 μmole/litre) restricted sprouting to 2.9% after 100 days (Chen *et al.*, 2007). On the contrary, Chope *et al.* (2007a) reported that exogenous application did not increase endogenous bulb ABA concentration. Pre-harvest application of isopropyl–N (3-chlorophenyl) carbamate (CIPC) (2%) at 75 days after planting was found to reduce sprouting significantly in *kharif* onion varieties—Bhima Raj and Bhima Red—after three months of storage (DOGR, 2012, 2013). Its application in *rabi* crop was ineffective.

Post-harvest practices

They include external application of phytochemicals as well as management practices. Treatments with ethephon, an ethylene supplier, and silver thiosulphate, an anti-ethylene compound, were carried out as post-harvest application to investigate ethylene role on sprouting of onion-bulbs (Benkeblia and Selselet-Attou, 1999). It appeared that ethephon had almost no effect on sprouting, whereas silver thiosulphate slowed down sprouting. Pre-storage treatment with ethanol, which has ability to inhibit synthesis and action of ethylene, delayed rotting, sprouting and decay without any adverse effects on the quality (Qadir *et al.*, 2007). On the contrary, continuous application of ethylene in commercial cold storages of onion was found to restrict sprouting (Johnson, 2006). Bufler (2009) substantiated that exogenous application of ethylene inhibited sprouting in onion-bulbs. Exogenous ethylene and ethylene binding inhibitor, 1-methylcyclopropene (1-MCP), when applied continuously have been demonstrated to be sprout suppressants to onions (Downes *et al.*, 2010). Nevertheless, both the treatments did not show any impact on rotting. Propham (CIP) or its chlorinated form chlorpropham reduced sprouting to 38% (CIP 60 mg/litre) and 35% (CIP 120 mg/litre) as compared to 75% in control at 20°C (Benkeblia, 2004a). Post-harvest application of CIPC (hot fogging) did not control sprouting (DOGR, 2012).

Immediately after harvest, bulbs are in a natural stage of dormancy, and re-growth of the shoot can be controlled by physical influence such as temperature, gamma-irradiation and sprout-suppressant chemical treatments (Vasseur, 1991; Sinha *et al.*, 1994). Sprouting inhibition by ionization is advantageous as it is irreversible owing to damage to meristematic cells, and does not leave any residual effects. The success of gamma-irradiation to inhibit sprouting adequately is dependent on the pre-harvest growing conditions, seasonal variations, curing period, bulb dormancy as well as storage environment/structures (Benkeblia and Varoquaux, 2003). Gamma-irradiation on some varieties indicated that it could effectively check sprouting and rotting in all onion varieties (Tripathi *et al.*, 2011). However, no significant effect was observed on weight loss and black mould. Sulphur fumigation significantly reduced black-mould infestation. Sprouting of onion-bulbs was found only after 24 weeks when they were stored at 4°C, and it was observed after 6 and 8 weeks when storage temperature was 10°C and 20°C, respectively (Benkeblia *et al.*, 2002). Post-harvest chemical treatment of CIP (600 ppm) and gamma-irradiation (0.15kGy) on the inhibition of sprouting was as effective as chilling (4°C) treatment (Benkeblia, 2004a).

Among all post-harvest management practices, curing is the most important one before storage. Curing is a high temperature process, which allows formation of strong intact outer protective skin, and closure of onion-neck (Brice *et al.*, 1997). Albeit, curing significantly decreased onion surface from 89.5 to 84.5 cm^2 and volume from 0.084 to 0.078 m^3; the bulk density of freshly harvested onions with and without foliage (335 and 405 kg/m^3) increased (485 and 525 kg/m^3) significantly (Satish and Ranganna, 2002). Furthermore, curing increases hardness of onion-bulbs (9.75 to 10.5 kg/cm^2) and helps develop colour of cured bulbs. Both, wet conditions during field curing and topping before field curing increased incidence of bulb-rot (Wright and Triggs, 2004). Field curing of onion-bulbs for three days led to significantly higher marketable yield of 103.30 and 147.75 q/ha after storage with reduced losses of 15.08% and 16.9% in field curing compared to 30.78% and 32.23% losses, respectively, without curing (Sharma *et al.*, 2007). Storage life also enhanced when well cured (10 days) onions were kept in 30% perforated brown-paper packets (Kumar *et al.*, 2000). Enterobacter bulb decay in storage was more severe on bulbs cured at 40°C than those at 25, 30 or 35°C (Schroeder 2010).

Pre-cooling has been found to maintain high quality of produce, and onions should be pre-cooled at < 4°C temperature within 4 to 6 hours of harvest. Hydro-cooling, forced air cooling and vacuum cooling may be used with crushed ice over the produce to maintain temperature and moisture (Adamicki, 2013). Last but not the least, it was substantiated that the weight loss was higher in onion-lots inspected regularly than those inspected at the end of the storage. Also, even a slight damage to the dry outer scales may hasten loss of water during storage (Sidhu, 2008).

Storage environment

This has significant impact on the dormancy and the storage-life of onions (Komochi, 1990; Murkute and Gopal, 2013). Onion has two distinct optimum storage temperature conditions— 0–2°C and 25–30°C—where storage losses are lesser than other temperature regimes (Brice *et al.*, 1997). The optimum temperature for sprouting is 10–20°C in dry storage. Moisture loss is greater at temperature ranging < 10°C and > 27°C (Gubb and MacTavish, 2002). In general, sprouting is inhibited by low and high temperatures, and is more pronounced at intermediate temperatures (Chope *et al.*, 2006).

In the traditional ambient storage, lack of proper ventilation and loading height, increases storage losses in bulk storage. It is suggested that air-flow rate should be kept at 114 m^3/hr/tonne of onion-bulbs for forced-air ventilation (Brice *et al.*, 1995). Losses were reduced to 10.2% after three months storage in the forced ventilated storage structure (total flow rate 1,710m^3/hr) from 23.7% occurring in the natural ventilated storage in Talaja Red variety (Dabhi *et al.*, 2008). The stacking height also has effect on spoilage.

The Directorate of Onion and Garlic Research has developed different ventilated storage structures to provide optimum storage conditions (Murkute and Gopal, 2013). These are as follows.

- Top and bottom ventilated mud-plastered structure with asbestos roof
- Bottom and side ventilated structure with asbestos roof and chain-link side-walls
- Bottom and side ventilated single-row structure with Mangalore tile roof
- Bottom and side ventilated low-cost structure with thatched-roof
- Bottom ventilated double-row structure with asbestos roof

The bottom and side ventilated structure with asbestos roof performed better than other structures with physiological weight loss up to 12–15%, sprouting loss of 8–10% and decay loss of 5–8% in six months storage of *rabi* (i.e. May harvest) produce. The Maharashtra Government is providing 25% subsidy to farmers to construct these innovative storage structures (Murkute and Gopal, 2013).

Different onion-storage structures were evaluated for black and blue mould occurrences (Naik *et al.*, 2008). Bottom and side ventilated single-row storage structure with thatched-roof was the best for small farmers as it showed low severity (15–25%) by onion moulds and its cost of construction was also low. Modified bottom and side ventilated double-row storage structure with asbestos roof was the best for big farmers and traders because of its high capacity and low spoilage. The varietal difference among cultivars for mould infection up to 90 days after storage (DAS) was significant. Arka Kalyan and Arka Pitamber showed less severity (<10%) of black mould (*Aspergillus niger*) till 30 DAS. Arka Kalyan remained absolutely free from blue mould (*Penicillium digitatum*) up to 15 DAS, and severity was up to 20% at 90 DAS, and Arka Pitambar withstood blue mould severity up to 20% till 75 DAS (Naik *et al.*, 2008).

Cold storage

Although, innovations in the ambient storage designs have been made, there are certain limitations (Lawande and Murkute, 2011) with them.

(i) They are vulnerable to climatic conditions, being not fully protected, and thus at least 20-25% post-harvest losses are inevitable
(ii) The losses are huge in coastal and hot-humid zones
(iii) Air circulation and humidity cannot be controlled
(iv) The capacity of the structures is only up to 100 tonnes
(v) Quality deterioration hampers export
(vi) These structures have trivial impact on supply chain and price stabilization

Use of cold storage for reducing post-harvest losses has been found a suitable alternative to ambient storage structures (Albert *et al.*, 1979). About 70% of the bulbs stored at 1–2°C and 55–70% RH were marketable as compared to 51% bulbs stored at the room temperature. In cold storage, roots may grow, but rot incidence was managed, particularly at 0°C (Iglesias *et al.*, 1987). The severity of the rot increased with time in cold storage. The healthiest samples were those which had been air-dried for the longest time. Bulbs air-dried for 30–60 days before cold storage showed less weight loss than those without drying (Lee, 1984). The bulbs stored under cold conditions (–1 to –3°C, 70–80% RH) in trays had lower losses than those in the wooden boxes up to seven months (Pirov, 2000).

Sprouting is delayed as a response to physiological and cellular effects of low temperature. Optimum temperature (–1 to 0°C) and relative humidity (65 to 70%) are required for long-term storage (6 to 8 months) (Benkeblia, 2003). For maximum storage period and minimum losses in low temperature storage, the bulbs should be fully mature at harvest and dried until neck of the bulb is tight (Opara, 2003). The store should be properly ventilated to provide required temperature and humidity without inducing condensation of water on the surface of the bulbs. Excessive humidity in stores promote root development and rotting, while higher temperature and relative humidity lead to sprouting and development of pathological disorders (Opara 2003).

Controlled Atmosphere (CA) storage, wherein air composition of CO_2 and O_2 is altered using N_2, has also been advocated to extend storage life of onions. CA storage increased pungency characteristics of cultivars (Opara, 2003). Uddin and MacTavish (2003) and Chope *et al.* (2007b) reported reduction in pungency in CA storage. A consumer, however, may not be able to perceive the difference, as human sensitivity ranges from 1 to 7 μmol. The optimum condition for storage was found to be 2% O_2 and 98% N_2 with temperature ranging between –1 and –3°C, and optimum air humidity from 80 to 98%. As the concentration of CO_2 in the atmosphere increased from 5 to 10%, incidence of physiological disorders and damage caused by *Botrytis allii* increased (Magomedov, 2006). Under CA storage (2–4% O_2 and 0–5% CO_2, with a relative humidity of 86–92%), bulbs can be stored with minimum losses for 8 months. CA at 1% O_2 and 5% CO_2, temperature set to 2 ± 1°C and RH 52 to 87% was found superior over regular atmosphere (RA) 2 ± 1°C, with a RH ranging from 58 to 75% (Poldma *et al.*, 2012). For all cultivars, bulb dry matter and soluble solids content were higher in CA conditions compared to regular atmosphere (RA) storage.

Physiology and biochemistry

Post-harvest losses due to weight loss and sprouting have been attributed to physiological processes that occur over the storage period. The alterations in the processes are natural phenomena owing to prevalent biotic and abiotic factors. TSS decreased sharply between 6 and 10 weeks storage kept at room temperature, but it was slight in cold stored bulbs. Pyruvic acid decreased in cold storage bulbs between 13 and 17 weeks, but did not vary at room temperature (Albert and Cuquerella, 1979). Reducing sugars, total soluble sugars and ascorbic acid contents decreased with increased storage temperatures in all cultivars (Iglesias *et al.*, 1987). Furanui was more resistant to freezing than Kitamiki owing to high soluble solids content (Tanaka *et al.*, 1987). Thus storage temperature affects storability by altering physico-chemical processes. Decreased peroxidase enzyme activity coincided with sprouting (Benkeblia, 2000), which was delayed in onions grown at low nitrogen supply or harvested in dry soil (Sorensen and Grevsen, 2001). Higher storage potential of light-red colour variety (cv. N 2-4-1) over dark red (Baswant 780 and Agrifound Dark Red) and white coloured (Phule Safed) varieties (Tripathi and Lawande, 2010) substantiate role of biochemical attributes interlinked with physiological processes. Biochemical properties are affected by environmental factors and have manifested differential role in storage. Therefore, scoring them as markers could be useful to assess shelf-life.

The results indicated that later the onions are harvested, lower is the content of almost all free amino acids (FAA) in the dry matter. These differences in FAA are maintained throughout in a long-term storage (Hansen, 2001). Although, the amounts of quercetin 4'-monoglucoside increased during field curing, there was no significant change in it during 5 months storage at 0°C and 90% RH (Mogren *et al.*, 2005). Total soluble sugars (glucose, fructose and sucrose) did not vary significantly during storage at 20°C, but increased slightly at 4°C (Park *et al.*, 2006).

Among the three major causes of post-harvest losses, sprouting, has been considered the most difficult to control. The phenomenon of sprouting after a phase of dormancy is attributed to complex physiological processes. Normally, sprouting during storage is characterized by specific changes in the development and it may be possible to extend storage duration if biochemical changes involved in the dormancy are determined (Benkeblia *et al.*, 2002). Abscisic acid (ABA), a growth inhibitor, (Thomas and Isenberg, 1972) is believed to be associated with the dormancy of onion-bulbs (Matsubara and Kimura, 1991). Sprouting in dormant cultivar could be delayed by 35 days by soaking bulbs in 10^{-5} M ABA aqueous solution two weeks after harvest, and 10^{-4} M ABA was required to delay sprouting in non-dormant cultivars (Yamazaki *et al.*, 1999). The post-harvest concentration of ABA in the basal bulb sheath was found positively correlated with the number of days to sprouting in *A. wakeigi* Araki L. a cross between Japanese bunching onion and shallot (Yamazaki *et al.*, 2002). ABA levels in onion-bulbs (*Allium cepa* cv. Sochaczewska) at harvest, after curing, and during storage were affected by growing season and bulb maturity at the harvest. On an average, highest level was recorded during storage for bulbs that were grown when lowest temperature and favourable rainfall distribution prevailed. Significantly higher ABA was recorded for bulbs that did not mature (90 and 50% green foliage). ABA level changed in bulbs during storage affected by weather conditions but not by bulb maturity at the harvest (Kielak *et al.*, 2006). Chope and Terry (2008) reported bulb ABA concentration declined during storage in all cultivars with the same pattern irrespective of the initial ABA concentration (initial ABA concentration in short-storing bulbs was 2.5-fold lesser than in long-storing bulbs). Also, storage potential of different onion cultivars was inversely related to time at which they reached a minimal ABA concentration (ca 50–120 ng/g DW).

The principal biological factor leading to onion-bulb deterioration is respiration, which increases with storage time (Benkeblia, 2004a; Chope *et al.*, 2006). Weight loss due to water loss is a function of storage temperature and relative humidity. At high temperature and low relative humidity during storage, weight loss increases (Sidhu, 2008). Biochemical changes during storage are probably linked with respiration. A gradual change in relative composition of growth regulators occurs as the concentration of growth promoters or inhibitors rise or fall, respectively (Chope *et al.*, 2006). Q_{10} coefficient was found higher at low temperature range but low at higher temperature range. The heat production was also high at higher storage temperature (Tripathi and Lawande, 2010). Onions are regarded as non-climacteric (absence of an autocatalytic ethylene burst during ripening) with continuously low endogenous ethylene production (<0.1 μL/kg/hr at 0–5°C) during storage (Suslow 1998). Respiration rate of the bulb increased immediately after being treated with ethylene but to a lesser extent or not at all when treated with ethylene-binding inhibitor, 1-MCP (Downes *et al.*, 2010).

An increased sucrose concentration acts as a trigger for release from dormancy and onset of sprouting (Benkeblia *et al.*, 2005; Chope *et al.*, 2007b), and metabolism of sucrose into glucose and fructose is largely temperature dependent (Benkeblia *et al.*, 2004a; Chope *et al.*, 2007b). A cultivar having higher fructans concentration, i.e. fructose, glucose and sucrose and a series of oligosaccharides, possesses higher storability (Chope *et al.*, 2006). Fructo-oligosaccharides (FOS) hydrolysis is temperature independent, and storage time has more effect on higher degree of polymerization (DP) FOS than on lower DP FOS. Hydrolysis percentage of FOS was higher at 20°C than at 10°C; and ranged from 47 to 58% at 10°C, from 63 to 68% at 15°C and from 74 to 83% at 20°C. This indicates that high DP FOS has shorter longevity than low DP FOS (Benkeblia *et al.*, 2007). Field curing after lifting, leaving onions for about ten days in windrows on the field, significantly increased flavonoids without effecting onion dry weight in the edible part (Mogren *et al.*, 2008). The decrease in sugar concentration coincided with increased sprout length; energy is required for sprout growing (Chope *et al.* 2007b).

Fructose concentrations of onions treated with ethylene or 1-MCP before curing were not significantly different, however, after curing concentrations were 2-fold higher compared with the control. Inhibition of sprout growth can be achieved using just a short 24 hr treatment with ethylene or 1-MCP. However, skin thickness or permeability, which is dependent on cultivar and curing, may affect ethylene or 1-MCP influx,and therefore efficacy of sprout suppressant action (Downes *et al.*, 2010). The discrimination for vulnerability of white onion over red onion to high rotting incidence has been attributed to the absence of anthocyanins and phenolic contents (Sidhu, 2008). Total antioxidant capacity increased with four months of ambient temperature and ventilated storage in Pusa White Round and Pusa Red (Patil *et al.*, 2012).

Processing and value-addition

The changing contemporary life-style demands availability of fast food alternatives without compromising freshness and sacrifice of nutrient quality. Processing is a way to add value to the product without altering quality. Different methods of processing have been devised to suit a range of applications and needs. It is important to choose appropriate method based on the requirement.

Minimally processed onion

Minimally processed vegetables are defined as vegetables that are altered physically from its original form, yet retaining freshness. Pre-sliced fresh onions are most preferred by consumers who desire a healthy life-style and have a little time for food preparation (Brice *et al.*, 1995) (Fig.15.2). Undesirable physiological changes (increase in respiration, etc.) occur due to minimal processing, which shortens shelf-life of minimally processed onions. Different techniques are used for increasing shelf-life. Modified atmosphere packaging (MAP) storage and controlled atmosphere (CA) storage with or without different pretreatments augment storage-life and maintain physical and nutritional characteristics of the minimally processed onions. CO_2-enriched atmosphere delays onion deterioration and microbial development, particularly psychrotroph flora; 2% O_2/10% CO_2-enriched atmosphere is optimal to maintain sensory quality of diced onions (Blanchard *et al.*, 1996). Microbial proliferation and sensory quality aspects of sliced onions (0.7-cm thickness) were tested by Liu and Li (2006) in low density polyethylene (LDPE of 30 μm) packages. Microbial shelf-life of the tested onions at 2, 4 and 10°C was 12, 9 and 6 days, respectively, and their sensory shelf-lives were 10.5, 7 and 5 days, respectively. Different disinfectants are used to sterilize cut onions before packaging to increase shelf-life. But, it is reported that flavonoids in onions decrease by chemical disinfectant (sodium hypochlorite, amukine, hydrogen peroxide, and sodium dichloroisocyanate) due to solubility of flavonoids in immersion water. UV-C irradiation not only maintains initial flavonoid levels but also increases their levels (Perez-Gregorio *et al.*, 2011a). Ferrer *et al.* (1996) studied impact of perforated films on flavonoids of shredded onions after 7 days of storage at 8°C. The malonated anthocyanins were more stable than corresponding non-acylated pigments. The arabinosides were less stable than corresponding glucosides. Keeping potassium permanganate and activated alumina based absorbent in the diced onions package reduced ethylene, sulphur volatiles and carbon dioxide. Acceptable quality of diced onions can be kept for 10 days at 2°C using this absorbent (Howard *et al.*, 1994). With awareness for health concerns regarding the chemicals used to preserve quality of cut-onions, new alternatives have been studied in the recent years to find effective and environment-friendly processing techniques to ensure safety and to preserve quality. Mild heat treatment is one of the new techniques used to increase quality and firmness of sliced onions. Pre-storage heat treatment at 55°C for 2 min along with controlled atmosphere

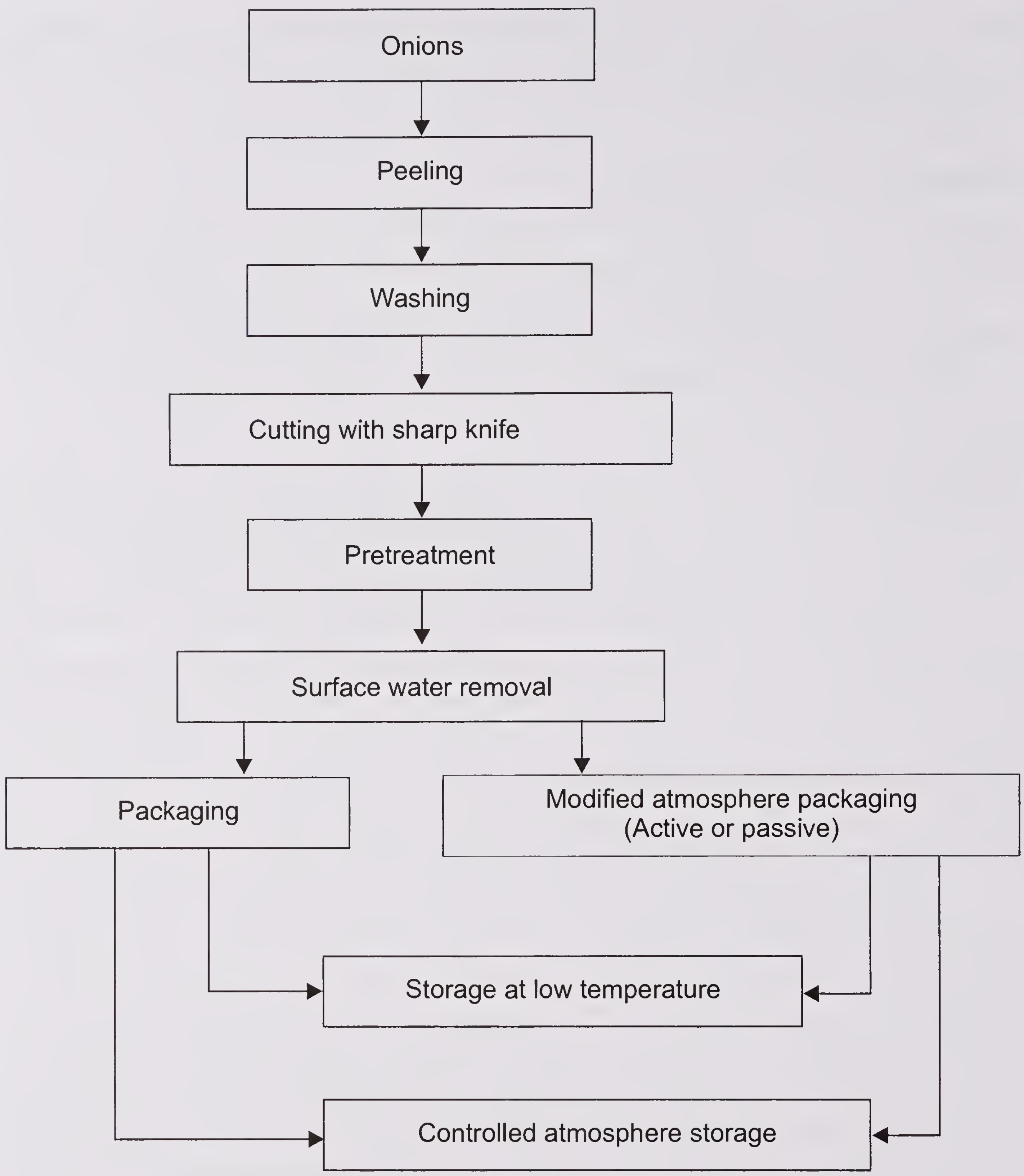

Fig. 15.2 Preparation of minimally processed onions

(CA) would increase shelf-life of minimally processed green onions to more than two weeks while stored at 5°C. Heat treatment also controls 'telescoping' of green cut-onions (Hong *et al.*, 2000). Onion slices can be heat treated at 50°C to preserve successfully antioxidant properties and colour quality for 21 days when they are to be stored storing at 4°C (Siddiq *et al.*, 2013).

Dehydrated onion and onion powder

Dehydration is the oldest method of food preservation practised by mankind. It is for producing concentrated product, which would have longer shelf-life when packaged properly, and can be simply reconstituted without any substantial loss of flavour, taste, colour and aroma. Onions are generally dried from an initial moisture content of about 86% (wet basis) to 7% or less for efficient storage and processing (Sarsavadia *et al.*, 1999). Removing moisture to this level decreases bulk to transport and also increases shelf-life. As free water is not available, microbial growth also is arrested on the product. Osmotic pressure exerted by the concentration of sugars and organic acids further inhibit microorganisms (Mitra *et al.*, 2012). Different methods used for dehydration of onion are solar-drying, convective air-drying, freeze-drying, fluidized bed drying, microwave drying, vacuum drying, infrared drying and osmotic dehydration. All onion varieties are not suitable for dehydration. Specific characteristics recommended for drying are—white coloured flesh, 15–20% total solid content, high pungency, high insoluble solids and low reducing to non-reducing sugars ratio (Mitra *et al.*, 2012). (Fig. 15.3).

Solar-drying is the simple and low-cost drying method but due to the problem of insufficient, irregular sunshine and lack of sanitation, convection drying is used in commercial dehydration of onions (Sharma *et al.*, 2005a). Convective drying of onions at 30°C, 50°C and 60°C has no effect on chemical components

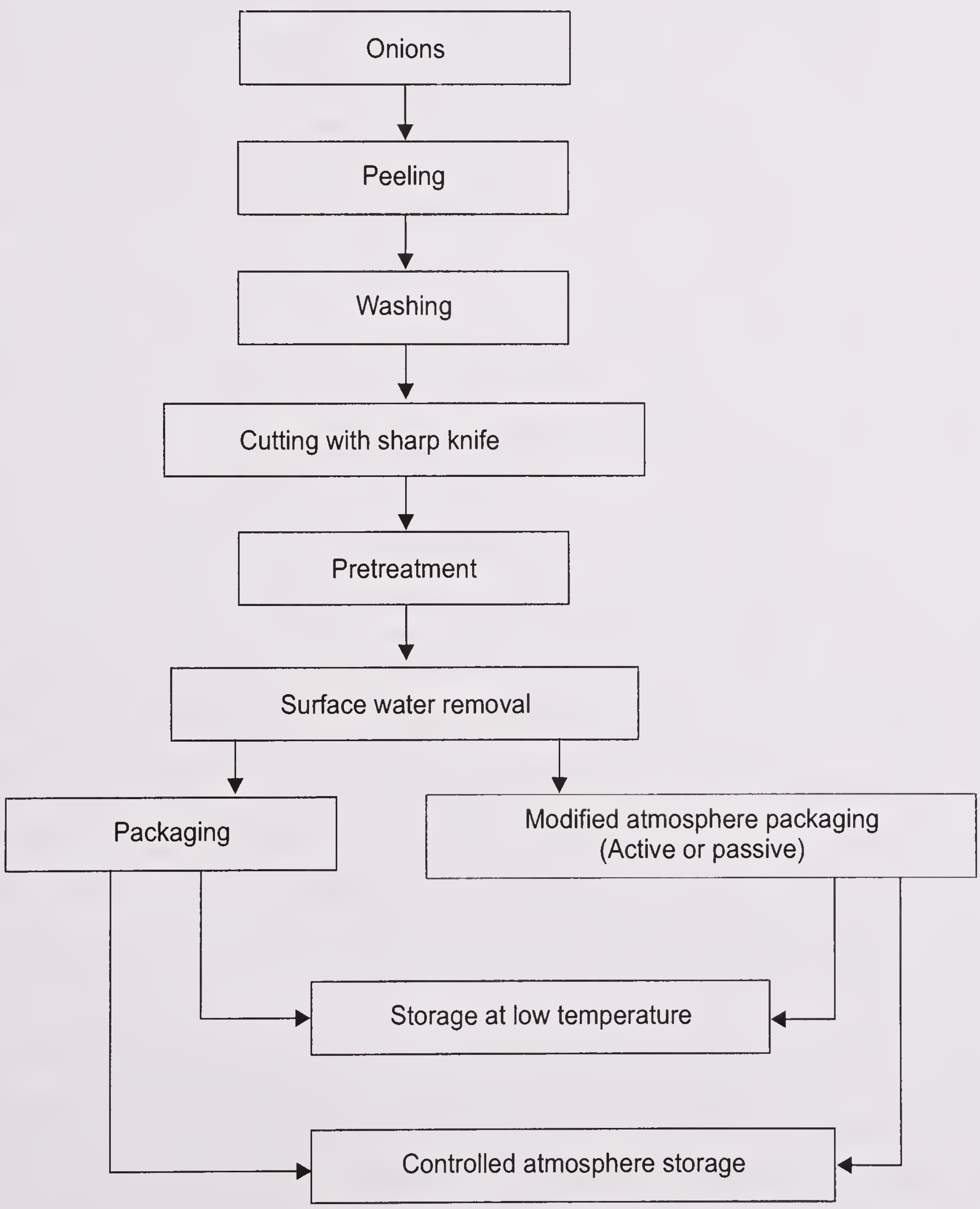

Fig.15.3 Preparation of dehydrated onion and onion powder
Source: Anonymous (2013c)

like ash, fat, protein and fibre; but sugars, acidity and vitamin C are influenced considerably by drying (Motaa *et al.*, 2010). Freeze-drying increases extraction levels of total flavonols and anthocyanins, up to 32% and 25%, respectively, due to change in tissue structure. All flavonoids in freeze-dried onion powder are stable up to 6 months when stored in water-tight glass bottles at room temperature in dark (Perez-Gregorio *et al.*, 2011b). Vacuum drying gives higher drying rate, lower drying temperature and an oxygen-deficient processing environment compared to conventional methods (Wu *et al.*, 2007; Mitra *et al.*, 2011). There is heavy loss of thermal energy during convective drying. So an alternative has come in the form of infrared radiation (IR) drying. In IR drying, higher drying rate gives significant energy saving, and uniform temperature distribution gives better quality product (Mongpraneet *et al.*, 2002). During IR drying, material is dried directly by absorption of IR energy. When IR is used to heat or to dry moist materials, radiation impinges on the exposed material surface, penetrates it, and energy of radiation converts into heat. Increase in infrared power at a given air temperature and velocity reduces drying time. With increased air velocity at a given infrared power and air temperature, there would be a cooling effects at the product surface; it would lead to increase in drying time (Sharma *et al.*, 2005b). Combined electromagnetic radiation and hot-air heating is more efficient than radiation or hot-air heating alone because of their synergistic effects (Pathare and Sharma, 2006). Colour and flavour are two most important quality attributes of the dried onions. Non-enzymatic browning reaction and loss in pungency are dominating factors in quality deterioration during drying and storage. Drying conditions are to be optimized to retain maximum product quality along with process economics (Praveen Kumar *et al.*, 2006). To reduce discolouration and browning during drying, the ratio of reducing to non-reducing sugars should be low (Mitra *et al.*, 2012). Maximum browning in the heated onion slices occurs in the range of 0.60–0.70 water activity (Rapusas and Driscoll, 1995). Colour, flavour and texture of the fruits and vegetables can be improved by giving osmotic pretreatment prior to drying. Osmotic dehydration is the process of water removal. by immersion of water containing cellular solids in a concentrated aqueous solution during which simultaneous solid gain also takes place. Difference in the osmotic pressure between the food and its surrounding solution causes water removal,which depends upon the solution concentration, immersion time and solution temperature, sample to solution ratio and agitation or circulation of the osmotic solution. Optimum condition for osmotic dehydration for further drying of onion slices is 20% salt concentration, 28°C solution temperature and 1hr of osmosis (Sutar and Gupta, 2007).

Onion powder is a product prepared from dehydrated onions by grinding them to obtain a free-flowing powder. Onion-flakes prepared from above mentioned different methods are grounded into fine powder by using different mills to produce onion powder. Onion powder belongs to a class of food powders that are highly hygroscopic. For processing and packaging of dehydrated foods, moisture-absorption data give useful guidance. The monolayer moisture contents (moisture-free basis), corresponding to Brunauer Emmett Teller (BET) theory, which are considered as the safe minimum levels in onion powder are 2.09, 1.96 and 1.94%, for freeze-dried, vacuum shelf-dried and thorough flow-dried onion powders, respectively (Debnatha *et al.*, 2002). Onions have a characteristic taste and odour because of which many people don't like to consume them although being rich in nutrition. Hui (2004) in their published patent described a process to produce onion powder without characteristic taste and odour. This process involves freezing onions at –20°C for about 24hr without peeling outer skin,then peeling and cutting quickly into a predetermined size, drying at 60°C for about 24hr in a drier and then grinding to 70 meshes or less.

Onion paste

Onion is one of the main ingredients in every curry preparation of Indian households. With the surge in number of working couples, people prefer to spend less and less time for food preparation. Availability of onions in the form of ready-to-use paste would curtail inconvenient process of cutting onions, and thereby reduce total time for food preparation. Onion paste is convenient to use. It is a semi-solid product which retains original colour and flavour of onions (Ahmed and Shivhare, 2001). Preparation of onion paste is a simple process, but it entails proper packaging and storage conditions to retain its colour, flavour besides microbial safety.

Onion pickle

Our ancestors have explored pickling process to preserve surplus food supplies for long winters, famine and other times of need. It is a global culinary art. Pickles add a special taste to many snacks and meals. Pickles are foods soaked in different solutions that prevent spoilage. The solutions change taste and texture besides preserving foods (Fig.15.4).

In general, pickling is done in two ways, i.e., pickling in vinegar in which a few bacteria can survive because of strong acid, and pickles soaked in salt brine allowing fermentation. Fermentation encourages growth of "good" bacteria that make food less vulnerable to "bad" spoilage-causing bacteria (Anonymous, 2013a). Maintaining proper acidity is important in pickling to contain growth of microorganisms.

Onion vinegar

Onions are considered to be a promising source of vinegar as they are rich in sugar and many nutrients (Horiuchi *et al.*, 1999). Horiuchi (2000) described an effective onion vinegar production fermentation system by a two-step fermentation system. Fu and Dong (2011a) reported a new method of vinegar production from onions (Fig.15.5). Horiuchi *et al.* (2004) developed a biological approach combining vinegar fermentation and composting to allow both value-addition and effective reuse of commercially unmarketable onions, i.e., pressing of onions in a mechanical juicer to give onion juice (60 wt %) and onion residues (40 wt %). The juice can be converted to onion vinegar by a two-step fermentation system. The onion residue is then utilized as a source of composting;this happens within a week.

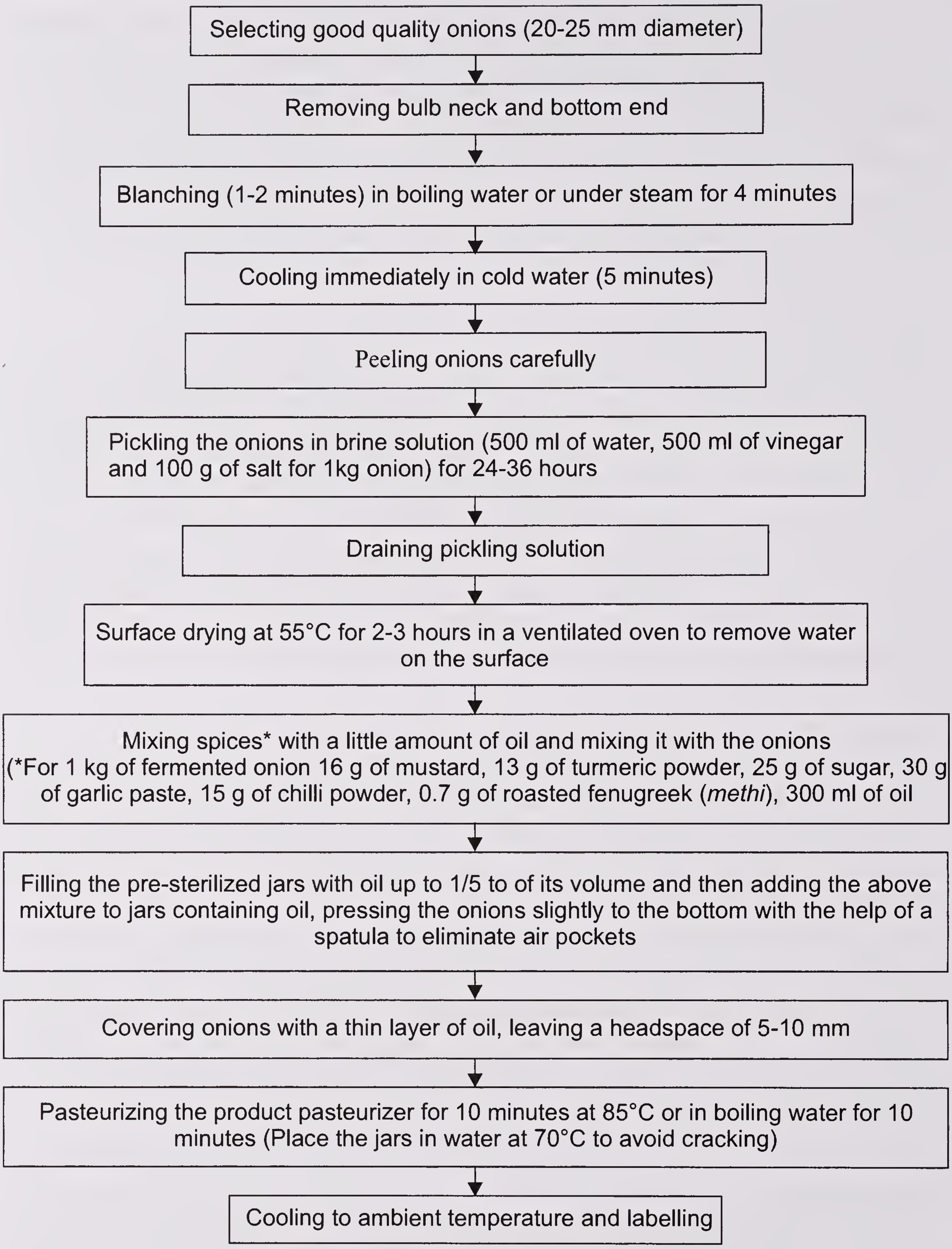

Fig.15.4 Onion pickle preparation
Source: Anonymous (2013c)

Onion oil

It is the concentrated oil of dark-amber colour obtained by distillation of minced onions. Oil yield varies from 0.002 to 0.03% (Lawande, 2001). Onion oil can be used for imparting onion flavour to processed food without difficulty of handling a large bulk of fresh bulbs. Onion oil is also used in non-alcoholic beverages, ice-creams, confectionery, baked goods, condiments, meats and pickles (Lawande, 2001). Since the last 50 years, protection of food from spoilers and pathogens has aroused a great interest, and it could be achieved by various physical and chemical

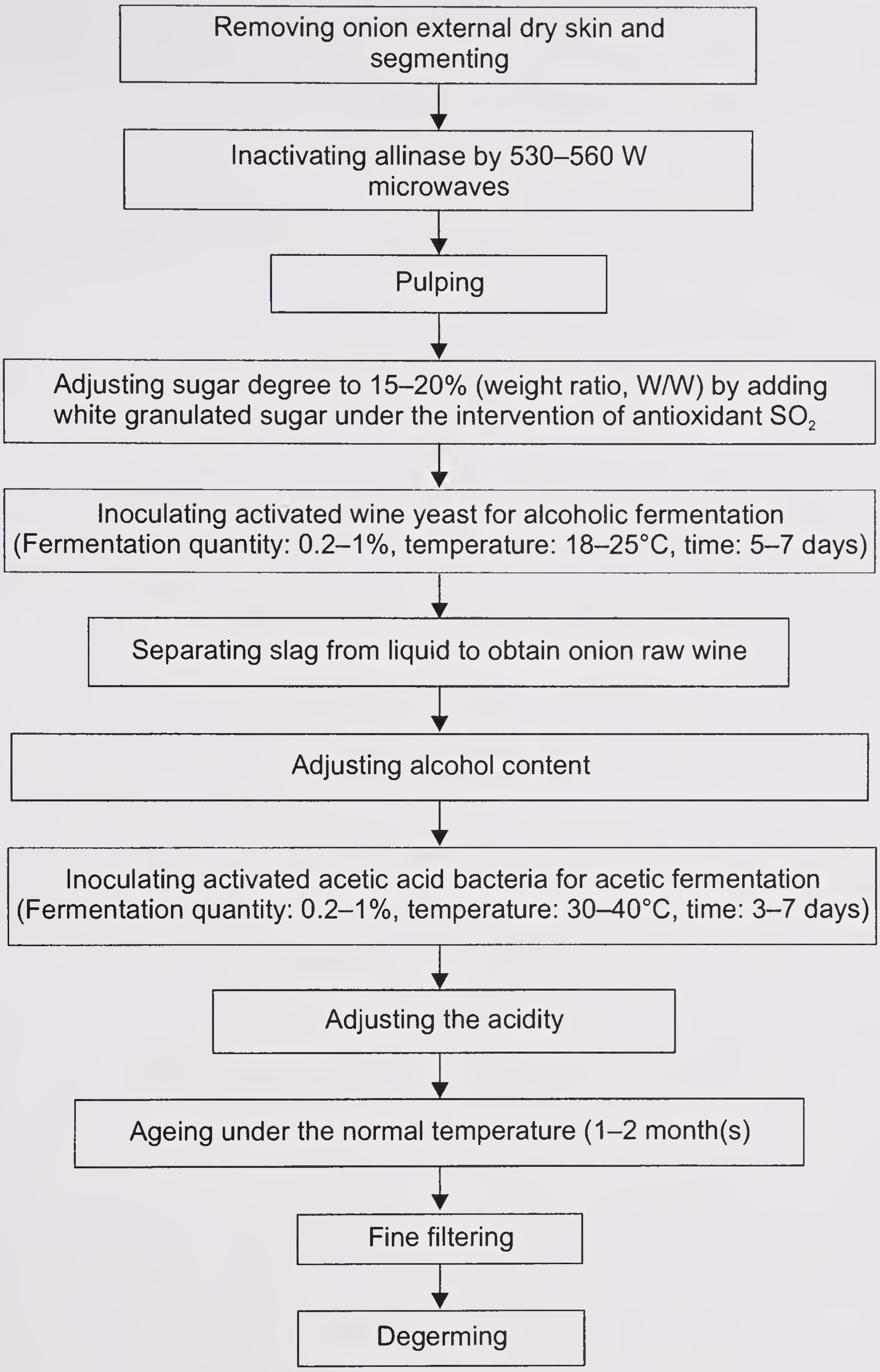

Fig.15.5 Onion vinegar preparation
Source: Fu and Dong (2011a)

methods (Benkeblia, 2004b). Use of onion oil is one of the natural ways of controlling pathogens. Ye (2013) tested essential oil of *Allium cepa* against food spoilage and food-borne pathogenic microorganisms and its antioxidant activity. *A. cepa* essential oil has antimicrobial effect against tested microorganisms with minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values in the range of 0.18–1.80 mg/ml and 0.54–3.6 mg/ml, respectively. A method for extraction of onion oil has been developed, which has advantages of no residues, strong selectivity, less effective component destruction, simple and easy operation, easy reclamation of reflux extracted solvent, higher yield of oil of stable quality and high output, is time saving, with less solvent use and lower energy consumption (Dai *et al.*, 2010).

Other processed products of onion

As onion is rich in nutrition, consumption of onion as beverage is another best way of adding onion nutrition to human body. Onion has better health benefits

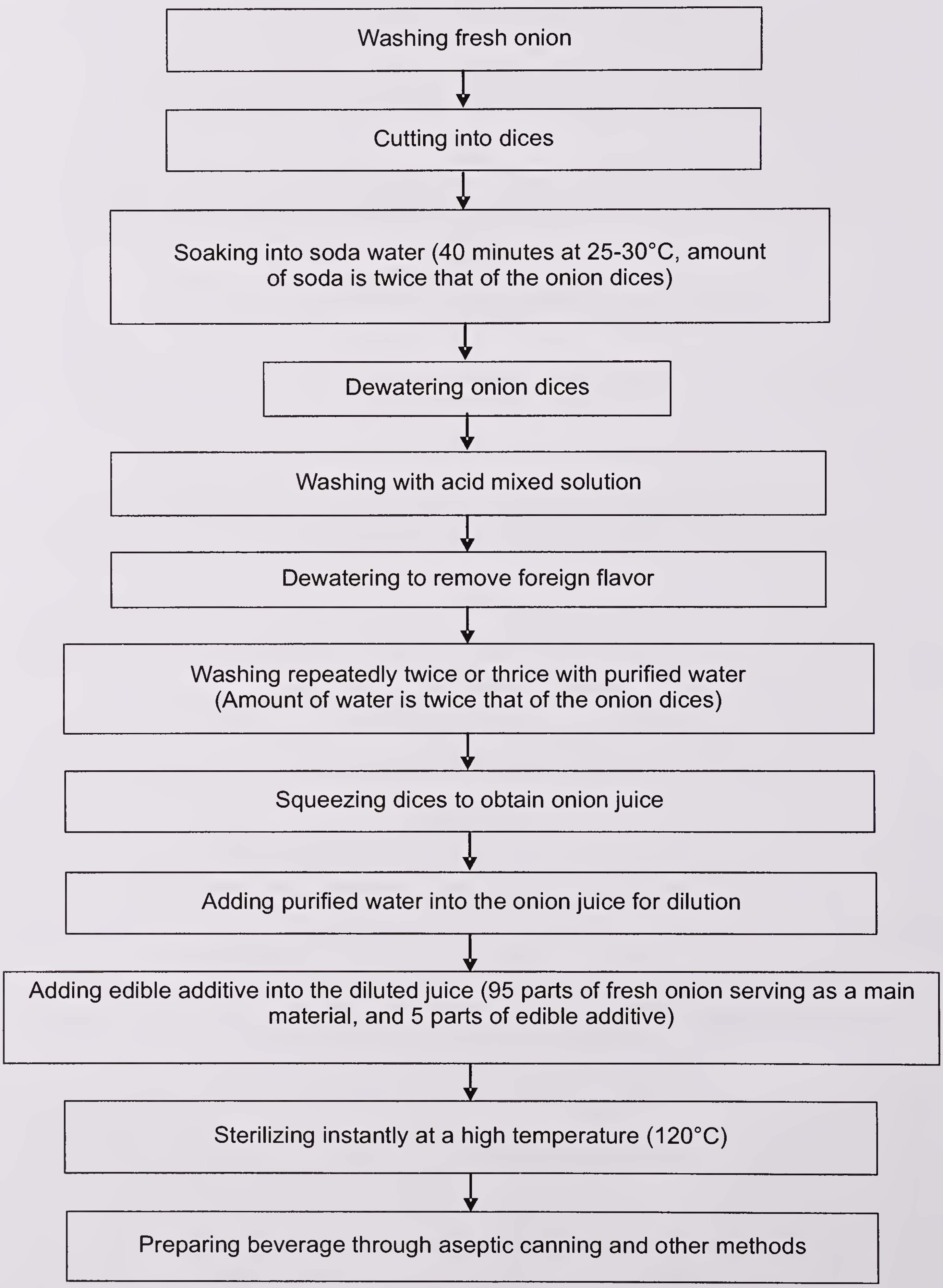

Fig.15.6 Preparation of onion-juice beverage
Source: Zhang (2010)

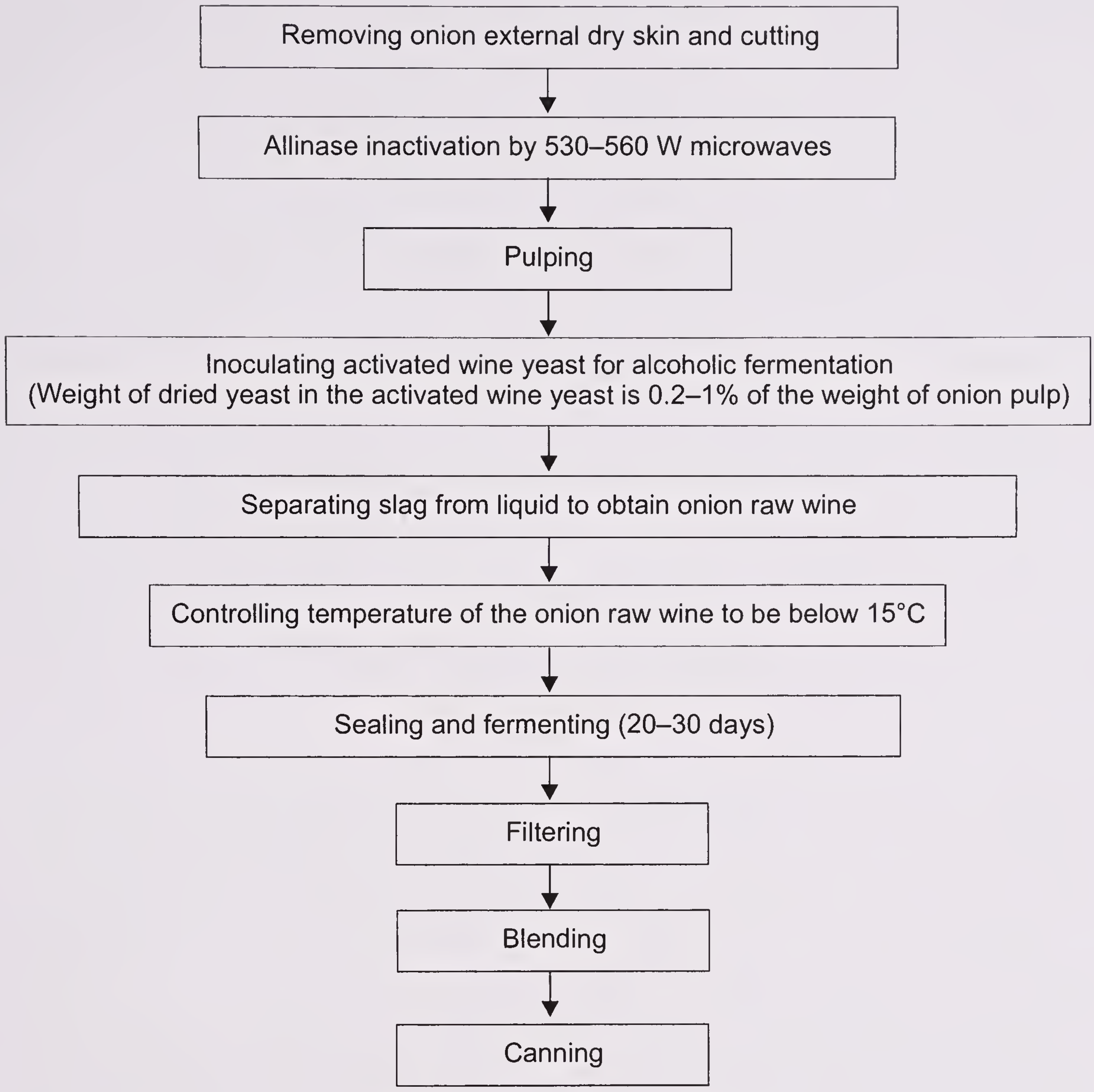

Fig. 15.7 Preparation of onion wine
Source: Fu and Dong (2011b)

and healing powers. Onion juice is anti-inflammatory, blood thinner, lowers risk of blood clots, protects against lung and breast cancer, and gets rid of excess mucus from body (Anonymous, 2013b) (Fig.15.6).

Onion can be processed into onion wine through fermentation. Different fermentation parameters—time, temperature and initial sugar content—affect physicochemical and sensory properties of wine. The optimum fermentation conditions of time, temperature and initial sugar content for better alcoholic content and overall palatability of onion wine are 80–90 hr, 28–32°C and 20–25°Brix, respectively (Choi *et al.*, 2013) (Fig.15.7).

In general, onion is used as one of the ingredients in the preparation of different sauces. Onion sauce is another promising processed product, which has gained popularity. Sauces can be liquid or semi-fluid, and are sometimes heterogeneous in texture with solid morsels. They often accompany dishes with little marked sensory properties such as starchy products (Avallone *et al.*, 2008). The most well-known of all the commercially available sweet onion sauces are manufactured by Marathon Enterprises, Inc., of Englewood, N.J., under the brand SABRETT®. While

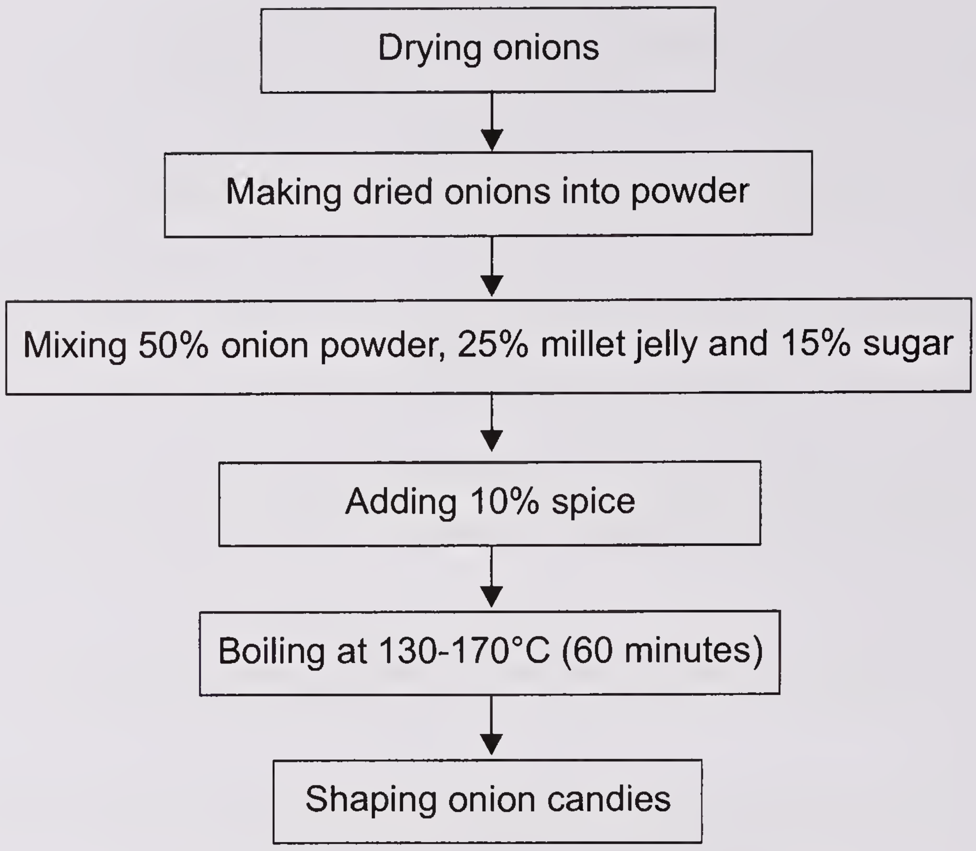

Fig.15.8 Preparation of onion -candy
Source: Bork (2000)

SABRETT sweet onion sauce does very well commercially, due to its frequent packaging with a more potent hot dog, its ingredients include a significant number of chemicals (i.e. preservatives, etc.), which lead to an undesirable flavour. Joseph (2013) has developed an improved process for developing sweet onion sauce.

Onion rings is a snack product, which is an excellent appetizer and side dish. Most of the processes for the preparation of onion rings involve deep frying in oil. Because of the high oil content, consumers who are health-conscious prefer to take lesser of this. So, the new processes for the preparation of healthy onion rings by baking instead of deep frying have been evolved. Candy is the most preferred product by children. Making onion available in the form of candy would improve nutritional status of the children. Bork (2000) has developed a process for preparation of onion candy (Fig.15.8)

Future Thrust

Cultivar colour, TSS and other biochemical attributes have enormous role in storage potential of onions. By understanding mechanism of physiological processes vis-à-vis biochemical reactions, it would be easy to manage these processes towards increasing storage potential. It has been well substantiated that though physiologically onion is regarded as non-climacteric, ethylene and ethylene-binding inhibitor, 1-MCP, both can suppress onion sprouting. However, transcriptional analysis revealed that sprout suppression of onion during storage using ethylene and/or 1-MCP was mediated through differential modes of actions (Cools *et al.*, 2011). The signal transduction pathways of both ethylene and 1-MCP may unfold cascade for sprouting in onion. Further, physiological weight loss due to respiration over the period of storage is a major issue. Carbohydrate metabolism during respiration, which is a primary cause of physiological weight loss during storage, needs to be unraveled to provide actual insight into the complex reactions.

The pre-harvest agronomic practices—irrigation regime, fertilizer regime, application of micronutrients, diseases and insect-pests attack, harvesting indices and stage—affect onion shelf-life. Therefore, comprehensive package of practices based on agroclimatic conditions is the need of hour. Apart from pre-harvest practices, post-harvest management practices including curing and storage environment need to be standardized. Cold storage can be a viable alternative when higher cost price fluctuations in the markets are of frequent nature. Innovations in during the cold storage technology during the recent years have given an option to use cold storages for onion without irradiation. The primary R&D endeavours have substantiated that non-irradiated onions can be stored in cold storages with appropriate ventilation facility that maintains appropriate CO_2 concentration in the storage. The technology needs to be tested further for appropriate recommendations on the following operations.

- Pre-cooling temperature and schedule
- Optimum humidity with controlled effective ventilation vis-à-vis ambient temperature
- CO_2 and O_2 concentrations in cold storage
- Gradual cooling period after loading or conditioning
- Maximum period of storage in case of glut
- Gradual heating period before unloading or conditioning
- Re-loading temperature in case of sudden price fall in the market due to glut

Onion is one of the nutrient-affluent vegetables, which is consumed daily as an ingredient in different food products. The demand for its convenient and ready to cook or eat processed products is growing day by day. Processing of onion into different value-added processed products would lead to reduced post-harvest losses when there is a glut in the production, and would also augment value of onions and give better remuneration to farming community.

Onion storage has been found to be a multifaceted function. The innovations done in post-harvest handling and storage of onion have largely been evolved from the traditional approaches. Processing sector is limited to export. Therefore, it is high time that post-harvest handling, storage and processing of onion should be dealt with scientific and engineering dimensions. There is an urgent requirement of varieties with high storability, uniform colour, size, shape, etc. without compromising yield. Development of low-cost storage structures, preferably cold storages, would be highly valued. Entire packaging line for onions needs to be revisited to improve working efficiency. Apart from minimally processed products, powder and paste, development of blended products is also a demand of the present time.

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Biochemistry and Nutraceutical Properties

16

Shamina Azeez and K.S. Shivashankara

Many claims have been made regarding the medicinal properties of the onion—it is a source of energy; acts as a stimulant and mild counter-irritant; crushed raw onion can be applied to the forehead to relieve headache. Red small onion can be used as an expectorant. Raw onion helps control coronary heart disease, thrombosis and blood pressure, and reduces cholesterol level by increasing high-density lipoproteins. Onion is also used in the treatment of anaemia, urinary disorders, bleeding piles, teeth disorders and ulcer and as platelet anti-aggregating agent (Yadav *et al.*, 2012). Moreover, onion is antimicrobial, antioxidant, antiasthmatic, immunomodulatory and prebiotic (Crozier *et al.*, 1997). In India, onions are also used to heal infected blisters. However, onions can cause migraine and flatulence also. Eating raw onions also lead to bad breath. In India, some people do not consume onions as they believe them being aphrodisiac. Various schools of Buddhism also advise against eating vegetables of *Allium* family.

Onion is used in both fresh and dried forms; dried onions are important in world trade, and are made into flaked, minced, chopped and powdered forms to add flavour in the processed food (Yadav *et al.*, 2012).

Onion Chemistry

Proximate composition

According to the USDA National Nutrient Database for Standard Reference (2007), the nutritional composition of raw onion per 100 g of edible portion contains 89.11 g of water, 1.10 g of proteins, 0.10 of total lipids (fat), 0.35 g of ash, 9.34 g of carbohydrates, 4.24 g of total sugars and 1.7 g of total dietary fibre, corresponding to energy of 40 kcal. The most important minerals are potassium, calcium and selenium. Onion is a very good source of vitamins B6 and C, chromium, biotin and fibre. They are also a

Table 16.1 Chemical composition of the onion (Sharma, 2006)

Constituents	Nutritional value (per 100 g)
Energy	166 kcl
Carbohydrates	9.34 g
Sugar	4.24 g
Dietary fibre	1.7 g
Fat	0.1 g
Protein	1.1 g
Water	89.11 g
Calcium	23.00 mg
Potassium	146.00 mg
Vitamin C	7.40 mg
Riboflavin	0.027 mg
Sodium	4.00 mg
Niacin	0.116 mg
Phosphorus	29.00 mg

Source: USDA Nutrient Database (2007)

good source of folic acid and vitamins B1 and K (Table 16.1).

Polysaccharides

Golovchenko *et al.* (2012) extracted polysaccharides and reported that they contained a mixture of galactan with short-length sugar chains, pectic polysaccharides and proteinaceous material. Galacturonan and rhamnogalacturonan are the main constituents of the linear regions of the sugar chains of the pectic polysaccharides (Fig. 16.1). The ramified regions include rhamnogalacturonan-I, the side chains of the ramified region mainly contain 1, 4-linked ß-d-galactopyranose residues and lesser content of 1,3-linked ß-d-galactopyranose and 1,5-linked ⟨-l-arabinofuranose residues. The proteinaceous material was found partly linked to sugar chains. The structure of a water-soluble pectic polysaccharide (PS) isolated from immature onion was investigated using acid hydrolysis, methylation analysis, periodate oxidation study, and NMR studies by Patra *et al.* (2013), and deduced to be d-galactose, 6-O-Me-D-galactose, 3-O-acetyl-d-methyl galacturonate and d-methyl galacturonate.

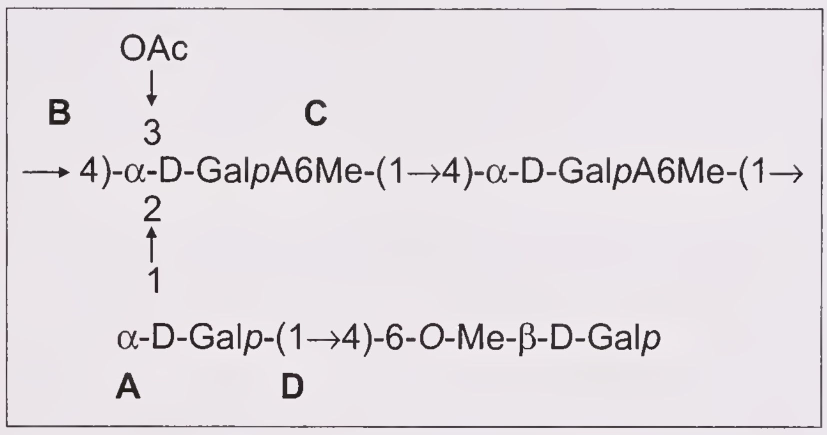


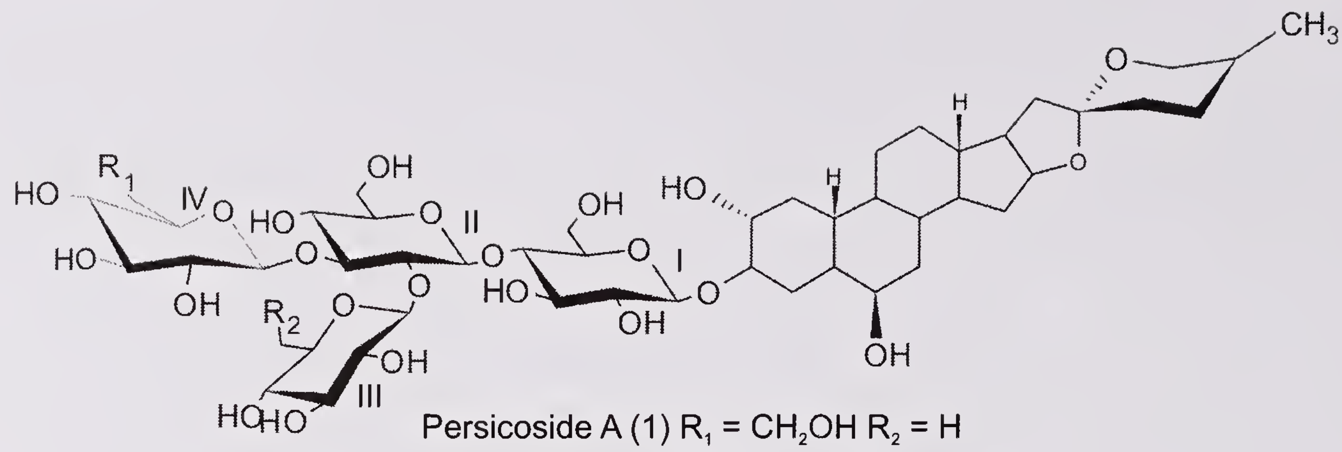
Fig. 16.1 Structure of a water-soluble pectic polysaccharide from immature onion-stick (Patra *et al.*, 2013)

Sadeghi *et al.* (2013) isolated new phytochemicals from seeds of Persian leek. Two new spirostane glycosides (persicosides A and B) and four new furostane glycosides (persicosides C1/C2 and D1/D2), one cholestane glycoside (persicoside E) together with furostane glycosides (ceposides A1/A2 and C1/C2, tropeosides A1/A2 and B1/B2, and ascalonicoside A1/A2,) have already been described in white onion, red Tropea onion and shallot, respectively (Fig. 16.2).

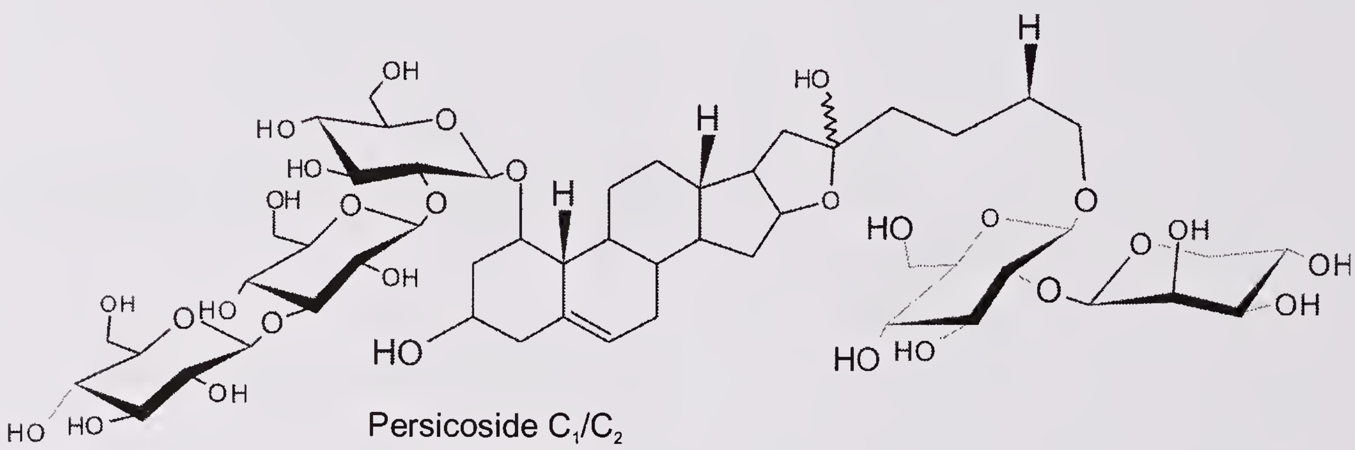
Phenolic acids and flavonoids

Other constituents found in onions include phenolic acids: ellagic, caffeic, sinapic and p-coumaric acids; pectin; sterols; saponins and volatile oils. In many countries, the major sources of non-nutritive components such as dietary flavonoids are onions, apples and tea (Hertog *et al.,* 1992). Onions contain significant amount of a flavonoid called quercetin (3,3',4',5,7-pentahydroxyflavone) (Fig. 16.3), which is two to three times more bioavailable from onions than from tea or apple (Singh, 2005). Shallots have the most phenols, six times the amount found in Vidalia onion(the variety with the lowest phenolic content); shallots also have the most antioxidant activity. Western yellow onions have most flavonoids, eleven times the amount found in Western white (the variety with the lowest flavonoid content).

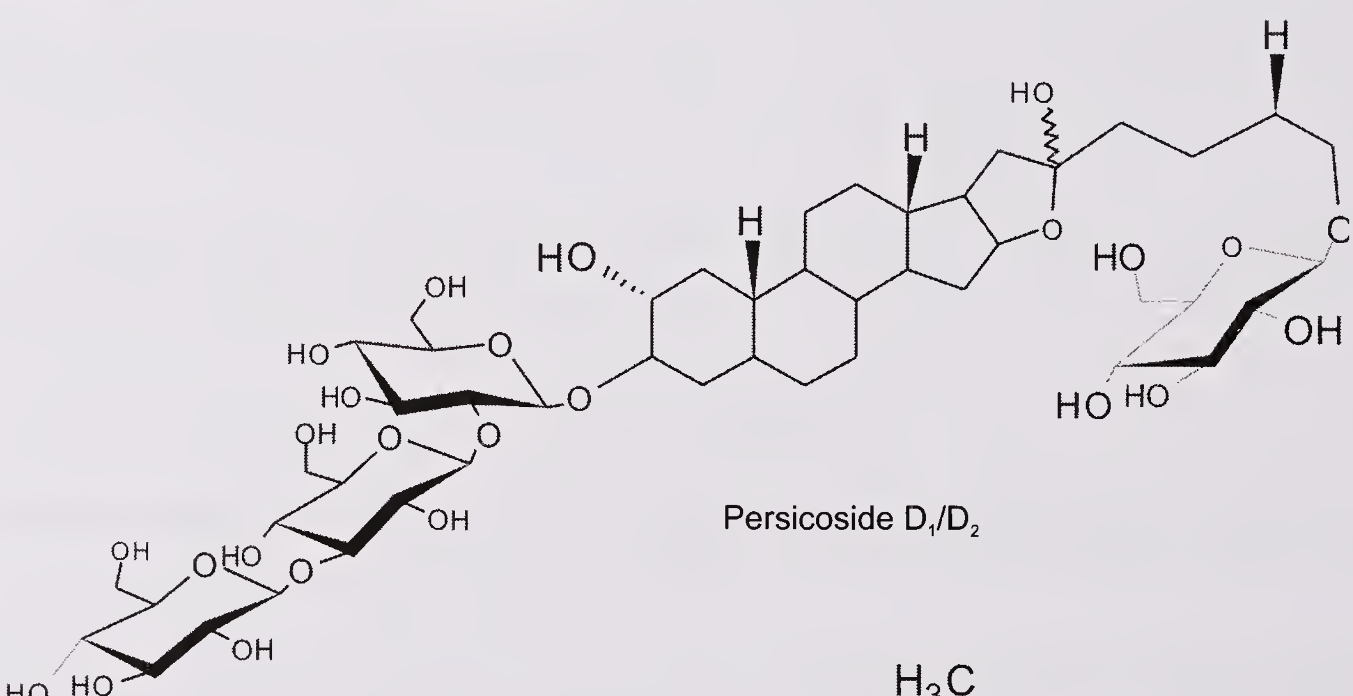
The major flavonols of a mature red onion bulb are quercetin derivatives (3,42-O-diglucoside and 42-O-monoglucoside) (Pérez-Gregorio *et al.*, 2011a) (Fig. 16.3), accounting for about 93% of the total flavonols (334±60 mg Q per kg, fresh weight), and are mainly responsible for IC 50 antioxidant activity of 15.84±3.73 g/kg. The



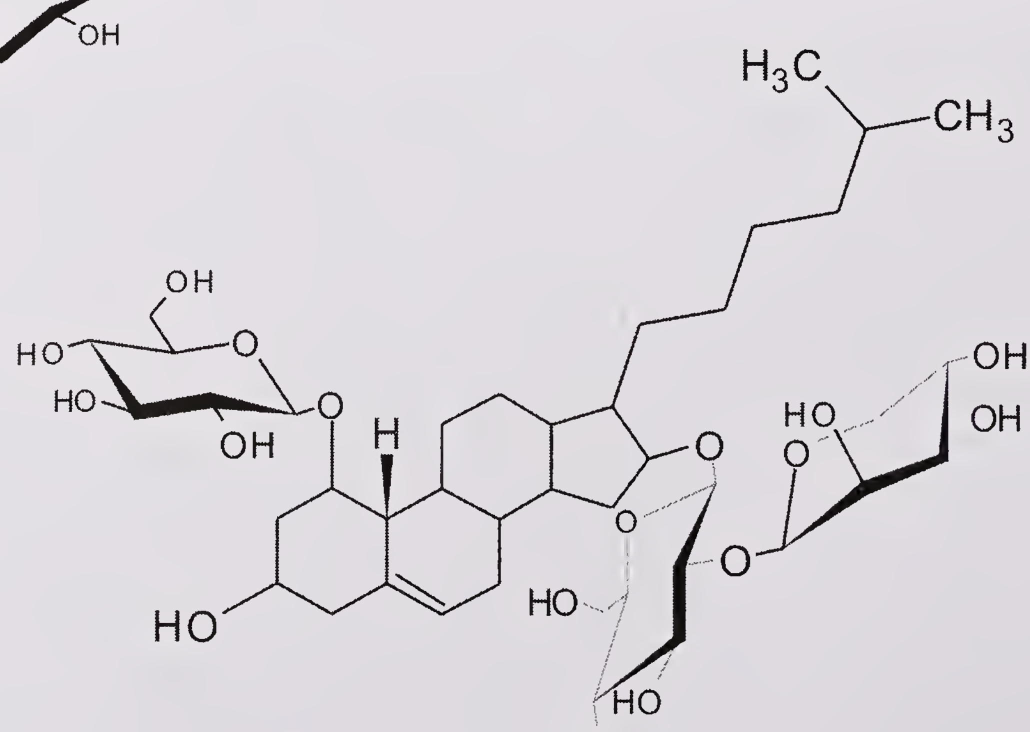
Persicoside A (1) $R_1 = CH_2OH$ $R_2 = H$
Persicoside B (2) $R_1 = H$ $R_2 = CH_3$



Persicoside C_1/C_2

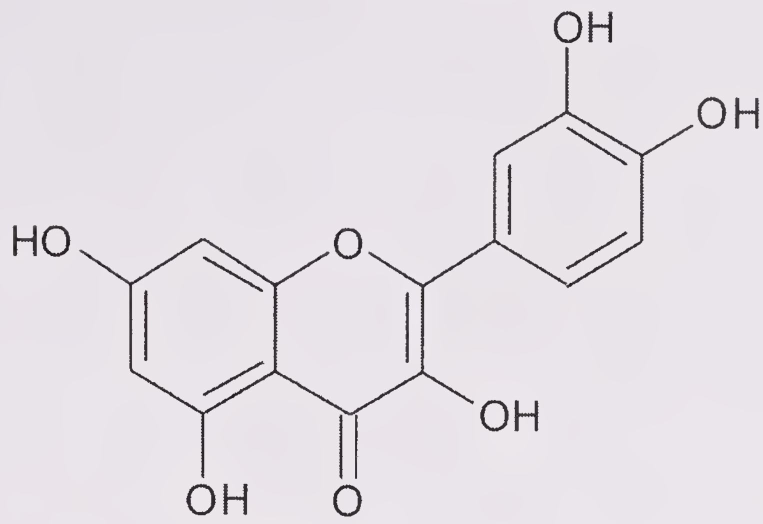


Persicoside D_1/D_2

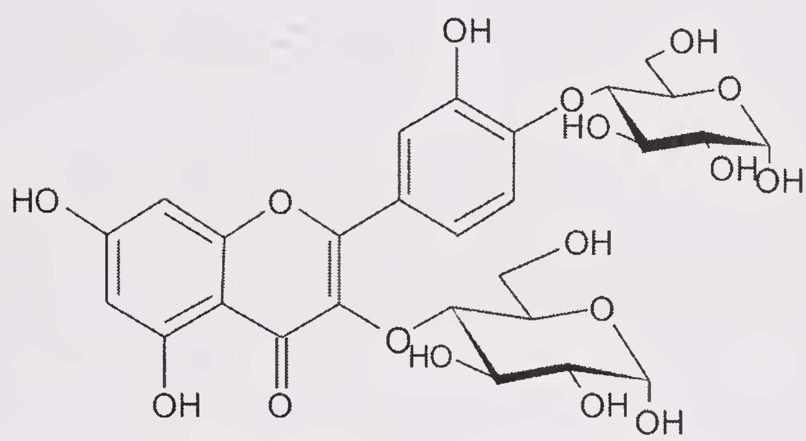


Persicoside E

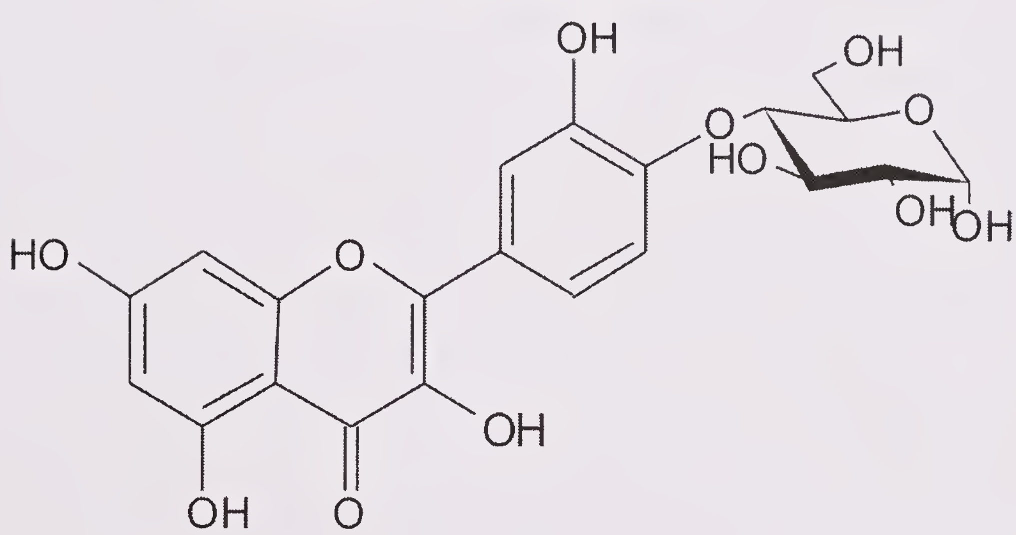
Fig. 16.2 New saponins of *Allium ampeloprasum* subsp. persicum (Sadeghi *et al.*, 2013)



Quercetin



Quercetin-3,4'-di-O-β–glucoside



Quercetin-4'-di-O-β–glucoside

Fig. 16.3 Chemical structures of quercetin (3,3',4',5,7-pentahydroxyflavone) and its major glucosides in onion

remaining flavonol fraction (approx. 7%) comprises 8 different components of which quercetin-3-O-glucoside and isorhamnetin-4-glucoside (Fig. 16.4) are prominent, although each contributes less than 3% of the total flavonol fraction. Instead, quercetin represents less than 1% of the total flavonols. In red onion, eight anthocyanins (which represent less than 1% of the total flavonols) are also found at a total level of 2.1±0.05 mg cyanidin-3-glucoside per kg (fresh weight). Also, 4 of them (cyanidin 3-glucoside (C3g) > cyanidin 3-(62 2-malonylglucoside) > cyanidin 3-(62 2-malonyl-laminaribioside) > cyanidin 3-laminaribioside) account for 95% of the total anthocyanins (Figs 16.5a, b, c, d). Among the eleven flavonoids characterized in onion, isorhamnetin-4'-O-galactoside was identified for the first time by Lee *et al.* (2012d). When the healthy bulb was inoculated with fungus *Fusarium oxysporum*, two quercetin derivatives and two isorhamnetin derivatives underwent concentration changes typical for the defence mechanism against the pathogens.

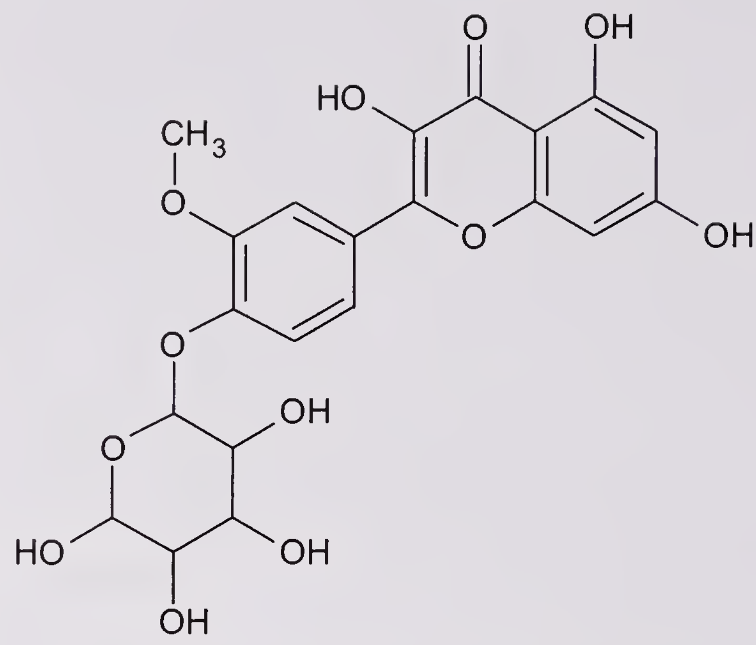
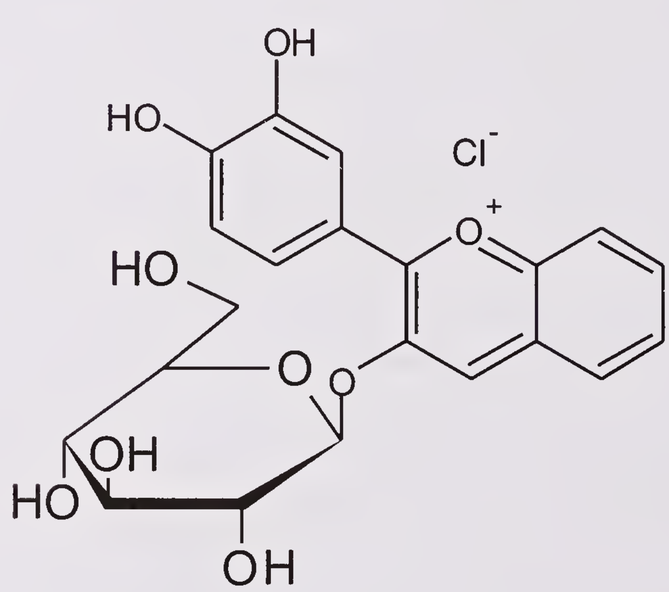


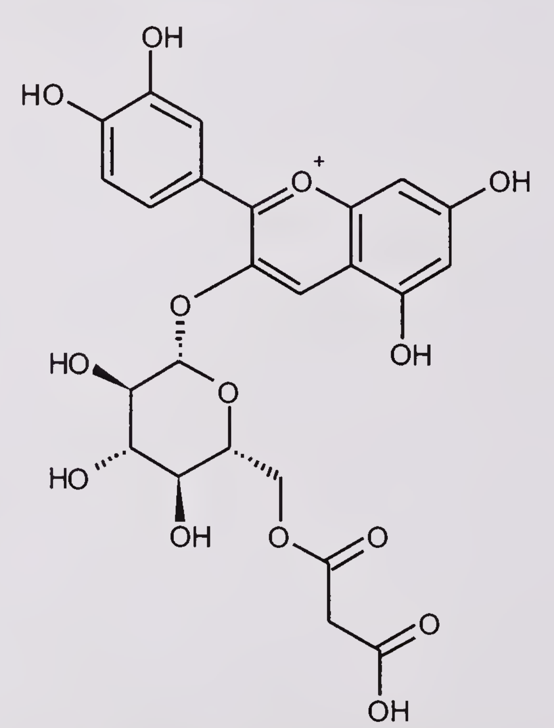
Fig. 16.4 Isorhamnetin-4'O-glucoside

Quercetin occurs as glycosides in foods, and it is species- and cultivar-specific. In humans, quercetin undergoes extensive biotransformation to a range of metabolites (i.e. sulphate, glucuronide or methyl conjugates), which determine its bioactivity. Primary metabolites identified in human plasma over 24 hr after consumption of onion powder containing quercetin glycosides include quercetin sulphate, quercetin glucuronide, quercetin diglucuronide and a quercetin glutathione adduct (Lee *et al.,* 2012c).

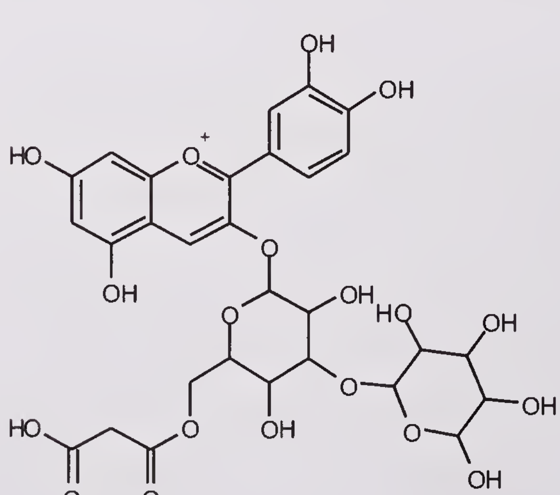
a Cyanidin 3-glucoside



b Cyanidin 3-(6"-malonylglucoside)



c Cyanidin 3-(6"-malonyl-laminaribioside)



d Cyanidin 3-laminaribioside

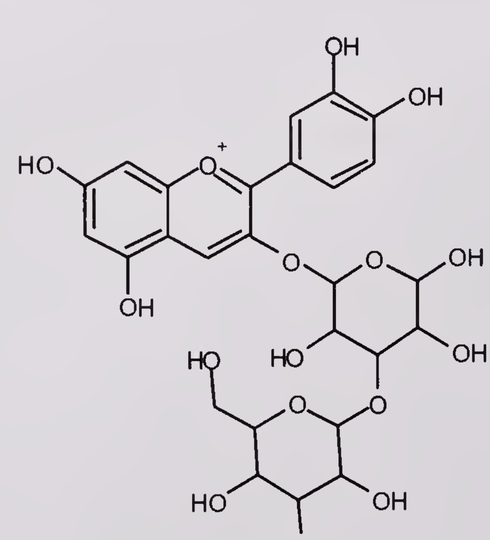


Fig. 16.5 Major anthocyanins in onion

Onion aroma, flavour and pungency

Allium spp. have been classified chemotaxonomically based on the nature and abundance of thiosulphinates and related compounds (Block *et al.*, 1992; Thomas and Parkin, 1994). Sensory appraisals of strong-flavoured onion (pungency or aroma) correlates positively with concentrations of certain non-protein sulphur amino acid compounds such as thiosulphinates, thiopropanal sulphoxide (the lachrymatory factor) and pyruvic acid (Freeman and Whenham, 1975; Crozier *et al.*, 1997). These compounds are produced during tissue disruption and subsequent hydrolysis of S-alk(en)yl-L-cysteine sulfoxide (ACSO) by alliinase (Lancaster and Kelly, 1983; Block, 1992; Randle, 1997). Hydrolysis of ACSOs yields ammonium pyruvate and an unstable sulphenic acid, which rapidly decomposes to thiopropanal sulphoxide (Block, 1992; Thomas *et al.*, 1992). Pyruvic acid determination is relatively simple and is used to measure *Allium* flavour (Abbey *et al.*, 2001).

The principal volatile flavour component in edible and decorative species of *Allium*, the amino acid precursor, present in the intact tissues of *A. cepa* L. (onion) is S-1-propenyl-L-cysteine sulphoxides; of *A. sativum* L. (garlic)is S-2-propenyl-L-cysteine sulphoxides and of *A. aflatunense* B. Fedtschenko is S-methyl-L-cysteine sulphoxides (Freeman and Whenham, 1975).

According to Randle *et al.* (1995), understanding dynamics of flavour accumulation in onion and other Alliums is important for food and phytomedicinal industries for greater product standardization and characterization. They have reported that sulphur deficiency during active bulbing, resulted in dominance of ACSO flavour precursor (+)S-methyl-L-cysteine sulphoxide, and the flavour pathway was a strong sink for available S. At luxuriant S fertility levels, *trans*-(+)-S-(1-propenyl)-L-cysteine sulphoxide (PRENCSO) was the dominant ACSO; concentration of γ-Glutamyl peptide (γ-GP), the penultimate compound leading to ACSO synthesis, correlated with S fertility. Nearly 95% of the total bulb S could be accounted for in the measured S compounds at low S fertility. However, at the highest S treatment, only 40% of the total bulb S could be attributed to the ACSO and γ-GP, indicating that other S compounds were significant S reservoirs in onions. Concentrations of enzymatically produced pyruvic acid were most closely related to PRENCSO (*trans*-(+)-S-(1-propenyl)-L-cysteine sulphoxide) concentrations.

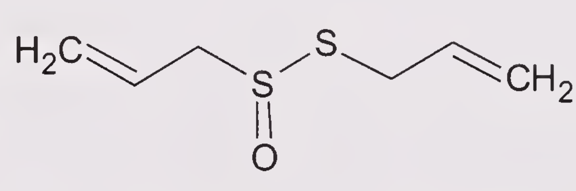
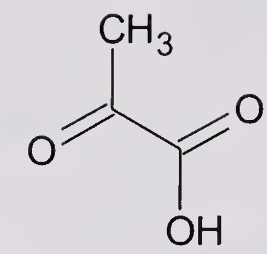


Fig. 16.6 Allicin, an organo-sulphur compound in onion

Like garlic, onion-bulbs contain significant amount of beneficial organo-sulphur compound allicin (Fig. 16.6) and its derivatives or flavonoid glycosides (Xiao and Parkin, 2002), as also the Allinase enzyme, released when an onion is cut or crushed. One of the most intriguing questions about the flavour compounds is their role within Alliums, which is discussed at length in a review by Jones *et al.* (2004)—two roles ascribed are for defence against pests and predation, particularly in over-wintering bulbs, and for carbon, nitrogen and sulphur storage. In general, mild flavoured onions are reported to have poorer storage properties.

Onion flavour and pungency are attributed to its pyruvic acid content (Freeman



Pyruvic acid

and Whenham,1975). Enzyme allinase acts only on the S-alk(en)yl cysteine sulphoxide precursors to produce pyruvic acid as a product of enzymatic cleavage (Randle and Bussard, 1993). Onions with low levels of pungency and sweet flavour are more popular with international consumers, and this trend is predicted to increase. Large-scale screening of onion-bulbs for pungency requires a fast and cost-efficient method. The original method proposed by Schwimmer and Weston (1961), is slow and tedious, and involves use of dinitrophenyl hydrazine (DNPH), a chemical difficult to handle and very toxic. This method is not user-friendly when large quantities of samples are to be analyzed in breeding programme. Also studies by Yoo *et al.* (2011) have revealed that when pyruvic acid concentration is estimated by the DNPH test, fructose, a major sugar in onion juice, causes degradation of colour adduct in onion pungency test, resulting in underestimation of pyruvic acid concentration. A 96-well microplate procedure was developed for pyruvic acid analysis by Ibáñez *et al.* (2012) to screen a large number of onion-bulbs in breeding programmes, based on the selective reaction of p-dimethy laminobenzaldehyde with enzymatically produced pyruvic acid. With this method, which showed high correlation with spectrophotometric method, it is possible to determine pyruvic acid content in 96 onion-bulbs in just a few minutes. Russo *et al.* (2013) have developed a non-destructive, metal oxide sensor (MOS)-based electronic nose to discriminate three "Tropea Red Onion" PGI ecotypes from one another and common red onion, which is usually used to counterfeit it. The e-nose analysis is an artificial olfactory system, with potential for use as an innovative, rapid and specific non-destructive technique, and may provide a method to protect food products against counterfeit it.

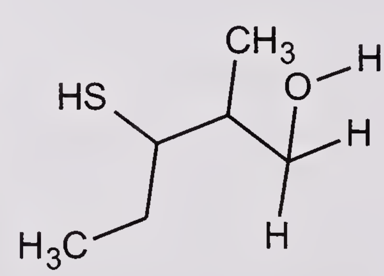


Fig. 16.7 (±)-2-methyl-3-sulfanyl-pentan-1-ol; the key odourant in fresh green onion

The long-lasting presence of onion flavour in the mouth is due to the action of mouth microflora on the non-volatile flavour precursors. The key odourant for the fresh green onion tonality is (±)-2-methyl-3-sulfanyl-pentan-1-ol (Fig. 16.7), and it originates from its corresponding cysteine-S-conjugate. The glutathione cycle ultimately releases volatile organic sulphur compounds (Fig. 16.8). The occurrence and concentrations of four S-(+)-alk(en)ylthio-l-cysteine derivatives in onion are estimated to be 0.19 mg/kg S-methylthio-l-cysteine, 0.01 mg/kg S-propylthio-l-cysteine, and 0.56 mg/kg (S-(1-propenyllthio)-l-cysteine; concentrations which are about 3,000 times lower than isoalliin (S-(1-propenyl-S-oxo-l-cysteine). These compounds were treated with *Fusobacterium nucleatum*, a microorganism responsible for the formation of mouth malodour. These l-cysteine disulphides were demonstrated to predominantly produce tri- and tetrasulfides. Isoalliin is almost entirely consumed by plant enzyme alliin lyase (EC 4.4.1.4 S-alk(en)yl-S-oxo-l-cysteine lyase) in a few seconds, but is not transformed by *F. nucleatum*. This example of flavour modulation shows that plant produces different precursors, leading to formation of the same type of volatile sulphur compounds. Whereas the plant enzyme efficiently transforms S-alk(en)yl-S-oxo-l-cysteine; mouth bacteria are responsible

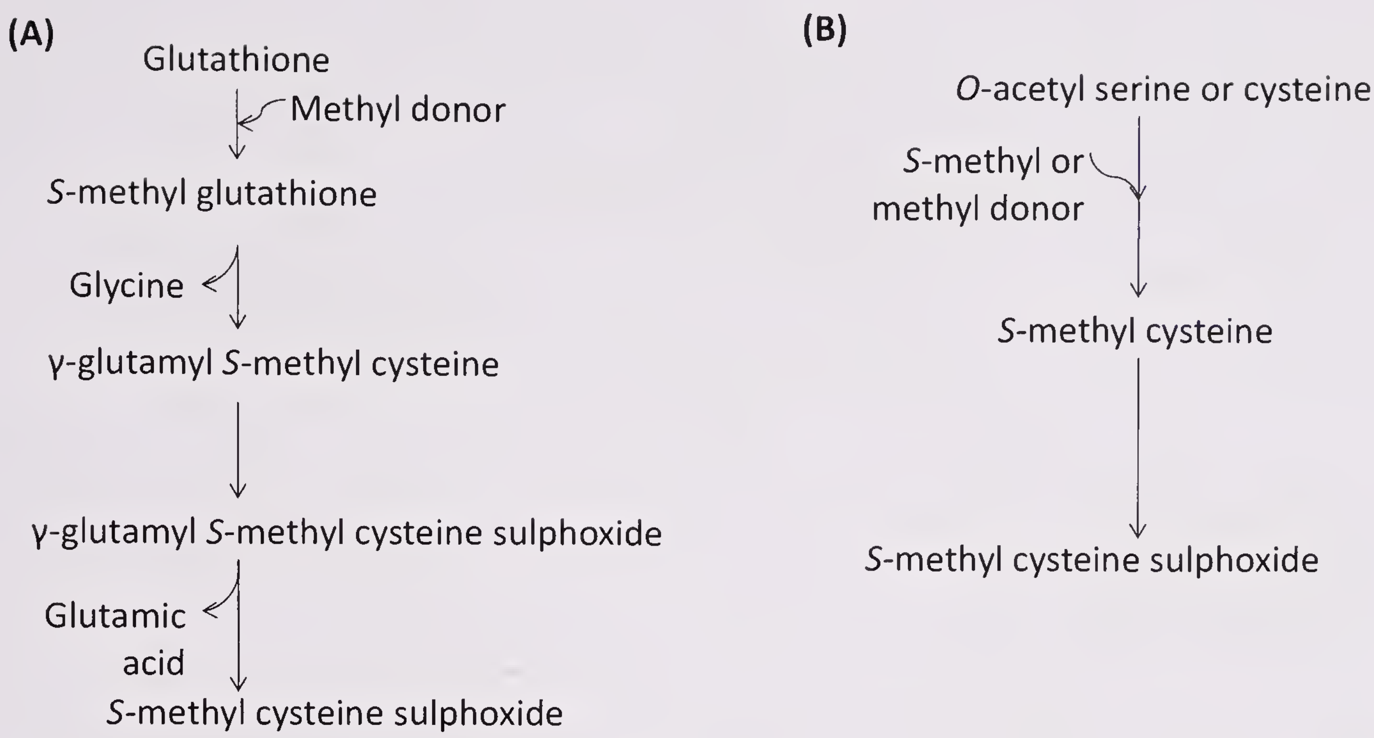


Fig. 16.8 Two proposed pathways for synthesis of *Allium* flavour precursors, shown for the synthesis of methyl cysteine sulphoxide. (Adapted from Granroth, 1970; Lancaster and Shaw, 1989). Pathway **A** (*left*) illustrates participation of glutathione, which is methylated, and then through loss of glycine, oxidation, and, finally, loss of the γ-glutamyl group, converted to methyl cysteine sulphoxide. Pathway **B** (*right*) shows an alternative route *via* direct methylation of *O*-acetyl serine to yield methyl cysteine sulphoxide).

for transformation of S-alk(en)ylthio-l-cysteine (Starkenmann *et al.*, 2011a, b).

Aziz Qureshi *et al.* (2012) reported that increased application of selenium (Se) in a sand culture trial gave an antagonistic effect on sulphur (S) assimilation, and decreased pungency and quercetin concentration. Though Se is essential from a health point of view, its application up to 10 kg/ha was sufficient for enriching onions without much effects on the other essential bulb-quality parameters.

Lachrymatory factor in onion

Most people experience lachrymatory smell, which is emitted when an onion-bulb is cut. Among all varieties, Asian white onions have the most eye-irritating reaction. In normal onion, *trans*-S-1-propenyl-l-cysteine sulphoxide is transformed *via* 1-propenesulphenic acid into propanethial S-oxide, a lachrymatory factor (LF), through successive reactions catalyzed by alliinase and lachrymatory factor synthase (LFS) (Corzo-Martinez *et al.*, 2007) (Fig. 16.9).

LF was identified more than 40 years ago, and LFS was identified in 2002. As LF is pungent to humans, a low-LF-producing onion would be sweet; and moreover, suppression of LF production would cause increased thiosulphinates (previously reported as "zwiebelane isomers"), which may be a precursor of health beneficial sulphur compound. After purification by recycle high-performance liquid chromatography, Aoyagi *et al.* (2011) established planar structure of the putative "zwiebelane isomers" and their inhibitory activities against cyclooxygenase-1 and a-glucosidase *in vitro*. He *et al.* (2011) and Masamura *et al.* (2012a) have characterized LFS found in onions, which catalyses rearrangement of 1-propenesulphenic acid to (Z)-propanethial S-oxide, the onion lachrymator. Based on the type of the reaction it catalyzes, the onion LFS is classified as an isomerase, and called "sulphenic acid isomerase". Masamura *et al.* (2012c)

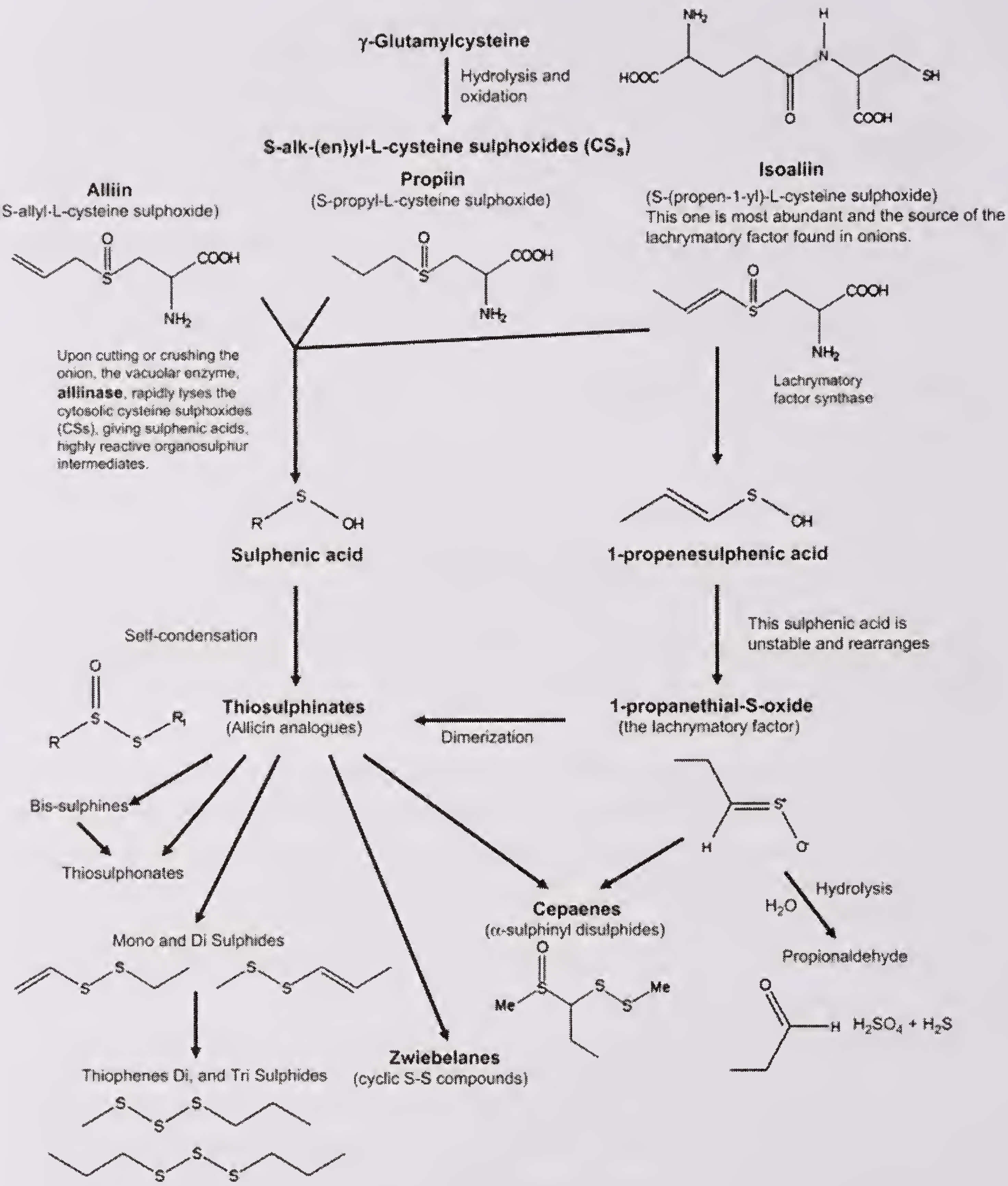


Fig. 16.9 Formation of organo-sulphur compounds during metabolic pathways in processed onion (Corzo-Martinez *et al.*, 2007)

identified catalytic amino acid residues of *LFS* to elucidate unique catalytic reaction mechanism of this enzyme—two amino acids (Arg71 and Glu88) were indispensable for LFS activity. *LFS* is an important target gene in onion breeding for both flavour intensity and health. Masamura *et al.* (2012b) showed that *LFS* genes are localized in the proximal region of the long-arm of chromosome 5.

Pink discolouration of onion

"Pinking" of onion is initiated when E-(+)-S-(1-propenyl)-l-cysteine sulphoxide is first cleaved by alliinase to yield colour developers, which react with amino acids, like valine to form pigment precursors (PPs) (Kato *et al.*, 2013). The PPs react with naturally occurring carbonyls to form pigments. A trimeric structure was predicted for one of the pink pigments by these authors; which was the first report. The chemical structures of pink-red pigments produced from individual amino acids (glycine, alanine, leucine, asparagine, glutamine, tyrosine, and cystine) responsible for 'pinking' in macerated onion were tentatively elucidated by Lee *et al.* (2012b).

Factors Affecting Nutritive Value

Stage of maturity and storage

Nutritional composition of onions varies depending on the variety and the stage of maturity. During maturity, there is a massive export of carbohydrate reserves, total and reducing sugars from the leaves to onion-bulb (Benkeblia, 2012). Storage conditions also affect quality of onion cultivars: when 'Pusa White Round' and 'Pusa Red' were stored under ambient conditions, pungency and ascorbic acid content decreased, while total antioxidant capacity increased. 'Pusa Red' was found suitable for storage as pungency loss was least; 'Pusa White Round' was suitable for dehydration with minimum browning (Patil *et al.*, 2012). Shallot cultivars, when stored under different atmosphere compositions, showed highest weight loss in normal atmospheric conditions but dry matter increased in 5% CO_2+5% O_2 atmospheric composition. Colour of dry and fleshy scales changed depending on the cultivar and the atmosphere composition (Bajer and Gajewski, 2012).

Due to the maritime climate of the UK, onions are artificially cured in closed environments. Curing removes excess water from the outer skin, and seals neck to reduce infection and to minimize weight loss. Current curing practise involves holding onions at 28°C for three-six weeks, which results in a golden-brown colour appreciated by consumers. Cepaic acid, a possible oxidation product of quercetin, has been identified as a pigmented compound in the dry onion skin. Cools *et al.* (2012) showed for the first time that increase in brown pigmentation during curing at higher temperatures is linked to loss of quercetin glucosides, possibly by conversion into brown oxidative products.

Processing effect

Sterilization is a good method to stabilize onion by-products for use as a potential dietary fibre ingredient (Benítez *et al.,* 2011). Physicochemical properties of onion waste change slightly with sterilization. Insoluble dietary fibre decreases and soluble dietary fibre increases with sterilization, improving soluble: insoluble ratio, decreasing oil holding capacity, cation exchange capacity and swelling capacity. The main sanitizing procedure contributing to the loss of flavonols in fresh-cut onion slices is their solubility in immersion water, followed by acidified sodium hypochlorite (Perez-Gregorio *et al.,* 2011a). In dry decontamination treatments like UV-C irradiation, natural levels of flavonoids in fresh-cut onion slices significantly increase to 35% for flavonols and 29% for anthocyanins. This is a recommended treatment.

Freeze-drying of mature red onion bulb increases extraction of flavonoids up to 32% of flavonols and 25% of anthocyanins; freeze-dried onion powder when stored at room temperature, in dark, in air- and water-tight glass bottles retained stability of all flavonoids up to 6 months (Pérez-Gregorio *et al.,* 2011b). In spite of low recovery of extractable flavonoids (quercetin 3,42-diglucoside, 42-glucoside and 3-glucoside), extraction by microwave (which induces disruptions of vacuoles and cell walls), hydrodiffusion and gravity exhibited highest antioxidant activities compared to conventional solvent extraction method (Zill-e-Huma *et al.*, 2011b). Extraction by this new method, a modified form of solvent-free microwave hydrodiffusion and gravity technique, proved to be an efficient and environment-friendly technique, for extraction of flavonols at the lower reactor temperature with improved alterations of tissues, in less time, and in the absence of any solvent (Zill-e-Huma *et al.,* 2011a).

Medicinal Properties of Onions

Onion has been reported to alleviate cataract, cardiovascular disease, asthma and ulcer (Canizares *et al*., 2007). It is also used as an antimicrobial (Whitmore and Naidu, 2000), an anti-aggregating agent and as an antioxidant (Nuutila *et al.*,

Table 16.2 Uses of onion in folk medicines (USDA Nutrient Database 2013)

Ailments	Onion preparation
Cough	Onion juice mixed with ginger juice and honey as an expectorant
Cold	Eating raw onion or applying raw onion juice on the forehead relieves cold
Asthma	Onion juice mixed with ginger juice, black pepper and salt or ground onion with honey control asthma, and cure throat and lung problems
Tuberculosis	Eating raw onions prevents TB infection
Ear pain	Drops of lukewarm onion juice cures ear pain
Eye	One drop of onion juice diluted with rose water improves eyesight
Hysteria	Loss of consciousness due to hysteria can be cured with the smell of onions or by rubbing patients' feet with crushed onions
Cholera	One cup of onion juice mixed with juice of one lemon, one teaspoon of ginger juice, pinch of salt (table salt or black salt) given in four equal doses a day prevents cholera
Jaundice	Small onion cut into four pieces soaked in vinegar or lemon juice taken with salt and black pepper twice a day helps cure jaundice
Kidney stone	Onion juice mixed with sugar helps break kidney stones
Diarrhoea	Applying onion paste on navel region helps cure diarrhoea
Nose bleed	Few drops of onion juice applied to nose
Skin diseases	Onion mixed with turmeric powder and mustard oil, heated on fire and applied on abscesses, helps drain out pus. Onion-juice (¼ cup) mixed with water (one cup) used to wash wounds etc., and applying a dressing of the same, acts as a disinfectant and relieves itching
Heat stroke	Eating raw onions in summer reduces chances of heat strokes
Menstrual disorders	Onion juice mixed with gur taken regularly helps relieve menstrual disorders
Dental problems	Eating raw onion prevents bacterial growth in the mouth, stops dental decay, helps cure dental problems
Insomnia	Onion juice (1 tsp) mixed with milk or honey taken at bed-time induces sleep
Arthritis	Rubbing onion juice with sesame oil cures arthritis

2003). It is also known to enhance reproduction, improve growth performance (body weight gain, feed consumption, feed conversion) and delay ageing, which are attributed to phenolic compounds (flavonoids, anthocyanins, phenolic acids and flavonols), organosulphur compounds, vitamins and minerals (Teyssier *et al.,* 2001; Furusawa *et al.*, 2003; Kamal and Daoud, 2003; Ismail *et al.,* 2003; Wang *et al.*, 2005) (Table 16.2). Millet *et al.* (2012) found that compared to aqueous and methanolic extracts, lactic-acid fermented aqueous extracts, which lack usual onion flavonoid profile, were most bioactive in assays such as antibacterial, antigenotoxic and antiproliferative activities. Fresh white onions contain higher quantities of bioactive compounds (polyphenols, flavonols, flavonoids, anthocyanins and tannins) than onions boiled for 10 min. (Heeim *et al.*, 2012). Boiling also led to decrease in bioactivity; however, fresh and boiled (for 10 min) white onions can be considered as a functional food with high antioxidative and antiproliferative activities. Onion, being a rich source of many phytochemicals, as enumerated above, has many health promoting effects, and is considered to be a major nutraceutical. Composition of some of the flavonoids, anthocyanidins, total flaovonoids, phenols and antioxidant capacity is given in Tables 16.3 and 16.4.

Table 16.3 Phytochemicals in onion-bulbs (mg/100 g fresh weight) (USDA website)

Phytochemical	Red onions	White onions
Cyanidin	3.19	Nil
Delphinidin	4.28	Nil
Peonidin	2.07	Nil
Quercetin	39.21	7.30
Isorhamnetin	3.41	0.85
Myrcetin	2.70	Nil

Table 16.4 Total phenols, flavonoids, antioxidant activity, ferric-reducing property (FRP) and DPPH (radical scavenging activity) of white, yellow and red onions (Shivashankara and VeereGowda, 2005)

Genotypes	Colour	Phenol	TF	FRAP	DPPH
JNDW 85	White	51.34	2.94	8.08	23.62
PKV Selection	White	65.88	2.33	7.65	19.24
Pb White	White	74.39	2.16	8.08	27.49
Phule Suvarna	Yellow	76.61	3.85	30.21	30.32
Arka Pitamber	Yellow	79.06	4.93	31.91	25.74
Arka Niketan	Light red	88.76	4.75	23.46	30.23
INDAM DR1	Red	91.32	4.71	27.11	29.56
Arka Kalyan	Red	89.85	5.01	31.53	49.98
Agrifound Rose	Deep red	123.71	6.54	38.95	47.66
Arka Bindhu	Deep red	108.23	6.15	51.41	41.48

Antioxidant effects

Oxidative stress can increase risk of degenerative diseases and off-set premature aging related complications. The antioxidant compounds—polyphenols, anthocyanins, sulphur-containing compounds, vitamins and minerals—have been described in onion and garlic as powerful quenchers of singlet, hydroxyl and peroxyl radicals (Block *et al.*, 1994; Prasad, 1995; Suh *et al.,* 1999; Nuutila *et al.,* 2003; Ly *et al.,* 2005). Ascorbic acid present in the green onion plays a fundamental role in plant antioxidant response towards γ-radiation exposure, while polyphenols remain largely unchanged, as has been revealed from oxygen radical absorbance capacity, employing pyrogallol red (Jimenez *et al.*, 2011).

Xue *et al.* (2011) reported three phenolic compounds in onion peel—two known compounds, quercetin and quercetin 32-O-β-d-glucopyranoside (Q32 G), and one novel compound, quercetin 3-O-β-d-glucopyranoside-(4→1)-β-d-glucopyranoside (Q3M). Quercetin shows highest antioxidative activity, and Q3M is with the strongest anti-aging activity among these flavonoids, which may be related to its high hydrophilicity.

Red onions have higher flavonoids, anthocyanins, total phenols and FRAP and DPPH activities as compared to yellow and white onions. Red and yellow onions have significantly higher antioxidative and antiproliferative activities than white onions (Yang *et al.*, 2004). Red onion-peel is good and easily accessible source of nutraceutical compounds with significant antioxidant and antimutagenic properties, mainly due to the presence of polyphenols (ferulic, gallic, protocatechuic acids, quercetin and kaempferol) (Singh *et al.,* 2009) and induction of plasma SOD and GPx activities and inhibition of liver lipid peroxidation (Lee *et al.*, 2012a).

Lu *et al.* (2011) standardized use of mid-infrared spectroscopy to predict total antioxidant capacity of vegetables, including onions and shallots, and this provides a rapid and precise alternative to traditional wet chemistry analysis.

Immunomodulatory effects

Administration of Welsh onion green leaves (WOE) to mice showed a concentration-dependent inhibition on paw edema development after carrageenan treatment, closely attributing to decreased levels of tissue NO and tumor necrosis factor-a (TNF-a). Further evidence for WOE's protection was shown by reduction of lipid oxidation and increase of antioxidant enzyme activities, including catalase, superoxide dismutase and glutathione peroxidase *in vivo*. Further, WOE also decreased number of acetic acid-induced writhing responses and formalin-induced pain in the late phase in mice. Thus, WOE might have served as a natural source of anti-inflammatory compounds (Wang *et al.*, 2013). Supplementary onion extract enhanced humoral immune response in White Leghorn chickens; macrophages exhibited superior microbicidal activity and ROS production, likely to be attributed to high flavonoid contents (Hanieh *et al.*, 2012).

Anticancer effects

Preliminary studies have indicated that increased consumption of onions reduces risk of gastric and head and neck cancers (Dorant *et al.,* 1996). These antitumor and anticancer effects are attributed to organosulphur compounds (Block, 1994, 1997; Stavric, 1997), which reportedly increased activities of carcinogen detoxifying enzymes like quinine reductase and glutathione transferase in gut, liver, kidney, lungs, urinary bladder and spleen tissues of rats (Munday and Munday 2001). Onion extracts are reported to prevent brain edema and brain blood barrier hyperpermeability (Hyun *et al.*, 2013). Extracts of onion inhibited estrogen biosynthesis in human ovarian cells, an important strategy in treating breast cancer (Lu *et al.*, 2012).

Protection against cardiovascular diseases

Onion and its extract are reportedly effective against cardiovascular diseases, because of their hypocholesterolemic, hypolipidemic, anti-hypertensive, anti-diabetic, antithrombotic and anti-hyperhomocysteinemia effects. Liver abnormalities in rats fed with cholesterol-containing diet were corrected by supplementation with garlic, followed by red and white onions (Gorinstein *et al.*, 2011).

Onion diallyl sulphides (diallyl sulphide, diallyl disulphide, diallyl trisulphide) and thiosulfinates (methyl methane-TS, propyl propane-TS and 2-propenyl 2-propene-TS (allicin)) reduce risk of cardiovascular diseases by reducing erythrocyte and platelet oxidation and platelet aggregation (Briggs *et al.*, 2000; Chan *et al.*, 2002). Mechanism for antiplatelet effect of onion may, at least partly, involve inhibition of arachidonic acid release from platelets, thromboxane A2 synthase inhibition and TXA_2/PGH_2 receptor blockade (Moon *et al.*, 2000). Onion was found to have more favourable effect on the inhibition of thromboxane B2 in diabetic rats (Jung *et al.*, 2002).

Rapidly dried onion powder (OP) prepared from outer layers (second to fourth scale leaves from the surface) of onion-bulbs was effective in decreasing risk of arteriosclerosis in rats fed with high-fat diet as the result of the content of quercetin derivatives (Hamauzu *et al.*, 2011). Onion-peel extract changes expression of genes associated with cholesterol metabolism in favour of lowering blood LDL-cholesterol and enhancing HDL-cholesterol through increasing mRNA abundance of LDL receptor and ATP-binding cassette transporter *A1* genes (Lee *et al.*, 2012f). The anti-thrombotic effects of onion powder extract may also occur as a result of restricting induced expression of tissue factor *via* down-regulating mitogen-activated protein kinase activation upon coagulation stimulus, leading to prolongation of time for arterial thrombosis (Lee *et al.*, 2013).

Formation of cholesterol gallstones in gallbladder is controlled by procrystallizing and anticrystallizing factors present in the bile. Dietary garlic and onion have anti-lithogenic potential by beneficial modulation of biliary cholesterol saturation index. These *Allium* spices also influence cholesterol nucleating and anti-nucleating protein factors, which contribute to their anti-lithogenic potential (Vidyashankar *et al.,* 2010). In mice fed with high cholesterol diet, fenugreek, onion and their combination reduced incidence of cholesterol gallstones, with attendant reduction in total cholesterol, cholesterol/phospholipid ratio content in the serum, liver and bile; reduced fat accumulation in liver and inflammation of gallbladder membrane (Reddy and Srinivasan, 2011).

Whole, quarters and crushed onions lost their *in-vitro* anti-platelet activity after 30, 20, and 10 min. of oven heating, respectively. The longer retainment of antiplatelet activity in intact bulbs was attributed to a later alliinase inactivation. In fact, extensively cooked onions may stimulate rather than inhibit platelet aggregation (Cavagnaro and Galmarini, 2012).

Antiobesity effect

Moon *et al.* (2013) demonstrated that the antiobesity effects of quercetin-enriched onion peel extract (OPE) are through suppression of pre-adipocyte differentiation and inhibition of adipogenesis. They found that lipid accumulation and triglyceride contents in 3T3-L1 preadipocytes cells were markedly suppressed by OPE; mRNA levels of activating protein (AP2) were down-regulated and those of carnitine palmitoyl transferase-1 α (CPT-1α) and fatty acid binding protein 4 were up-regulated. Peroxisome proliferator-activated receptor ã mRNA levels were down-regulated in epididymal fat of OPE, and significant down-regulation of CCAAT/enhancer binding protein mRNA levels in OPE was also observed. The mRNA levels of CPT-1α and uncoupling protein-1 were up-regulated by the OPE, while those of fatty acid synthase and acetyl-CoA carboxylase were down-regulated.

Antimicrobial properties

Green onion extract had significant antilisterial effect against *Listeria monocytogenes* cocktail in retail milks (full-fat milk, fat-free milk, nano-calcium milk and nano-iron milk). Combination of green onion extract and nisin resulted in synergistic antilisterial activity, thus indicating potential application of combining these as antilisterial agents in the food industry (Yan *et al.*, 2011).

Ye *et al.* (2013) found that the essential oil of onion may be a new potential source of natural antimicrobial agent against food-borne pathogenic microorganisms and antioxidant agents for application in food systems. Persicosides A and B, novel spirostane glycosides isolated from the seeds of Persian leek, showed high antifungal activity against pathogens—*Penicillium italicum*, *Aspergillus niger*, *Trichoderma harzianum* and *Botrytis cinerea*—highlighting positive effect of the spirostane skeleton on the antifungal activity.

Three saponins—ceposide A, ceposide B, and ceposide C—isolated from the bulbs of white onions, are found to have antifungal activity which increases with their concentration and varies in the following descending order: ceposide B>ceposide A>ceposide C. There was a significant synergism in antifungal activity of three ceposides against *Botrytis cinerea* and *Trichoderma atroviride* (Lanzotti *et al.,* 2012).

A fructan (composed of terminal and 2,1-linked ß-d-Fruf residues with 1,6-linked ß-d-Glcp residues; molecular weight 1.5×10^3), which acts as an anti-influenza A virus material, has been isolated from the hot-water extract of green leafy part of Welsh onion (Lee *et al.*, 2012e). Although fructan did not show anti-influenza A virus activity *in vitro*, it demonstrated an inhibitory effect on the virus replication *in vivo,* when it was orally administered to mice. In addition, the polysaccharide enhanced production of neutralizing antibodies against influenza A virus. Thus, the authors opine that antiviral mechanism of the polysaccharide is dependent on the host-immune system, i.e. enhancement of the host immune function is achieved by administration of polysaccharide.

Methanolic and ethanolic extracts of onion-bulbs, which contain secondary metabolites, saponins, tannins, alkaloids, cyanogenic glycosides and flavonoids, are inhibitory to *Staphylococcus aureus, B. subtilis* and *P. aeruginosa* (Bello *et al.,* 2013).

Traditional remedies using onion

Onion has been used for thousands of years for various conditions, including insomnia, wound-healing and baldness. A traditional Maltese remedy for sea-urchin wounds is to tie half a baked onion to afflicted area overnight. Similarly, in Bulgaria a half-baked onion with sugar is placed over the finger and fingernail in case of inflammation. Raw onion can also reduce swelling due to bee-stings. In the United States, products containing onion extract are used in the treatment of topical scars. Though some studies have found these remedies ineffective, others find them as anti-inflammatory or bacteriostatic. Onion may be beneficial for women, who are at increased risk for osteoporosis as they go through menopause, by destroying osteoclasts. An American chemist has stated that pleiomeric chemicals in onions have the potential to alleviate or prevent sore-throat. Onion in combination with jaggery has been widely used as a traditional household remedy for sore-throat in India. Tying an onion near the light repels mosquitoes, and keeping a white onion prevents snakes from entering the house.

African medicine: In south-eastern Morocco, onion is popularly used to treat diabetes and hypertension.

Arab medicine: Onions have been combined with eggs and sesame oil to cure coughs and colds and to relieve sore-throat. Onion juice as eardrops is used to treat ear infection as well as deafness.

Ayurveda: Onion is used for relieving earache, cardiovascular disorders and bleeding hemorrhoids. For the latter condition, an ounce of onion crushed in water and two ounces of sugar is prescribed twice daily. A paste of mustard oil, turmeric and onion juice has also been used. Honey and onion juice mixed in equal amounts is used to treat coughs. Onion has also been used as an aphrodisiac, although strict practitioners may avoid them, as they might increase desire. *Hing* is generally used as a substitute here. According to Karta Purkh Singh Khalsa's book, 'The Way of Ayurvedic Herbs', the famed Yogi Bhajan once said, "I said, in this universe, in Ayurveda, the basic method of healing, there are only three things: ginger, garlic, onion. These are called Triyajhad, three roots." This combination is ideal for spinal issues. Raw, chopped onion is believed to be a "cure-all" herb with rejuvenating capabilitiesand to promote longevity if consumed regularly. For fever, an infusion of onion and tulsi cooked in coconut oil is applied to the head.

Caribbean medicine: In the Bahamas, cold is treated by placing an onion slice in shoe near the heel. Onion is used with honey to treat respiratory disorders such as bronchitis and catarrh in the Dominican Republic. In Haiti, headaches are relieved by placing sliced onions on the head. In Trinidad, onion decoctions are made for coughs, colds and tuberculosis. In Curaçao, tinnitus and earache are treated using neck of the onion as a plug.

Central/South American medicine: In Bolivia, onion-bulbs are eaten for curing respiratory disorders, kidney disorders (kidney stones) and urinary disorders, and as a sleep aid and anti-inflammatory. Candied onions are used for cough and respiratory disorders (pertussis). Onion skin tea has also been used to treat respiratory disorders such as laryngitis with vocal loss in both Peru and Bolivia. In Nicaragua, the Garifuna supposedly ingest onion juice for respiratory disorders and parasitic infections (particularly intestinal parasites).

Chinese medicine: Onion is used in Chinese medicine to regulate *qi*, improve circulation, warm body, treat respiratory disorders (loosen phlegm) and as an appetite stimulant and sleep aid. Abdominal pain associated with parasitic infections may be treated using one tablespoon each of green onion juice and sesame oil daily. Ulcers are treated using 2–3 tablespoons of green onion juice with brown sugar and hot-water twice daily.

European medicine: Onions are used in Italian traditional medicine for chilblains and wound healing. In Russia, vinegar-boiled onion is applied to treat skin conditions such as corns. During World War II, Russian soldiers used onions as an antiseptic. In Spain, onion is used to treat deafness and tinnitus.

Japanese medicine: In Japan, a cut onion is placed under a pillow as a supposed sleep-aid.

Modern (Western) herbal medicine: In modern herbal medicine, onion has been used for hypercholesterolemia and hypertension.

Veterinary medicine: Secondary sources suggest that onions are allegedly toxic to animals. (*Source:* www.naturalstandard.com)

It is stated that the above are only claims and further study is needed before definitive conclusions may be drawn about onion's effectiveness for the treatment of these or any other conditions. Some of the common ailments and the onion preparations used for their control are given in Table 16.2.

Value-addition in Onion

Onion supplementation in food

Processing of onion produces a large amount of discards, mainly skins. The soluble extracts of selected onion varieties (Pearl, Red, Yellow and White) have a higher phenolic content and antioxidant activity than insoluble-bound extracts, exhibited notable inhibition of LDL cholesterol oxidation, DNA scission and COX-2 expression at concentrations as low as 5 μg/ml. Pearl onion skin phenolics exhibited the highest activities among the tested onion varieties (Albishi *et al.,* 2013).

Studies by Swieca *et al.* (2013) showed that when different types of breads were enriched with onion skin, phenolic contents and antiradical abilities increased moderately. Fortification also influenced protein digestibility (a reduction from 78.4% for control breads to 55% for breads with a 4% supplement), due to the presence of indigestible and other bread proteins–flavonoid complexes. Thus supplementation was found to have multiple effects on food quality and pro-health properties.

Increasing bioavailability of iron and zinc

Among the flavonoids in both red and yellow onions, myricetin was the most bioaccessible after digestion, suggesting that antioxidant activity of yellow and red onions was stronger in the outer layer than in the inner layer; a strong correlation is found between antioxidant activity and total phenolic contents (Shim *et al.*, 2011). Gautam *et al.* (2011) have reported increased bioaccessibility of iron in specific grains, when used with combinations of onion–carrot, and onion–amaranth. Also, *amchur*–onion had additive effects on zinc bioaccessibility. These observations are useful in evolving dietary strategies to maximize bioavailability of minerals from grains. In onion powder, quercetin occurs as quercetin 3,4'-O-glucoside and 4'-O-glucoside, which can be analysed in human plasma using 96-well SPE and LC-(ESI)MS/MS. Consumption of onion peel powder led to faster absorption, higher concentration, and greater bioavailability of quercetin (Lee and Mitchell, 2012).

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Marketing and Export

17

T.M. Gajanana and D.Sreenivasa Murthy

Onion is the only vegetable that is exported in large quantities from India. It is unlike many vegetables, which are with major share in the world production, but contribute lesser in terms of foreign exchange earnings. At the same time, onion is one of the most market-sensitive commodities, which create ripples in the trade and also in the political circles. Increase in the price of onions affects the consumer by way of an increase in budget or reallocation in food-consumption budget, while a decrease in its price lowers cost of cultivation and affects the producer. Apart from this price sensitiveness, the other major domestic marketing constraints are post-harvest losses and high price spread, leading to dwindling producer share in the consumer rupee. Keeping these in view, a detailed analysis has been attempted on the marketing and export potential of onions in this chapter. The chapter covers growth pattern, marketing practices, price analysis, post-harvest losses in domestic- and export-oriented onions, export performance, potential importers, and cost and constraints in export of onions.

Domestic Market

Growth in production

It was examined from 1991–92 to 2011–12 as well as decade-wise separately. To examine historical and recent trends of onion production in India, secondary data of the area under cultivation and yield of onion have been used. Compound growth rate (%) in area, production, productivity and export of onion was worked out using the following functional form of growth function.

$$y = ab^t e^u \text{ .... (1)}$$

where

y is the production/area/yield/export of onion

t is the time trend

a is the intercept

b = (1+r) and r is the growth rate

u is the error term

By transforming expression (1) into semi log form

$$\text{Ln } y = \text{Ln } a + t \text{ Ln } b + u \text{ ... (2)}$$

Ln a and Ln b are obtained by application of ordinary least square (OLS) procedure to equation (2) and the growth rate (r) is computed as below.

$$r = (\text{anti log of Ln } b\text{-}1)*100$$

There was an impressive growth of 8.28% per annum in production during 1991–92 to 2011–12, and it was noticed that area-led growth (6.01%) was more predominant than productivity-led growth (2.48%) (Table17.1). Estimation of growth rates separately for two decades to facilitate detailed analysis indicates that the period from 2001–02 to 2011–12 showed nearly four-fold higher growth rate in production than the period 1991–92 to 2000–01. The growth in area during these two periods was 4.52 and 8.84%, respectively, which suggests that more area was brought under onion cultivation during the last decade due to profitability of cultivation and good prospects for export. As regards the productivity growth, it is clear that the latter period achieved a significant growth of nearly 5% while the former showed negative growth (–0.79). Improvement in productivity in the latter period is attributed mainly to release of high-yielding varieties/hybrids as well as adoption of improved production and protection technologies.

Table 17.1 Pattern of growth in onion area, production and productivity

Period	Growth rate (%)			Pattern of growth
	Area	Production	Yield	
1991–2001	4.52	3.69	–0.79	Area-led growth
2001–2012	8.84	14.24	4.97	Area- and yield-led growth
1991–2012	6.01	8.64	2.48	Area- and yield-led growth

Marketing of onion: a case study in Karnataka

For examining marketing issues like marketing channels, post-harvest losses and price spread primary data were collected directly from all stakeholders participating in the onion-marketing processes. The primary data were collected through survey method in Karnataka, as the state is one of the major onion-growing states, next only to Maharashtra, accounting for 15.18% of the area and 14.25% of the production, with a structured schedule for farmers, retail and wholesale traders and other market functionaries. Onion harvested in Gadag is marketed to distant markets like Bengaluru and hence, Bengaluru market was selected to study marketing practices and also to assess losses at the market level.

Marketing channel: After harvest, onion is left in the field for two days, and de-topping is done at the heaping yard. The de-topped onions are dried in the open for 5 days. After drying, onions are packed in gunny-bags. While field sale was the major marketing channel followed, some farmers

Table 17.2 Marketing cost and returns of the producer (₹/50 kg)

Items of cost	Cost (₹)
Harvesting	20.00
De-topping	12.00
Packing material	12.00
Bagging	2.00
Loading and transportation	50.00
Unloading and weighing	4.00
Total cost	100.00
Cost of post-harvest losses(10.43%)	32.85
Total cost	132.85
Price realized	314.77
Net price realized	181.92

Source: Gajanana *et al.* (2010)

sold onions in the distant markets like Bengaluru through commission agents. For distant market sale, onions in gunny-bags of 50 kg are transported in trucks. Costs and returns associated with the distant market sale of onion in Bengaluru were worked out.

Costs and returns of the market intermediaries: Cost of marketing 50 kg of onions worked out to be ₹ 132.85, consisting of harvesting (15.05%), de-topping (9.03%), packing material and bagging (10.54%), loading and transportation (37.64%), unloading and weighing (3.01%) and post-harvest losses (24.73%) (Table 17.2). On an average, farmers realized a net price of ₹ 181.92.

Retailers incurred a cost of ₹ 357.70, consisting of loading (0.56%), commission (5.28%), transportation (3.67%) and post-harvest losses (2.66%) besides the purchase price (Table 17.3). They realized a net price of ₹ 97.80 for 50 kg of onions.

Table 17.3 Cost and returns of the retailer

Particulars		Cost (₹/50 kg)
1	**Purchase price**	314.77
2	**Marketing cost**	
	Loading	2.00
	Commission	18.89
	Transport	13.14
	Total marketing cost	33.43
3	**Total cost** (1+2)	348.20
	Cost of post-harvest losses (2.12%)	9.50
Total cost		357.70

Table 17.4 Price spread in marketing of onions

Particulars	Price spread	
	₹/ 50 kg	%
Net price received by farmers	181.92	39.93
Post-harvest losses at the field level	32.85	7.21
Marketing cost of producers	100.00	21.95
Retailer's cost	33.43	7.33
Post-harvest losses at retail level	9.50	2.08
Retailer's margin	98.00	21.50
Consumer's price	455.50	100.00

Marketing efficiency: The producer share was very low, only 40% (Table 17.4). It may be noted that the marketing system for onions has not been as efficient as its efficiency index was less than 1.00 at 0.78 (Table 17.5). In this context, post-harvest losses and their impact on marketing efficiency was studied.

Efficiency of the marketing system was analysed normally using standard formula of Acharya and Agarwal (2001). This formula was later modified by

Table 17.5 Efficiency in marketing of onions

Efficiency parameters	Efficiency parameter values
Producer's share (%)	39.93
Marketing cost(MC) (₹/kg)	2.66 (3.51)*
Intermediaries margin (%)	21.50
Post-harvest loss (PHL) (%)	9.29
Marketing efficiency (ME) index	0.78 (0.66)**

*MC Marketing cost after inclusion of PHL as an item of cost, **ME after inclusion of PHL as MC

Sreenivasa Murthy *et al.* (2004) by including post-harvest losses as an item of cost, as is given below.

$$ME = \frac{NP_F}{MC + MM + PHL}$$

where ME = Marketing efficiency index
NP_F = Farmer's net price
MC = Marketing cost of the intermediaries
MM = Marketing margin of the intermediaries
PHL = Post harvest loss during marketing

Post-harvest losses: A case study in Karnataka: Like other vegetables, onion is also subject to losses at different stages of handling after the harvest. These losses will have implications on the efficiency of the marketing system. Keeping in view the losses that occur at different stages of handling, post-harvest losses (PHL) were estimated along with the causes in Karnataka as per the procedures highlighted in Gajanana *et al.* (2010).

Big onion: Post-harvest loss was estimated in one of the major onion-producing districts of Gadag in Karnataka. The PHL was estimated from 47 fields of onions in the district to assess losses during preparation of onions for the market, particularly during sorting and packing. The transit loss from production centre to destination centre was estimated at Bengaluru market, immediately after arrivals. Losses occurring at the retail level were assessed from 27 retailers of onions in Bengaluru. Simple averages and percentages are used for PHL estimation. The following channel was used for the estimation: *Producer → Commission Agent → Retailer → Consumer.*

The field level loss was observed to be 10.43%, consisting of rot (7.5%), skin out (0.17%), doubles/splits (2.99%)and sprouts (0.11%). C grade produce (double and small), which fetches only one-third the price, was observed to be 7.98% thereby suggesting that there is a need to standardize production practices for better quality onions. Atibudhi (1997) observed a field level loss of 13.75%; consisting of weight loss (8.71%), spoilage of bulbs (4.29%) and sprouting (0.75%). It may be noted that farmers did not have the storage facility and had to transport to distant markets immediately after drying of onions in heaps. In another study by Kishor Kumar *et al.* (2006), the estimated field level loss was observed to be 6.21%, and storage loss (decay, sprouting, de-scaling and rooting) was about 50% of this loss, as farmers had adopted traditional-heap method of storage.

There existed a significant positive association (r=0.35) between the field level loss and the acreage under onions, thereby indicating that more area under onions would dilute efforts towards proper crop management. It was further indicated by the regression analysis that an increase in area by one acre would bring about 1.05% increase in field-level loss. Production of onion per hectare had a positive and significant relationship with field-level losses of onions farmer would not be able to pay full attention to post-harvest operations when large quantity is produced, and the limited managerial skills lead to higher losses(Kishor Kumar *et al.*, 2006).

After harvest and curing, onions grown in Gadag are transported to Bengaluru market. Retailers buy onions from farmers through commission agents at the market place. Information on losses at the retail level was collected from retailers. At the retail level the loss was observed to be 2.12%; consisting of rot (1.52%), peel (0.49%) and sprouts (0.11%). Pathological investigation of the sampled lots of rotten onion-bulbs indicated that rotting of bulbs at the field level was mainly due to soft-rot (*Erwinia carotovora* var. *carotovora*), black-rot (*Aspergillus niger* var. Tieghem) and bulb-rot due to *Sclerotium* sp. For managing post-harvest diseases, curing of the harvested onions in the field for two days and then further drying in the shade for 10–15 days before storage is effective. Care should be taken to avoid injury to bulbs during post-harvest handling. For controlling black mold (*A. niger*), the crop should be sprayed with Carbendazim (0.2%) 10–15 days before harvesting and for white-rot (*Sclerotium rolfsii*), seed treatment with Thiram (4 g/kg of seeds) and drenching of the soil with Mancozeb (0.25%) are recommended.

Post-harvest losses (PHL) account for about 9% of the consumer's price in the marketing channel. As PHL increases the cost of marketing, it also has an impact on the marketing efficiency. Price spread was observed to be 60%, which without the PHL, would have been just 51%. If PHL is also included as an item of cost of marketing, efficiency of the already inefficient marketing system further lowers. It may, therefore, be inferred that efforts are needed to reduce losses during post-harvest handling of onions to improve efficiency of the marketing system.

Export-oriented rose onion: Its post-harvest losses at the field level were estimated from 47 onion harvesting/harvested fields in Kolar and Chikkaballapura districts in Karnataka and at the exporters' level from 14 exporters in Chennai.

As pointed out earlier, production practices are not standardized; this results in more number of splits and very small bulbs, which do not meet export standards. Hence, efforts were made to assess post-harvest losses in rose onion, exclusively grown for export, in the study area to understand the extent and the cause of losses. Kolar and Chikkaballapur districts are the main rose onion-producing areas in Karnataka. It was observed that the growers were mostly of small and marginal categories with a holding size of less than 2 ha. Average area under rose onion was observed to be 0.5 ha. Rose onion growers in the area follow *Field Sale* for marketing of onions. Onion cultivation is not so well organized, though a sort of unwritten contract between the traders and the farmers exist. Onions grown in the area are bought by traders in the field itself and sold to exporters in Chennai. Thus, marketing channel followed is: *Farmers → Local Traders → Exporters.* Losses occurring in this channel and their causes were studied.

In rose onion in Kolar and Chikkaballapur districts, total field level loss (due to sorting) was 16.51%; consisting of very small (4.17%), doubles/splits and rotten bulbs (8.64%) and physiological loss in weight during storage was 3.70%. Field level losses in Bagepalli were significantly lesser than Chintamani; due to less percentage of doubles/splits in Bagepalli area.

At the exporter's level, onions brought from the farmers' fields are sorted based on the size into less than 27 mm and more than 27 mm. Losses at exporters' level assessed in Chennai were mainly due to sorting, which worked out to 7.13%. In less than 27 mm onions, loss was 3.36%, consisting of soiled bulbs and very small damaged bulbs. In case of more than 27 mm onions, sorting loss was 3.77%; consisting of doubles and skin-out bulbs.

Losses occurring at the field level (16.51%) and at the exporters' level (7.13%) together accounted for 23.64%. It therefore indicates that there is a need to standardize production practices so as to have lesser splits/doubles and very small bulbs to meet export criteria.

Major onion markets and price analysis

There are reports that onion trade is domestically in more than 100 markets in India (The National Horticulture Research and Development Foundation, NHRDF). Recent look at the total arrivals in these markets shows that the arrivals increased from 4,617 thousand MT in 2008–09 to 6,040 thousand MT in 2009–10, and then declined to 5,897 thousand MT in 2010–11. The latest decline was due to drought. The total arrivals in these markets together are not a true representation of the total production in a particular season due to cross arrivals from one market to another market, and hence there is duplicity of recording quantum of arrivals. Arrivals do not include self consumed or sold in the villages/ towns. The arrivals in the top 50 markets accounted for around 95% of the total arrivals in all these markets for which data were available. The share of the top ten markets was nearly 55%. Maharashtra alone accounted for 24 of the top 50 markets, followed by six in Gujarat, four in Karnataka, and three each in Rajasthan and Uttar Pradesh.

An attempt has been made to analyze the major onion markets and about seasonality of arrivals and prices; for which data were collected from the secondary sources(The secondary data were collected from Ministry of Agriculture and Agriculture Marketing Departments of different states).

Region-wise price analysis

To analyze price and spatial market integration among different markets, weekly wholesale real prices of onion from 30 major onion markets, including Mumbai, Delhi, Kolkata, Chennai and Bengaluru, published in Horticulture Information Service of National Horticultural Board were collected for the period from January 1991 to September 2007. However, data were not available for all weeks/years in 30 markets, and hence, only 23 major markets were analyzed (Figs 17.1, 17.2). Twenty-three major markets for which complete data were available were grouped into four regions as follows.

(i) Eastern regions : Bhubaneswar, Kolkata, Guwahati and Patna

(ii) Western region : Ahmedabad, Bhopal, Mumbai, Nagpur, Pune, Surat

(iii) Northern region : Chandigarh, Delhi, Jammu, Jaipur, Kanpur, Srinagar, Agra

(iv) Southern region : Bengaluru, Hyderabad, Chennai, Madurai and Thiruvananthapuram

Data of weekly wholesale real prices of onions, which were averaged to the year for different states, are presented in Table17.6. Data indicate a large volatility in onion price in every market over the years. Onion price is also found volatile across time due to supply shocks, perishable nature, vagaries of monsoon, change

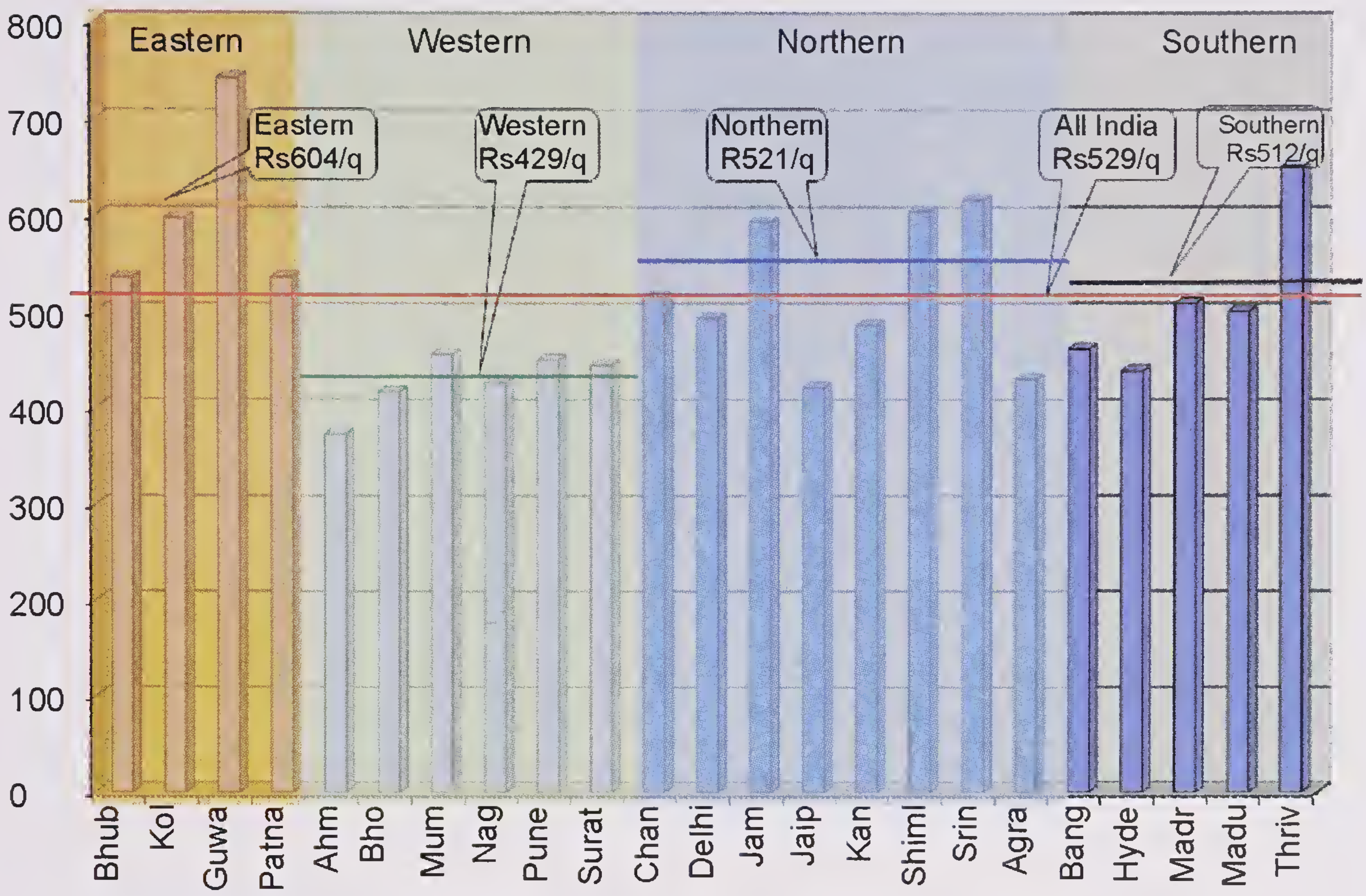

Fig. 17.1 Price relationships of different markets in India —Average prices of onion, 1991 to 2007

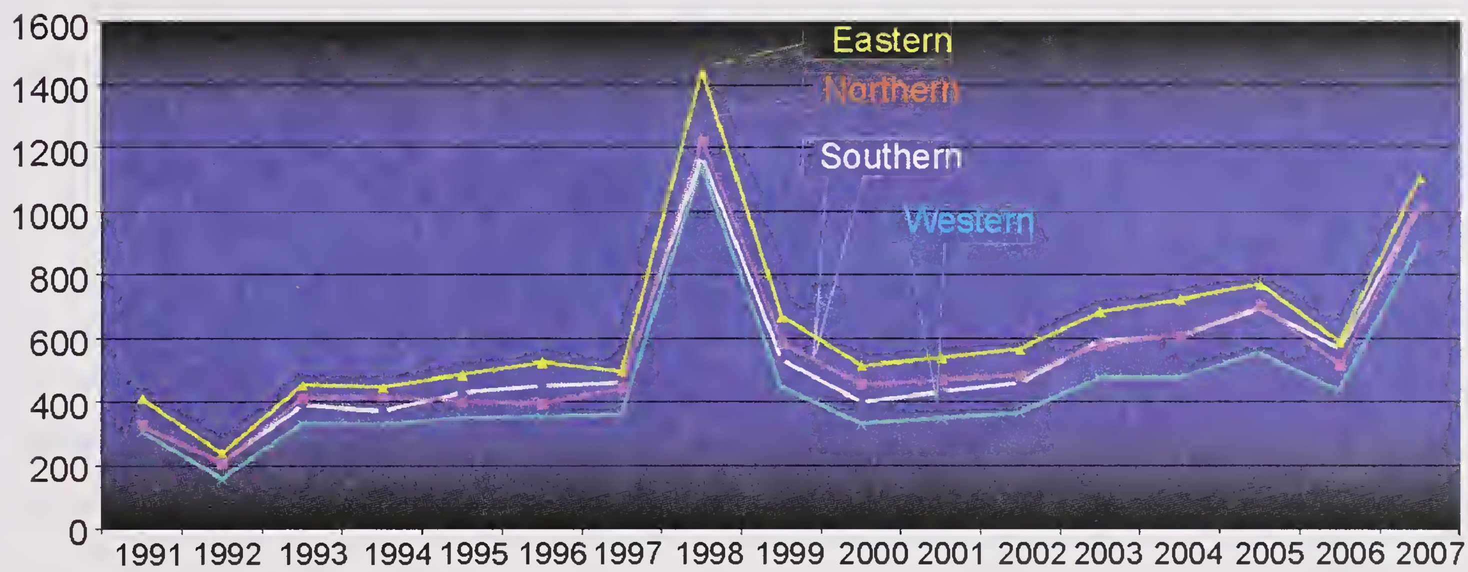

Fig.17.2 Price relationships between the different regions in India

in international scenario, etc. Except for the years 1998 and 2007, the trend in each of the market was gradual and steady.

The aggregation of the prices of onion at the national level indicated that the triennium average price of ₹ 312/q in January 1991 increased to ₹ 735/q for the triennium ending 2007. The details on the aggregation of the average wholesale real price of onion per quintal for four regions as well as of national average are given in Table 17.7. The lowest prices of onions were observed in Western region markets, where the distance between the producing areas and the markets was minimum. As the onions move to different markets during and after harvesting, cost of the onions increases, and this results in higher wholesale prices in distant markets like Jammu, Kolkata, Guwahati, etc. For instance, the average price of onions in the western markets (where the production regions are located) during

Table 17.6 Market -wise yearly price in different markets in four regions of India

Year	Eastern Markets				Western Markets						Northern Markets								Southern Markets				
	Bhub	Kol	Guwa	Patna	Ahm	Bho	Mum	Nag	Pune	Surat	Chan	Delhi	Jam	Jaip	Kan	Shiml	Srin	Agra	Beng	Hyde	Madr	Madu	Thiru
1991	370	410	443	432	244	475	290	290	263	287	315	338	341	337	300	357	402	253	304	294	320	330	385
1992	216	253	291	206	140	155	163	170	143	185	211	221	225	156	177	249	279	160	192	159	208	220	277
1993	439	477	501	399	300	311	359	303	369	349	482	415	458	358	360	460	477	320	344	326	388	409	493
1994	401	442	561	386	292	342	339	338	311	343	439	399	449	344	386	483	517	347	342	304	366	392	461
1995	451	499	587	417	296	350	398	347	367	355	411	395	458	332	363	455	491	327	410	358	428	439	509
1996	484	518	656	448	297	337	395	344	351	400	391	377	451	302	363	429	558	302	403	381	478	419	584
1997	460	501	639	399	292	293	403	337	383	465	415	443	618	333	352	506	563	340	402	403	456	483	574
1998	1262	1455	1721	1333	1047	1062	1217	1170	1186	1185	1193	1307	1226	1159	1426	1514	860	1121	1085	1139	1181	1122	1365
1999	530	688	862	603	355	483	484	438	492	436	562	525	626	447	572	719	747	517	464	445	523	573	672
2000	431	515	674	448	297	353	364	321	345	310	478	410	537	371	382	567	573	366	345	326	415	392	529
2001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2002	499	544	716	521	313	378	403	383	377	367	486	418	570	372	445	560	660	395	378	402	458	469	610
2003	595	659	854	640	424	431	527	470	523	486	548	498	784	451	537	635	724	488	532	517	581	597	751
2004	654	685	927	640	437	439	502	481	525	482	613	556	706	434	567	717	784	525	549	522	604	603	767
2005	687	750	969	699	531	504	413	594	691	600	675	648	844	543	636	821	914	578	677	633	718	560	904
2006	562	577	749	484	349	363	603	432	442	447	516	464	617	393	435	605	709	426	505	380	506		893
2007	1068	1032	1279	1054	826	856	935	932	952	896	811	877	1108	915	987	1233	1273	965	979	875	1007		1250
Average	536	598	743	537	374	418	457	428	451	446	516	494	594	422	487	605	617	431	462	439	509	501	651

Bhub : Bhubaneswar, Kol: Kokata, Guwa: Guwahati, Ahm: Ahmedabad, Bho: Bhopal, Mum: Mumbai, Nag: Nagpur, Chan: Chandigarh,Jam: Jammu, Jai: Jaipur, Kan: Kanpur, Srina: Srinagar, Beng: Bengaluru, Hyd: Hyderabad, Chen: Chennai, Madu: Madurai, Thiru: Thiruvananthapuram

Table 17.7 Region -wise average price of onions from1991 to 2007 (₹/q)

Year	South	North	East	West	All India
1991	327	330	414	308	338
1992	211	210	241	159	202
1993	392	416	454	332	396
1994	373	420	448	328	391
1995	429	404	488	352	411
1996	453	397	526	354	420
1997	464	446	500	362	437
1998	1,178	1,226	1,443	1,145	1,232
1999	535	589	671	448	555
2000	401	461	517	332	424
2001	NA	NA	NA	NA	NA
2002	464	488	570	370	466
2003	596	583	687	477	576
2004	609	613	726	477	596
2005	698	707	776	555	678
2006	571	521	593	439	521
2007	1,028	1,021	1,109	900	1,005
Average	512	521	604	429	509

September 2007 was ₹ 900/q compared to the wholesale price of ₹ 1,021 in the northern markets, ₹ 1028/q in the southern markets and ₹ 1109 in the eastern markets. These higher prices were in the order of 13, 14 and 23% in these markets, respectively. The price difference across these markets is mainly due to transportation and transaction costs.

Market correlation: Correlations between weekly prices of onions for major 23 markets were estimated and the results are given in Table17.8. The relationship between prices of different markets was found strong and significant. This indicates the near perfect relationship in the movement of prices in different markets. However, the relationship between Jammu and Kashmir markets with other markets, though found significant, was not near perfect as values ranged between 0.4 and 0.6.

Onion price analysis during the last five years: A brief status report on onions (NHRDF, 2013) analysed the status of their production and marketing in India. According to this, the movement of average arrivals of last five years in the major consuming markets of Mumbai, Delhi, Kolkata and Chennai was almost same, except Kolkata, where arrivals fluctuated because of the export demand of Bangladesh through Kolkata arriving from Maharashtra (by rail) and from Karnataka (by road). In producing markets of Lasalgaon, Pimpalgaon, Bengaluru and Pune, arrivals were more from December to March because the produce harvested in these months was not for storage and was to be brought to the market. In Karnataka, major harvesting of *kharif* crop takes place in October and November.

In both consuming and producing markets, prices start increasing from October/ November and would remain at a higher level till January/February. During these months, demand for onion emanates from northern, southern and eastern states (non-*kharif* onion-producing regions), and this has to be met from the supply of onion from the *kharif* onion-producing states of Maharashtra, Gujarat, Rajasthan

Table 17.8 Correlation between wholesale prices of major onion markets in India

	Bhu	Cal	Guw	Pat	Ahm	Bho	Bom	Nag	Pune	Surat	Chan	Delh	Jam	Jaip	Kan	Shiml	Srina	Agra	Beng	Hyde	Madr	Madu	Thiru
Bhu	1.000																						
Cal	0.952	1.000																					
Guw	0.924	0.944	1.000																				
Pat	0.931	0.948	0.932	1.000																			
Ahm	0.927	0.936	0.907	0.924	1.000																		
Bho	0.834	0.850	0.833	0.906	0.850	1.000																	
Bom	0.932	0.933	0.901	0.904	0.959	0.824	1.000																
Nag	0.948	0.952	0.916	0.929	0.942	0.842	0.938	1.000															
Pune	0.936	0.940	0.903	0.910	0.932	0.814	0.956	0.954	1.000														
Surat	0.860	0.877	0.857	0.868	0.898	0.787	0.920	0.884	0.887	1.000													
Chan	0.899	0.917	0.913	0.895	0.915	0.826	0.903	0.899	0.886	0.852	1.000												
Delh	0.933	0.949	0.914	0.926	0.958	0.844	0.946	0.949	0.932	0.882	0.925	1.000											
Jam	0.534	0.502	0.493	0.489	0.500	0.441	0.496	0.557	0.561	0.481	0.513	0.527	1.000										
Jaip	0.898	0.916	0.885	0.903	0.918	0.824	0.901	0.915	0.895	0.848	0.881	0.926	0.487	1.000									
Kan	0.871	0.889	0.870	0.888	0.909	0.816	0.888	0.887	0.872	0.856	0.883	0.905	0.487	0.869	1.000								
Shiml	0.917	0.934	0.927	0.933	0.935	0.847	0.915	0.927	0.913	0.889	0.923	0.941	0.513	0.905	0.915	1.000							
Srina	0.704	0.655	0.671	0.669	0.606	0.584	0.599	0.656	0.666	0.550	0.614	0.607	0.521	0.623	0.585	0.642	1.000						
Agra	0.938	0.939	0.922	0.935	0.948	0.851	0.931	0.947	0.932	0.871	0.915	0.951	0.525	0.918	0.909	0.947	0.702	1.000					
Bang	0.928	0.911	0.882	0.879	0.886	0.784	0.913	0.936	0.949	0.847	0.840	0.889	0.565	0.853	0.833	0.863	0.680	0.894	1.000				
Hyde	0.935	0.930	0.900	0.901	0.923	0.810	0.937	0.939	0.945	0.865	0.879	0.925	0.547	0.879	0.859	0.890	0.648	0.911	0.942	1.000			
Madr	0.941	0.921	0.902	0.895	0.902	0.797	0.924	0.944	0.953	0.860	0.864	0.911	0.553	0.875	0.847	0.886	0.691	0.922	0.964	0.949	1.000		
Madu	0.944	0.923	0.918	0.887	0.881	0.773	0.900	0.916	0.936	0.872	0.880	0.904	0.433	0.856	0.835	0.887	0.629	0.911	0.945	0.941	0.962	1.000	
Trivan	0.900	0.875	0.884	0.855	0.853	0.758	0.899	0.879	0.889	0.807	0.856	0.856	0.528	0.820	0.803	0.865	0.702	0.890	0.884	0.865	0.907	0.945	1.000

Bhub: Bhubaneswar, Kol: Kolkata, Guwa: Guwahati, Ahm: Ahmedabad, Bho: Bhopal, Mum: Mumbai, Nag: Nagpur, Chan: Chandigarh, Jam: Jammu, Jai: Jaipur, Kan: Kanpur, Srina: Srinagar, Beng: Bengaluru, Hyd: Hyderabad, Chen: Chennai, Madu: Madurai, Thiru: Thiruvananthapuram and Karnataka. Because of higher domestic prices, the export is normally lesser during these months.

Market integration—A case study of five major markets: Markets are said to be spatially integrated if price changes in one market it is fully reflected in the alternative market. Prices in spatially integrated markets are determined simultaneously at various locations, and information of any change in price in one market is transmitted to other markets. Markets that are not integrated may convey inaccurate price signal that may distort producers marketing decision and contribute to inefficient product movement, and traders may exploit market and benefit at the cost of producers and consumers. Based on the information of the extent of market integration, government can formulate policies of providing infrastructure and information regulatory services to avoid market exploitation.

Spatial market integration is analyzed by estimating price relationship between spatially separated markets using the Equation given below.

$$\bar{\Delta} y_t = \mu + (\beta_1 - 1)(y_{t-1} - \lambda x_{t-1}) + \gamma_0 \Delta x_t + \varepsilon_t$$

Where y_t and x_t are prices in two spatially separated markets, μ is intercept, β_1 is parameter that measures the speed of adjustment to long-run equilibrium, γ_0 is slope on Δx_t, λ is market integration parameter. If the two markets are perfectly spatially integrated, the parameter λ is one or near to one.

An attempt has been made in the present study to examine how Bengaluru market is integrated with other major metropolitan cities. Care was taken that each market from each zone was selected, and the details are as follows.

1. *Bengaluru* market with Pune (western market), Delhi (northern market), Chennai (southern market–Nearest market) and Kolkata (eastern market–Farthest market)
2. *Chennai* market with Pune (western market), Delhi (northern market), Bengaluru (southern market–Nearest market) and Kolkata (eastern market–Farthest market)
3. *Mumbai* market with Pune (western market), Delhi (northern market), Bengaluru (southern market–Nearest market) and Kolkata (eastern market–Farthest market)
4. *Delhi* market with Pune (western market), Chandigarh (northern market), Bengaluru (southern market–Nearest market) and Kolkata (eastern market–Farthest market)
5. *Kolkata* market with Pune (western market), Delhi (northern market) and Bengaluru (southern market–Nearest market)

The results of the market integration between Bengaluru market and other major markets, viz. Pune, Delhi, Chennai and Kolkata are presented in Table 17.9. The market integration equation was found highly significant as the R^2 values for all four equations were more than 92%.

In the regression of Bengaluru on Chennai, the estimated value of λ was near to one, i.e. 0.9413 indicating that the price change in Chennai was almost fully reflected in Bengaluru. The estimated market integration parameter $\lambda = 0.8310$ for the regression of Bengaluru on Pune, 0.7712 for Delhi on Bengaluru and 0.7024 for Bengaluru on Kolkata was observed. These results indicate strong

Table 17.9 Spatial price relationships between Bengaluru and other onion markets

Dependent variable	Independent variable	Intercept μ	Adjustment parameter β	Slope on Δx γ0	γ1	Market integration parameter λ	R^2
Bengaluru							
	Pune	30.306	0.6729	0.5327	-0.2609	***0.8310***	0.9488
	Chennai	–5.464	0.6090	0.6666	-0.2985	***0.9413***	0.9536
	Kolkata	12.684	0.7643	0.2870	-0.1214	***0.7024***	0.9225
	Delhi	15.747	0.8312	0.4390	-0.3088	***0.7712***	0.9303
Chennai							
	Pune	32.306	0.6929	0.5927	-0.3452	***0.8426***	0.92
	Bengaluru	12.684	0.7643	0.2870	-0.1214	***0.9500***	0.95
	Kolkata	11.684	0.8643	0.3456	-0.3224	***0.7424***	0.91
	Delhi	17.747	0.7312	0.5567	-0.2345	***0.7963***	0.94
Mumbai							
	Pune	31.345	0.6929	0.6345	-0.3452	***0.9556***	0.892
	Bengaluru	–7.956	0.649	0.4356	-0.3256	***0.8310***	0.916
	Kolkata	13.562	0.8643	0.4156	-0.3224	***0.7924***	0.931
	Delhi	14.256	0.7312	0.4568	-0.2345	***0.8545***	0.904
Delhi							
	Pune	15.465	0.6349	0.5623	-0.3352	***0.8656***	0.892
	Bengaluru	8.562	0.557	0.6456	-0.5256	***0.6953***	0.913
	Kolkata	11.223	0.5864	0.5415	-0.4224	***0.8324***	0.823
	Chandigarh	11.003	0.6731	0.5568	-0.3345	***0.9246***	0.923
Kolkata							
	Pune	15.465	0.6349	0.5623	-0.3352	***0.8256***	0.903
	Bengaluru	12.684	0.7643	0.2870	-0.1214	***0.7024***	0.921
	Delhi	11.223	0.5864	0.5415	-0.4224	***0.8624***	0.895

spatial market integration among markets, which are nearer (Bengaluru and Chennai), and this becomes weaker with distant markets (Bengaluru–Pune, Bengaluru–Delhi and Bengaluru–Kolkata).

Market integration of Chennai market with other regional markets indicated that the model was found highly significant as suggested in the high R^2 values (0.91 to 0.95) in all equations, viz. Chennai with Bengaluru, Delhi, Pune and Kolkata. This indicates that the fitted models sufficiently explain the variations in the model. The estimated coefficients (market integration) of these four models were also found significant at 1% or 5% level. In the regression of Chennai on Bengaluru, the estimated value of 'l' was near to one, i.e. 0.95 indicating that the price change in Chennai was almost fully reflected in Bengaluru. A change of ₹ 1.00 in onion price in Chennai brought about ₹ 0.95 change in onion price in Bengaluru. The reverse estimation of market integration as reported earlier was also the same, indicating that the fitted model was consistent with the markets as regards to the coefficients.

The estimated market integration parameter 'l' was 0.8426 in the regression for Chennai on Pune, 0.7963 for regression of Chennai on Delhi and 0.7424 for regression of Chennai on Kolkata. These results show strong spatial market integration among markets, which were nearer (Bengaluru and Chennai), and weaker for markets located at distant places (Bengaluru–Pune, Bengaluru–Delhi and Bengaluru–Kolkata).

The market integration models of Mumbai market with other markets also exhibited very high R^2, indicating goodness of the fit of the models. The market integration coefficients were also found significant. The highest market integration of Mumbai market was found with Pune market with near perfect integration. Almost 95% of the change in price in Mumbai market was reflected in Pune market. The extent of change in prices in Delhi due to change in Mumbai market was only about 85%. As regards with the southern market Bengaluru, this integration value was 0.8310 and with the distant market Kolkata, the extent of translation of change was lowest with 'l' at 0.7924. Thus, the trend expressed here is as per the expected lines.

Delhi is one of the major markets in India for onions. The supply mostly comes from production centres of the western belt. The fitted model of market integration for regression of Delhi on Bengaluru, Pune, Chandigarh and Kolkata had high R^2 values indicating that fitted models sufficiently explained the variation. The coefficients of all the models were also found significant suggesting that the market integration coefficients also had significant relationships.

The highest market integration coefficient was found between Delhi and Chandigarh; indicating that they had very strong relationships regarding price movement. This was followed between Delhi and Pune and Delhi and Kolkata. Bengaluru being the distant market, the extent of relationship was relatively weaker as compared to other markets.

Kolkata located farther away from the production regions, gets onion supply from the western and eastern regions. The fitted models sufficiently explain the relationship as indicated in high R^2 values. The values ranged from 0.895 to 0.941. The coefficients of all the four models were also found significant indicating that the market integration coefficient was strong and positive. The highest market integration value l was found between Kolkata and Delhi market, suggesting that ₹ 1 change in price in Kolkata caused a change of ₹ 0.86 in Delhi market. The l value for Kolkata and Bengaluru market and Kolkata and Pune market was 0.7024 and 0.8256, respectively.

Price stabilization

The decline in production of onions during bad years affects availability for domestic consumption, which may many times lead to sensitive social, political and economical unrest in the country. The impact of such a situation is well documented, and the following measures/suggestions have been indicated to minimize impact during such a crisis, which may act as a price-stabilization mechanism.

- Strict vigil on the distribution system of the onions, especially on hoarding or black marketing at the distributor level.
- Exploring ways to bring withheld stock by the farmers.
- During the years of less production, a regular mechanism for forecasting and distribution system needs to be developed, and put into preventive action at an earliest possible situation.
- As the problem is recurring, strengthening of the existing storage systems needs to be taken up on the priority so as to supply produce throughout the

year. Even the storage at the local production areas need to be explored to help farmers.

- Proper distribution network needs to be developed for timely availability of onions in different places in sufficient quantities.
- Ensure more availability of onions for domestic consumption by moderating export of onions.
- Augment present availability with imports.
- On the supply side, development of hybrids/high-yielding varieties resistant to moisture stress and adoption of modern production methods to increase production are essential.
- Efforts to identify and reduce post-harvest losses in onion are needed as these would ensure more availability without any additional cost.

Export Market

Big (Bellary/Nashik Red) onion and Rose onion are the major types of fresh onions exported from India. Indian onions are exported to about 45 countries in the world. The National Agricultural Cooperative Marketing Federation of India Ltd (NAFED) has been the sole Canalizing Agent for export of onions from India. However, since 1999, twelve more agencies have been added with the overall monitoring by the NAFED. The NAFED is responsible for fixing minimum export price (MEP) of onions, which is done on a monthly basis. Factors such as market trends, world prices and domestic prices, and margins are considered while arriving at the MEP of onions (Mathur, 2001). The latest decision of the GoI to hike MEP is a measure to contain domestic prices by discouraging export.

Share of export in domestic production

During the last two decades (TE 1993–94 to TE 2011–12), there has been an impressive growth both in domestic production (8.64%) and in export (9.28%) of onions from India. It may be noted from Table 17.10 that the share of export in domestic production has been hovering around 9%. During the previous decade (1980–81 to 1993–94), the share of export in the domestic production increased mainly due to higher export growth compared to growth in domestic production (Sreenivasa Murthy and Subrahmanyam, 1999). The sudden decline in the share of export during TE 1998–99 was owing to the ban imposed on the onion export because of the steep rise in domestic onion prices.

Table 17.10 Share of export of onions in the domestic production

Year	Production Q (tonnes)	Export Q (tonnes)	Export Share (%)
TE 1993–94	3693966.67	372694.07	10.09
TE 1995–96	4040833.33	369801.00	9.15
TE 1998–99	4376666.67	325351.47	7.43
TE 2001–02	4957566.67	348526.20	7.03
TE 2004–05	6079233.33	760620.13	12.51
TE 2007–08	11331800.00	1115828.77	9.85
TE 2011–12	14929366.67	1385723.67	9.28
CGR (1991–2012 (%)	8.64	9.28	

Data Source: NHB Horticulture Data Base; APEDA Export Statistics

Growth and stability of Indian onion export

Export of onion grew at 9.28% in quantity and 15.22% in value of exports during the last two decades (Table 17.11). Export of onion during the second decade (2001–2012) registered a higher growth of 11.17% in quantity and 20.67% in value; though the performance in the previous decade was not satisfactory.

Table 17.11 Growth in export of onions

Period	CGR (%)	
	Quantity	Value
1991–2001	–3.81	4.05
2001–2012	11.17	20.67
1991–2012	9.28	15.22

Coefficient of variation (CV) is normally used to measure instability. Since time series data contain the trend element, it is suggested to use coefficient of variation around the trend (CVt) instead of simple CV. The appropriateness of CVt over CV was suggested by Nadakarni (1971). Further, Cuddy and Della (1978) developed an index of instability (CVt = CV" 1-R^2), where R^2 is obtained from the trend equation. This index is used to assess instability associated with the export of onion to different countries. It is interesting to note that the high growth as cited above was associated with less instability (CVt=20–22%).

Major international markets for Indian onion

A three-dimensional analysis of growth, import share and instability was used to identify potential markets for Indian onions. The results are presented in Tables 17.12 and 17.13. Trend in export of onion to major importers is shown in Figs 17.3 and 17.4.

Malaysia registered high growth (10–15%) with less instability (17–37%) during 1993–2012 and its

Table 17.12 Identification of potential importers of onions from India—Growth and Instability (1993–2012)

Countries	CGR (%)*		Instability index (%)	
	Q	V	Q	V
Malaysia	10.42	14.93	16.96	37.03
Sri Lanka	7.28	12.44	15.05	15.28
UAE	4.12	10.13	29.35	29.45
Bangladesh	20.63	27.59	34.27	37.85
Bahrain	12.99	17.99	42.80	31.78
Singapore	–2.53	–0.35	28.99	43.74
All countries	10.85	16.51	21.87	20.38

*All the growth rates are significant at 5 % level of probability

Table 17.13 Identification of potential importers of onions from India—Import share (1993–2012)

Countries	Import share (%)					
	TE 1995–06		TE 2006–07		TE 2011–12	
	Q	V	Q	V	Q	V
Malaysia	21.10	23.48	22.00	17.04	21.67	23.73
Sri Lanka	14.11	14.10	10.87	10.46	9.88	9.49
UAE	32.08	26.77	14.11	13.44	11.09	9.97
Bangladesh	11.62	10.04	35.62	27.03	34.31	34.38
Bahrain	1.13	1.05	2.01	1.93	0.91	0.78
Singapore	10.84	15.83	1.75	1.66	1.87	1.80

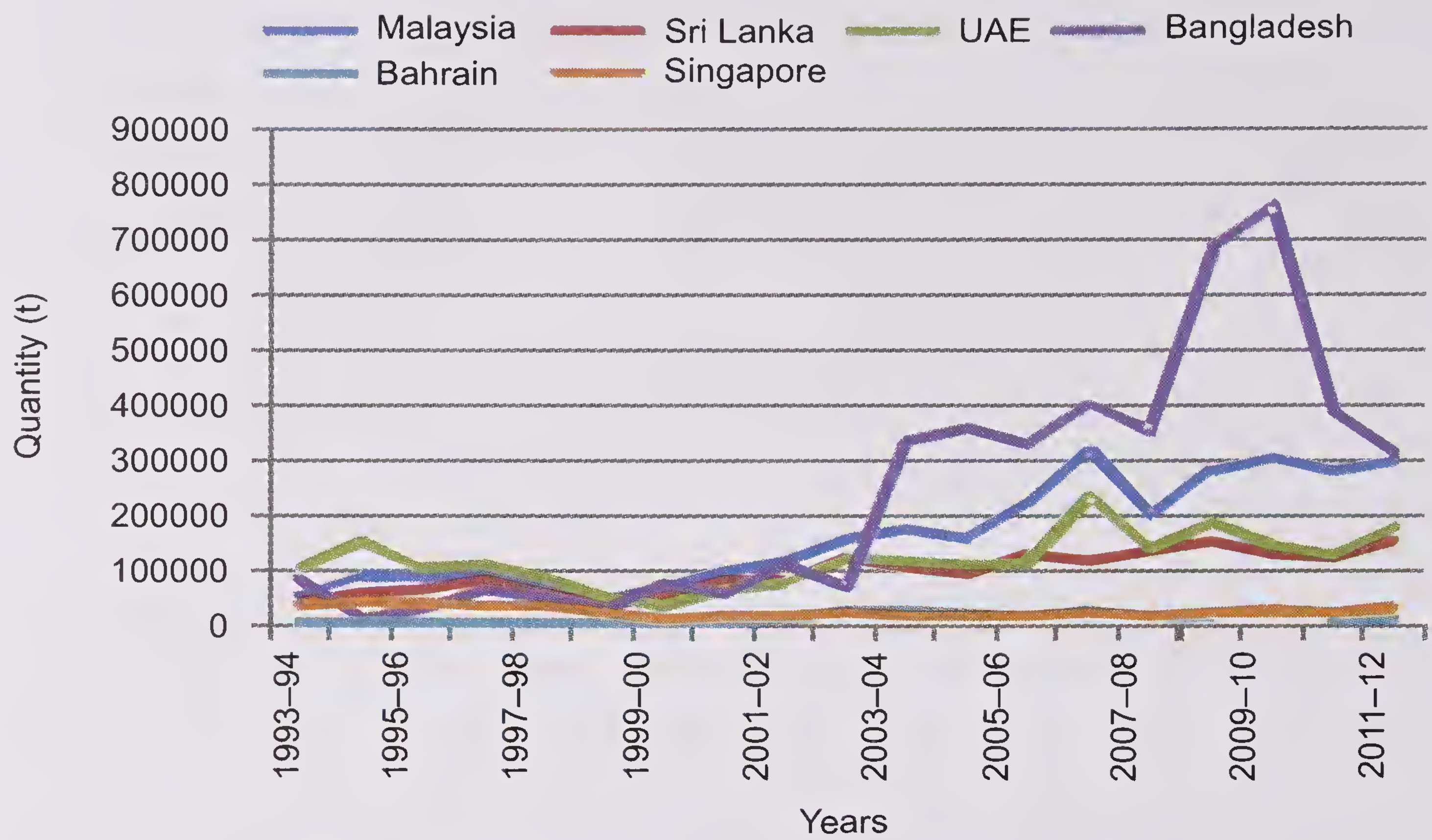

Fig. 17.3. Onion exports from India to different countries

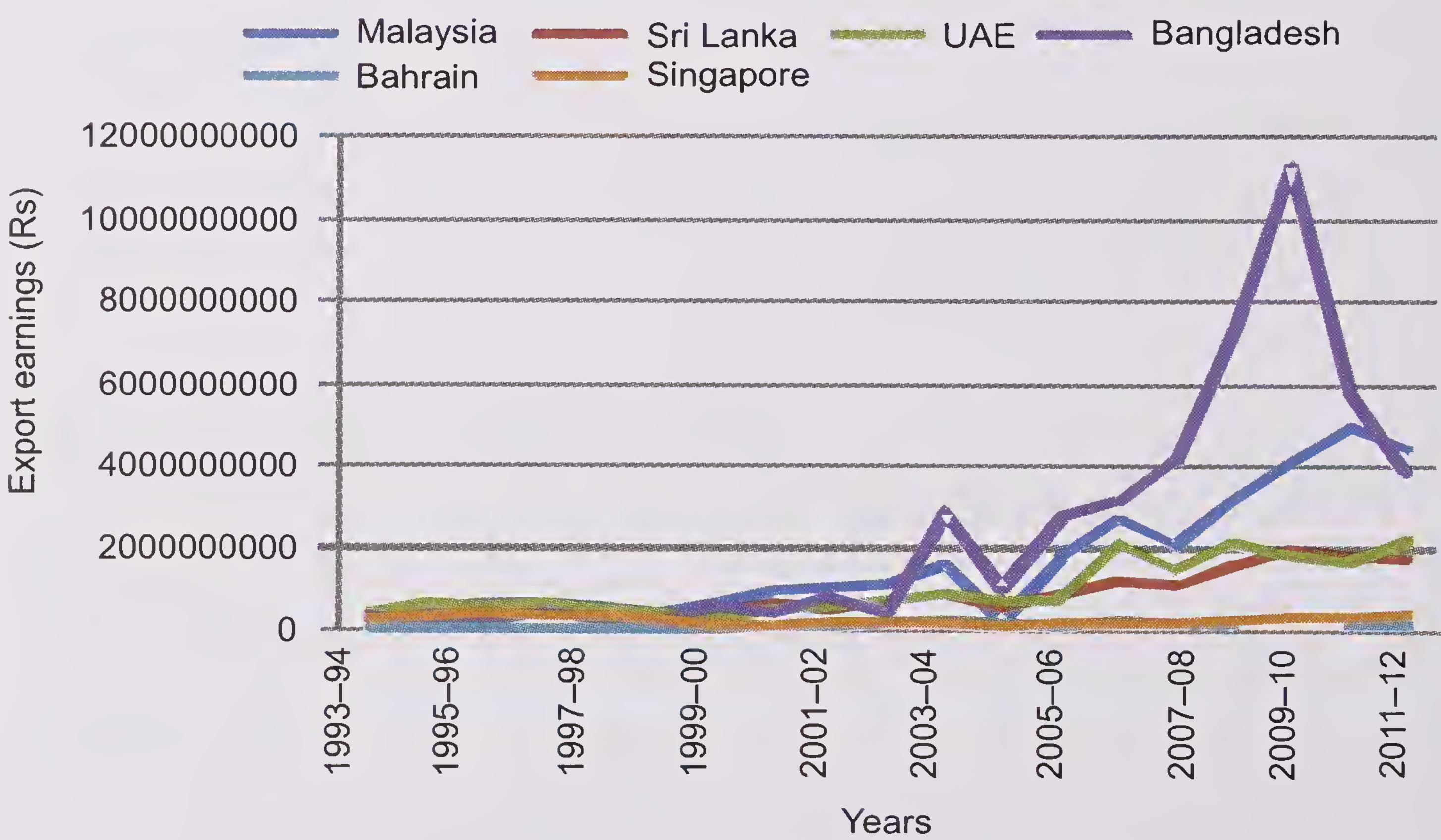

Fig. 17.4 Onion export earnings from different countries

share hovered around 22%. Sri Lanka registered high growth (7–12%) and the growth was found almost stable (15%) and a slight decline in its share from 14% during TE 1995–96 to around 10% during TE 2011–12 was observed. It is interesting to note that Bangladesh is emerging as a major importer of onions from India with a very high growth (20–28%) but with slightly higher instability also (34–38%). As regards the import share, there was a threefold increase in the share of Bangladesh during mid-nineties to TE 2011–12. High growth in export of onion to Bahrain was associated with high instability and its share was very low (1–2%). It is disturbing to note that the share of the earlier dominant importers, UAE and Singapore have, of late, come down drastically. In fact, the share of UAE has come down from 26–32% during the mid-nineties to around 10% during the TE 2011–12. In case of Singapore, there has been a significant decline in its share from more than 10% to less than 2% during the same period.

It is desirable to have high growth with stability for a country to be a potential market for Indian onions. Based on the increasing share and high growth with slight instability, Malaysia, Sri Lanka and Bangladesh may be considered potential markets for onions from India. Further, UAE may continue to be an important market for India. Khunt *et al.* (2008) and Reddy *et al.* (2013) based on the nominal protection coefficients (NPC), observed that export of onion, in general, has been competitive with the nominal protection coefficient NPC hovering around 0.8. However, to understand as to whether this holds good and if export is really profitable at the individual exporter's level, an attempt was made to work out costs and returns associated with export of onion from different ports.

Cost of exports: *Big (Bellary/Nashik Red) onion from Mumbai port:* Bangladesh, Malaysia, Nepal, Dubai and Sri Lanka are the major destinations for onions from Mumbai port. Cost of export of onion from Mumbai port to Dubai worked out to ₹ 3,242/tonne, consisting of packing (₹ 757), transport from field to pack house (₹ 757), from pack house to port (₹ 231), C&F charges (₹ 147), SPS, NOC and documentation charges (₹ 69), terminal handling charges (THC) (₹ 255) and freight (₹ 1703). With a purchase price of ₹ 7,000/tonne, the cost of export worked out to ₹ 10,242/tonne. Export margin varied from ₹ 1,000 to ₹ 1,500/tonne. Export realization depends to a great extent on the international prices.

Big (Bellary/Nashik Red) onion from Chennai port: Big (Bellary Red) onions (35–45 mm) are exported from Chennai port to Malaysia, Singapore, Sri Lanka, Brunei and the Philippines. Malaysia accounts for 60% of onion exported from Chennai port. The cost of export of onion to Malaysia worked out to ₹ 2,670/tonne, consisting of packing material like nylon-mesh bag (₹ 400/tonne), other packing materials like pallet, thread etc. (₹ 350/tonne), labour charges (₹ 400/tonne), transportation, field to port and port to port (₹ 1,140/tonne), other costs like NOC, documentation, etc (₹ 1,140/tonne), freight and terminal handling charges (₹ 380/tonne). With the purchase price of ₹ 6,000/tonne, cost of export of big onion to Malaysia worked out at ₹ 8,670/tonne. Export realization varied from ₹ 10,000/tonne to ₹ 13,000/tonne and the net realization worked out at ₹ 1,330–₹ 4,330/tonne.

Rose onion from Chennai port: Rose onion is grown exclusively for export. It does not have a domestic market. Rose onion grown in Karnataka, Andhra Pradesh and Tamil Nadu is exported from Chennai port to Malaysia, Singapore, Indonesia, Sri Lanka, Brunei and the Philippines. Malaysia accounts for 90% of export. Export earnings from Rose onion were to the tune of ₹ 45 crore in 2006–07. During 2010–11, exports stood at 22,346.49 tonnes, valued at ₹ 59.55 crore.

Information on cost and constraints in export of rose onion was obtained from 14 exporters based in Chennai. The cost of export of Rose onion from Chennai to Malaysia worked out at ₹ 4,700/tonne, consisting of packing material like bamboo-baskets and net (₹ 1,240/tonne), other packing materials like pallet, thread, etc

(₹ 350/tonne), labour charges (₹ 400/tonne), transportation, field to port and port to port (₹ 1,140/tonne), other costs like NOC, documentation etc (₹ 1,140/tonne), freight and terminal handling charges (₹ 470/tonne). With the purchase price of ₹ 10,000/tonne, the cost of export of rose onion to Malaysia worked out at ₹ 14,700/tonne. Export realization varied from ₹ 17,400/tonne to ₹ 24,000/tonne with a net profit of ₹ 2,700–₹ 9,300/tonne.

Constraints in exports

Constraints in export of big onion

- Only 30–40% is of exportable quality.
- Poor infrastructure facility for export, especially road, storage, transport etc.
- Onion is not covered under ECGC-insurance.
- Time-lag between port and destination due to lack of direct vessels.
- Non-tariff barrier in the form of fumigation of onion cargo.
- China is emerging as an important competitor for onions in the international market.
- Withdrawal of LC hinders proper transaction as there are cases of payment defaults.
- Cargo to reach the port well in advance (2 days), before the vessel leaves.
- Frequent export bans are bottlenecks for exporting onions.

Constraints in export of rose onions

- Production practices to be standardized so as to have lesser splits and very small bulbs.
- Grading is not done at farmers' fields level itself.
- Proper storage/godown facility is not available at the production centre.
- LC to be re-introduced for proper transaction.
- Cargo has to reach the port two days before the ship leaves.
- Only one foot of the container door is opened.
- SPS certification is needed for fumigation of onion cargo.
- Competition from China, Myanmar (Burma), Indonesia, Thailand and the Philippines.
- Rose onion is grown exclusively for export, and hence export ban on onions should not be applicable to rose onion—KAPPEC is making efforts with GoI to have a separate HS Code for rose onions.

Marketing of onions: India vis-à-vis China

The global scenario of onion production and export is given in Chapter 1. The order of preference for onions in the traditional markets in the descending order is India, Pakistan, Iran, Egypt and China. The demand for Indian onions, especially in the Asian countries, is more than the Chinese onions; as the yellow coloured Chinese onions are apparently less tasty. Further, the hybrid Chinese onions are bigger compared to the Indian onions. Customers in these countries turn to the Chinese products only during the time of higher price of Indian onions.

Of late, China is attempting to diversify its export market to the traditional importers of Indian onions. Since the last three to four years, it is reported that China has started promoting one of its varieties in these markets, which is similar to Indian onions in colour. However, it has been reported that their taste and shape are different due to different weather and soil conditions.

One of the considerations which make Indian onion export still advantageous in the near future is that onions from no other country can beat Indian onions in taste and other quality parameters. Secondly, price advantage; at present the difference between Indian onions and those from other exporting countries is more than $100/tonne in the international markets. China can enter into Indian traditional export markets only if the onions from India become too expensive during June to September in the domestic market, making exports difficult. And finally, the peak season for export of Indian onions is from January to March, when hardly any country, barring Egypt, which offers a small quantity, is represented in the market.

Future Strategies

It may be concluded from the foregoing discussion that the total post-harvest losses (PHL) worked out at 12.55% consist of 10.43% at the field level and 2.12% at the retail market level. At the field level, losses were mainly due to rotting of bulbs and occurrence of doubles/splits. At the retail market level also, rotting of bulbs, skin-out bulbs and to some extent sprouting are the main reasons for losses. Some suggestions for the management of these losses are as follows.

Management of post-harvest diseases: Curing of the harvested onions in the field for two days and then further drying in the shade for 10–15 days should be taken up before transportation. Care should be taken to avoid injury to bulbs during post-harvest handling. For the control of diseases like rots, the recommended treatments should be followed.

Development of varieties/hybrids resistant to diseases: Research has been initiated in this direction at the Indian Institute of Horticultural Research (IIHR), Bengaluru, Directorate of Onion and Garlic Research (DOGR), Pune, and National Horticultural Research and Development Foundation (NHRDF), Nashik. Many varieties of onions—Arka series, Bhima series, Agrifound series—have been released from these institutes. For example, ‘Arka Kalyan’ and ‘Arka Pragathi’ varieties developed at the IIHR, Bengaluru, were found superior to local varieties and they were less susceptible to rots. By adoption of these varieties, losses due to rotting of bulbs could be reduced to a great extent, thereby making available more number of bulbs for market (R. VeereGowda, IIHR, Bengaluru 2013, *Personal Communication*). The analysis of impact of Arka Kalyan variety by Krishi Vigyan Kendra (KVK), Hulkoti, indicated that it ranked first in bulb colour and shape, keeping quality, resistance to purple-blotch disease, marketability and yield. However, the only problem with this is the longer duration of 100–120 days (K.T. Patil, KVK, Kulkoti 2010, *Personal Communication*).

Adoption of better production and post-harvest practices: Adoption of better production and post-harvest practices would help the producers to bring better quality produce to the market to earn higher returns. Further, only *rabi* onions are suitable for storage and hence all the *kharif* onions are to be sold immediately after harvest. Post-harvest curing and proper drying of the *kharif* onions is a must for getting better market price.

Infrastructure facilities: Bad condition of roads, inadequate and improper storage, inadequate transport, etc. need to be addressed to minimize losses during post-harvest handling of onions. Improved storage facilities, packing and transportation facilities would reduce losses to a considerable extent.

It may also be concluded that the growth in export of onions has been good but this growth is associated with instability. To meet domestic and export market requirements, domestic production needs to be increased through enhanced productivity. Export of onions also has many constraints which need immediate attention of the Government, researchers and policy-makers. For improving export performance of onions from India to different countries following are the suggestions.

Development of varieties/hybrids suitable for export: Research has been initiated to meet export requirements at institutes like Indian Institute of Horticultural Research (IIHR), Bengaluru, Directorate of Onion and Garlic Research (DOGR), Pune, and National Horticultural Research and Development Foundation (NHRDF), Nashik. Many varieties of onions have been released from these institutes for export oriented cultivation. For example, 'Arka Bindu' variety of Rose onion developed at the IIHR, Bengaluru, was found to be superior to local varieties and by adopting this variety, number of splits/doubles and very small bulbs can be reduced to a great extent, thereby making available more number of bulbs for export.

Japanese, American and European markets require big sized (70–80 mm) yellow onions. So far, India has not been able to export yellow onions to these markets. Efforts are needed to develop yellow onion varieties/hybrids to suit the export requirements. Yellow onion varieties like 'Arka Pitambar' developed at IIHR, Bengaluru need to be improved to meet the export requirement. Considering the opportunities and potential of yellow onion, DOGR organizes programmes for identification of suitable varieties and hybrids, suitability of season and standardization of production technologies. The Directorate has recommended Mercedes, Couger, Linda Vista varieties/hybrids for growing from September–February. The trials conducted on BBF with drip irrigation indicated the yield potential up to 50 tonnes/ha as against 13 tonnes/ha as national average. This successful technology has been transferred to farmers' fields in Pune and Nashik districts who are convinced about the high productivity and quality. The trial consignments of yellow onion organized for export to Germany through private traders indicated a promising chance for enhancing export to European Union countries. Finalization of forward linkages and trans-shipment with established backward linkages, can help in developing export market to the tune of 2–3 lakh tonnes (DOGR website).

Adoption of better production and post-harvest practices: Adoption of better production and post-harvest practices developed at the above research institutes would help producers to bring better quality produce to the market—both domestic and international—and thereby fetch them better returns.

Need to support growing and export of 'Rose onion': Since Rose onion is grown exclusively for export and since it does not have domestic market, there is a need to have a separate HS Code for Rose onion so that export ban imposed on onions is not applicable to this. Further, organized production of Rose onion is crucial as majority of the growers are small and marginal.

Re-introduction of LC: Payment default and other associated problems in onion export call for re-introduction of LC. Exporters are of the view that NAFED, the Canalizing Agent may issue LC while issuing NOC.

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Onion Production and Price Volatility: Implications for Technology and Policy

18

Ramesh Chand, Raka Saxena and Sanjay Chayal

Agricultural production as well as food consumption in India are witnessing profound changes. Production is becoming increasingly commercialized accompanied by diversification towards high-value commodities. Demand diversification, market development, increasing liberalization and global interfaces and monetization of economy are aiding this process. Changes in food demand are the result of improved per capita income of consumers, rising urbanization, changing life-style and food preferences of the society. Changes in demand pattern of the societies have altered the demand-price linkages and responsiveness of the market price to fluctuations in demand. Lack of assimilation of these changes, for which, market and prices are exhibiting high level of volatility is disappointing for policy-makers. Price volatility is exacerbated by lack of appropriate policy regarding consumption patterns and technological interventions. As a consequence, so called, minor commodities in consumption basket, like onions, often cause major shocks to prices to farmers, to consumers as well as to overall price stability.

This chapter is an attempt to understand nature of changes in demand for onions and their implications on price and production of onions. It also examines changes in production and prices of onions in yesteryears to understand recent price shocks in the onion market. This is followed by suggestions to check price shocks and to bring in stability in onion markets. The analysis is based on the secondary data on area, production, productivity, market arrivals, market prices and exports obtained from various sources like Centre of Monitoring Indian Economy (CMIE) publications, National Horticulture Board, AGMARKNET website, etc.

Changes in production pattern

The onion production in India has consistently increased during the last three decades (Fig.18.1). This entire period can be divided in two phases. The first phase from 1980-81 to 2002–03 witnessed gradual increase in production, driven largely by area expansion. In this period, area under onion cultivation doubled, from 0.25 million hectares to 0.5 million hectares, and the production also doubled (refer to 2003–04). However, the yield level remained stagnant at 100 quintals per hectare. After 2002–03, all the three dimensions of the production witnessed exponential growth. Area under onion cultivation doubled in a decade, productivity increased by about 50% and production almost tripled. Netting-out the population growth, production of onion in India showed an increase from 4.56 kg/person/year in the biennium 2000–01 and 2001–02 to 13.97 kg/person/year in the biennium

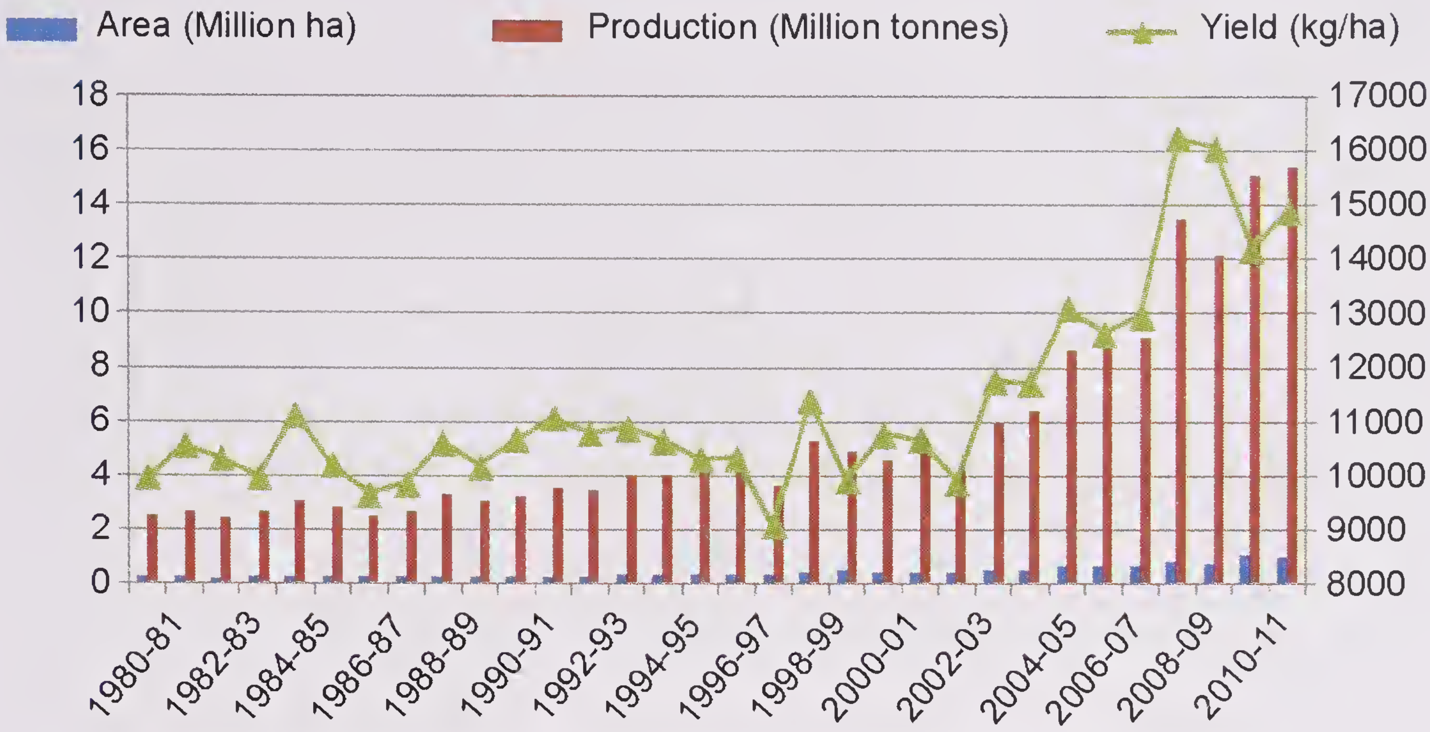

Fig. 18.1 Trends in area, production and productivity of onion in India

2011–12 and 2012–13.

Spectacular increase in onion production in 2012–13 increased its per capita domestic availability and consumption, and it also helped raising onion export from India from 330 thousand metric tonnes in 2000 to 1,822 thousand metric tonnes in 2012–13.However, like many other agricultural commodities, onion production in the country faces deviations from the trend or normal production. This often leads to price shocks and disruption in exports. Thus, despite being surplus nation, the country has to resort to costly imports in adverse situations. This instability in production forces the country to take abrupt decisions to sometimes curb export, and this in a way affects the reputation of India as a reliable supplier in the overseas markets.

Regional pattern of onion production

Unlike other agricultural commodities, onion production does not have any geographical clustering. Currently, close to 70% of the total onion produced in the country comes from Maharashtra, Karnataka, Madhya Pradesh, Gujarat and Bihar. Maharashtra is the highest onion- producing state in India, contributing approximately 30% of the share in total production (*see* Fig.2.1, Chapter 2).

Maharashtra has been the largest onion- producing state, followed by Karnataka (Fig. 18.2). Surprisingly, the production in Karnataka declined during the last five years (2007–2012). In general, production pattern witnessed increasing trend during the last five years; except in the year 2009–10 when onion production dropped owing to cyclone and unseasonal rains in Maharashtra, Gujarat and Karnataka. There was a drop in onion production in Maharashtra by 20% compared to the previous year. It can be seen that Madhya Pradesh remained the 5th largest onion-producing state in the four consecutive years, starting from 2007–08 to 2010–11. But it became 3rd in 2011–12, with an increase of 91% compared to the previous year. The reason for such an increase was expansion in onion area by more than 50% and noticeable, of more than 25%, of productivity increase.

It is important to mention that regional concentration of onion production in

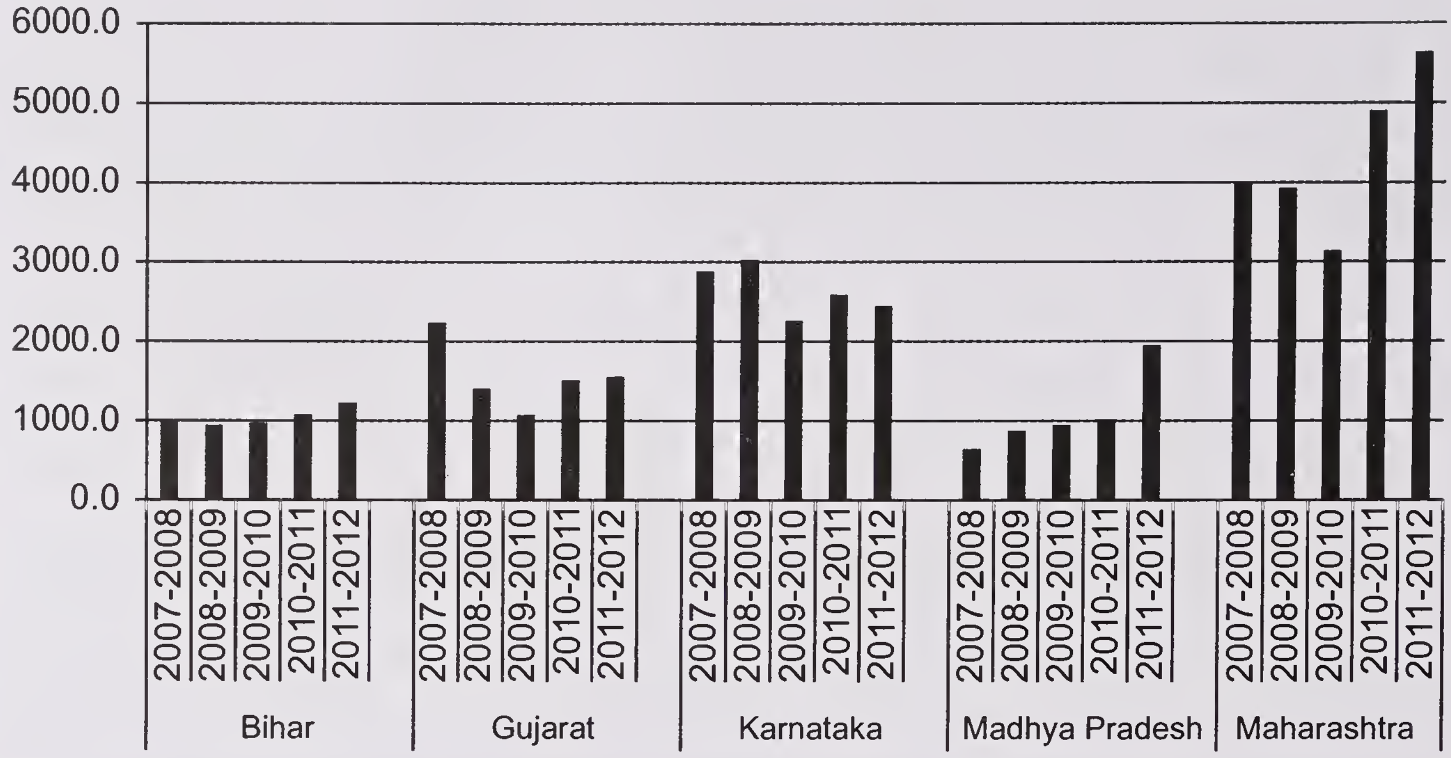

Fig. 18.2 Changes in production pattern of major onions-producing states (in '000 tonnes)

the country has increased during the past three decades, though with fluctuations. Five major producing states—Maharashtra, Karnataka, Gujarat, Madhya Pradesh and Bihar—together produced around 55% of the total production in 1980-81, but this declined to 50% in 1987–88 (Fig 18.3). The volatility in regional concentration was relatively higher during 1987–88 to 2000–01. Between 2000–01 and 2012–13, the regional concentration increased from 64 to 69% with some peaks and troughs in between.

Onion production has risen from below 5.5 million tonnes till 2002–03 to above 15 million tonnes during the last three years. And the country experienced annual growth rate of 13.36% in onion production since 2000–01. No other food crop in India has shown this type of spectacular growth in the recent past. However,

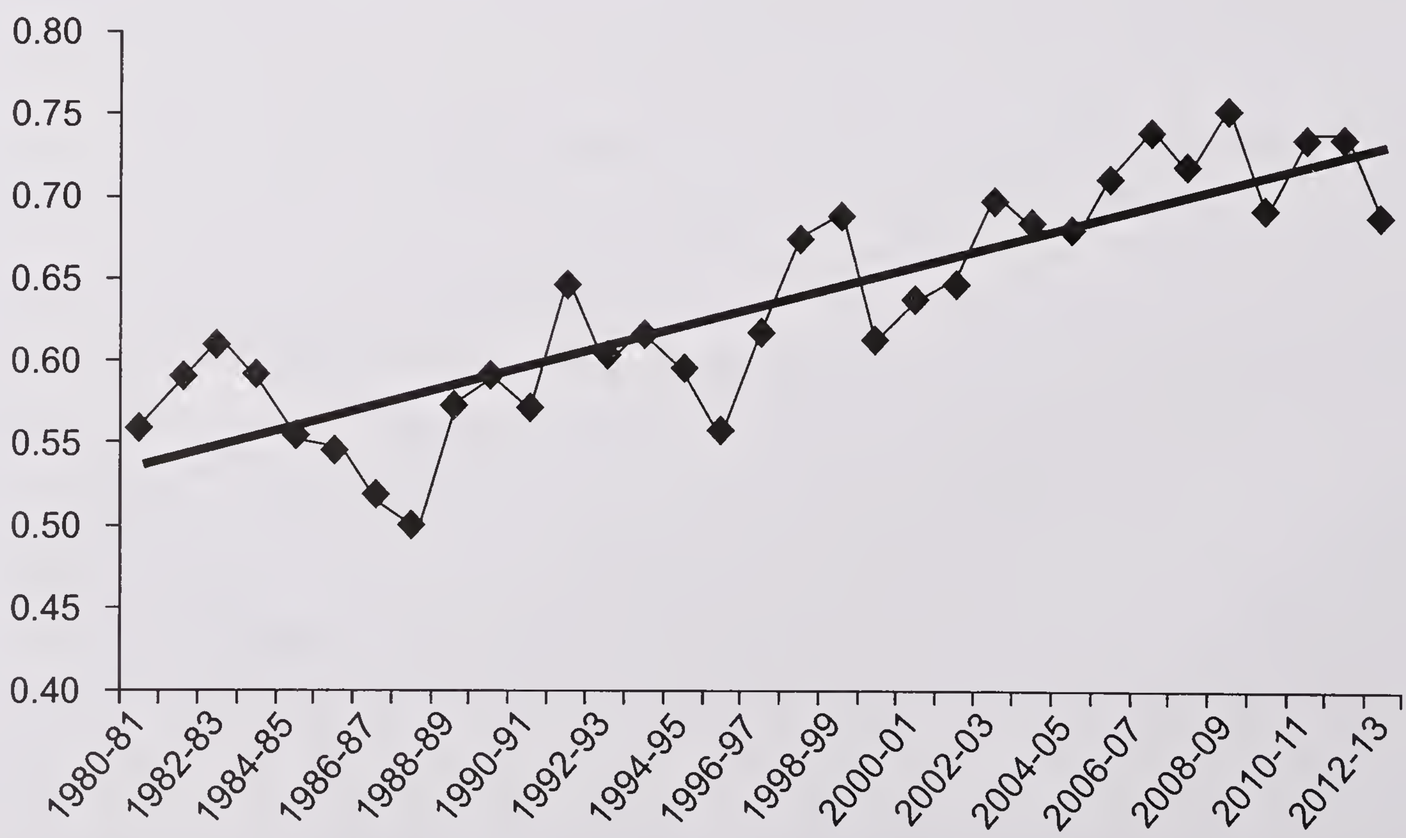

Fig. 18.3 Regional concentration in onion production (share of five major producing states)
Source: Office of the Economic Adviser, GoI.

domestic and overseas demand for onions seems to be outpacing growth in production. Per capita availability of onion increased from 4.0 kg in 2002–03 to 12.6 kg in 2012–13; witnessing an increase of 12% every year. This growth in per capita demand for onions reflects mind boggling preference of Indian consumers for onion.

Table 18.1 gives information on the changes in household consumption pattern of onion in India. The data were obtained from various rounds of the National Sample Survey Office (NSSO). Per capita onion consumption among rural households witnessed highly impressive growth during 1993–94 and 2009–10; and it increased by 61%. Due to changing life-style and dietary patterns, onion consumption among urban households is usually higher than rural households. Onion consumption in urban households also experienced high growth of 53% during 1993–94 and 2009–10.

Table 18.1 Consumption pattern of onions in rural and urban households

Round	Sector	Quantity per 30 days (kg)	Value per 30 days (₹)	% share in food, monthly per capita expenditure (MPCE)
1993–94	Rural	0.46	2.21	1.24
1999–00	Rural	0.58	3.68	1.27
2004–05	Rural	0.56	3.97	1.29
2009–10	Rural	0.74	10.89	1.82
1993–94	Urban	0.56	2.88	1.15
1999–00	Urban	0.72	4.77	1.16
2004–05	Urban	0.72	5.06	1.13
2009–10	Urban	0.85	13.34	1.51

Source: National Sample Survey Office, Various Rounds

If we account for onion consumption outside home, consumption level and its growth would be much higher than the household level data. Large expansion of eating joints, outside eateries, snack corners, restaurant in the recent years has added considerably to increase per capita onion consumption, as onion being the main ingredient that attracts consumers to spicy food.

According to an estimate of the NCAER, price elasticity of demand for onion is as low as 0.1. This implies rigidity in consumers' demand for onion. It seems the Indian consumers consider onion consumption as a much stronger necessary good than the staple food. As onion is an integral ingredient of Indian curry, it is difficult to imagine acceptance of food without onions. Over the years, onion has replaced its substitute spices, as they have turned much costly. This further explains low price elasticity of demand for onion, which implies that 10% increase in price can result only in 1% decline in demand for onion. This also implies that 10% shortfall in onion supply causes 100% increase in its price.

Onion price behaviour

Agricultural prices are influenced by umpteen number of factors, ranging from to social, economic, policy, market, trade, etc.The food inflation in recent years has remained stubbornly high, which has been causing a serious concern. In the case of products like onion, potato, tomato and some other horticultural products, prices have shown steep rise and also sharp fall even within a short span. The volatility has turned much more severe after the year 2009.

Behaviour of onion prices in the recent years can be captured from the monthly wholesale price indices (WPI) of onion (Fig.18.4).Compared to the WPI of food and non-food articles, the onion WPI has witnessed a highly volatile trend. In recent times, the volatility has become even much more severe and is getting explosive.

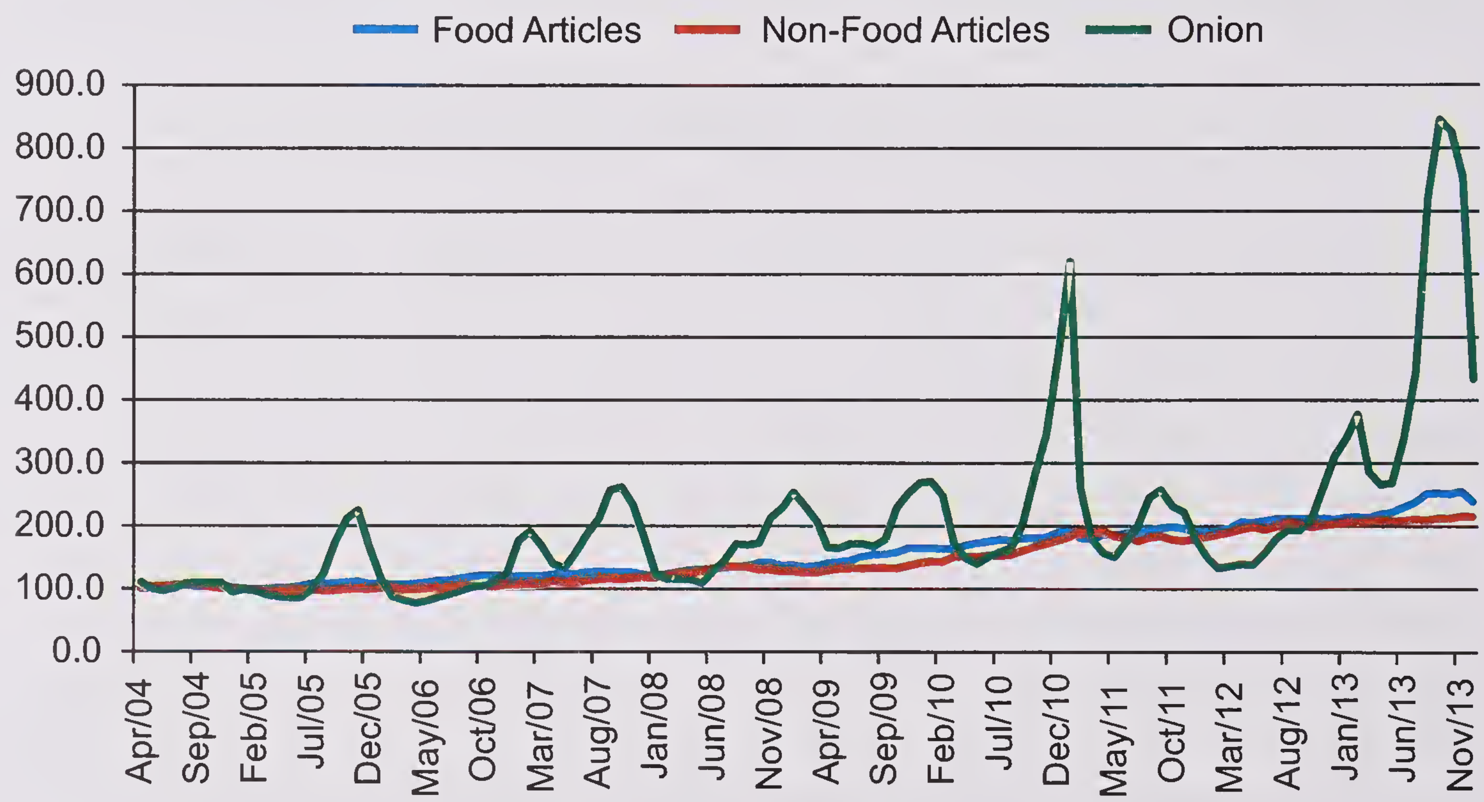

Fig. 18.4 Trends in wholesale price index of food, non-food and onion

Like any other agricultural commodity, onion production in India is also affected by rainfall, which in turn, affects the market arrivals and prices. The year 2009–10 was a bad year in India from agricultural perspective, which resulted in a decline of about 10% in onion production. Its impact was immediately visible in the market prices, and the onion WPI reached the historical peak of 619 (base 2004–05=100). After 2009, the onion WPI dipped below the general WPI of food and non-food articles. Sensitivity of onion prices to small variations in supply is evident from the fact that during the last 10 years, onion price shocks have hit the country thrice. In 2013, the country experienced more intense onion crisis, which has been described in details in the subsequent section.

Understanding onion price crisis of 2013

It has already been indicated that Maharashtra accounts for more than 30% of the share of the total production of onion in the country. The major onion markets in Maharashtra govern entire trade and affect price situation across the country. Therefore, it becomes important to understand the price and arrival behaviour of the leading onion- producing state, Maharashtra, in the country (Fig.18.5).The

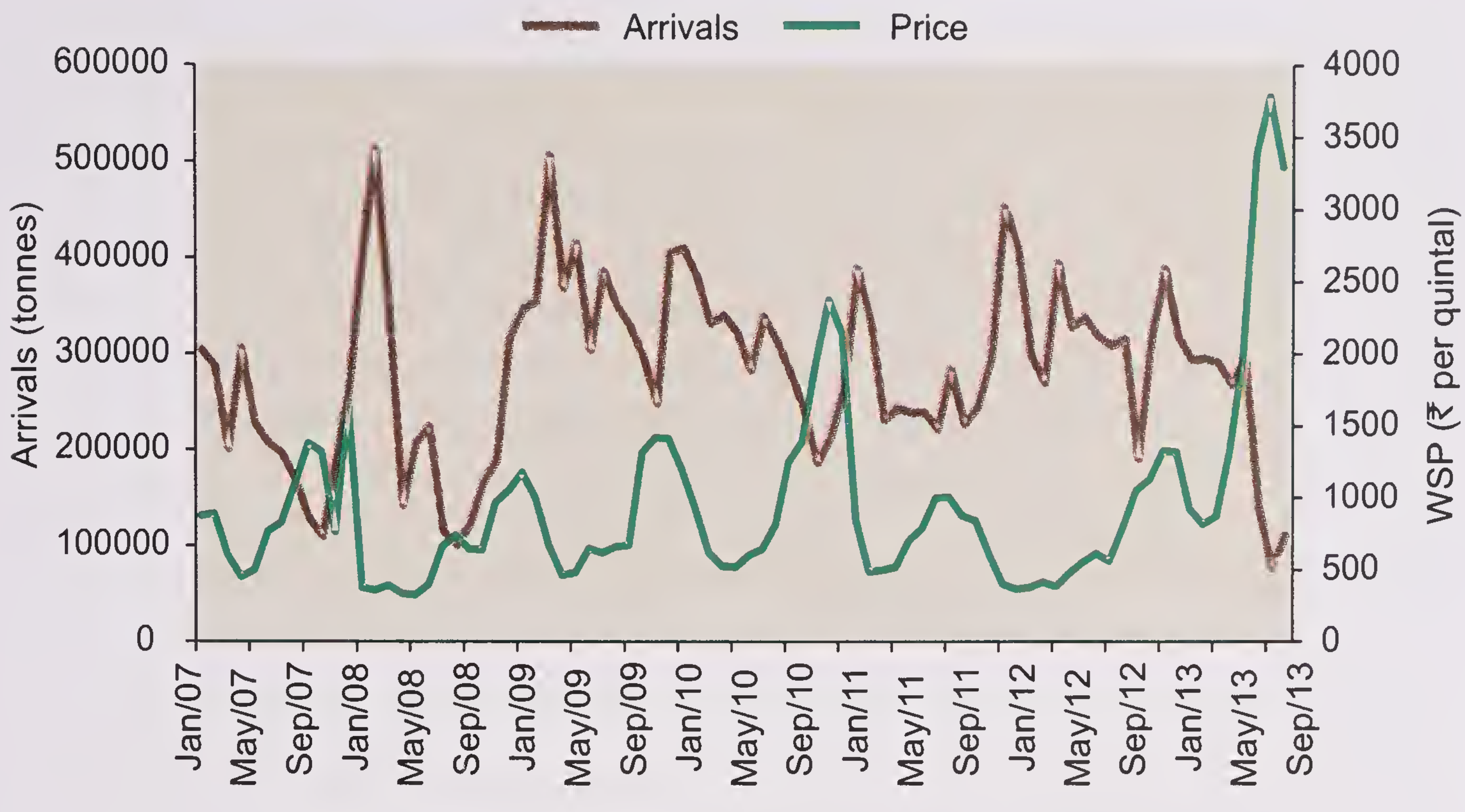

Fig. 18.5 Arrival and price pattern of onion in Maharashtra

arrival pattern indicates that peaks in the market arrivals are getting reduced whereas the spikes in prices are becoming steeper. These patterns may be due to many reasons. One, it could be due to increase in storage capacity of producers and their decision to stagger sales to take advantage of increased prices in the lean season. Thus, farmers holding back produce during below normal production, results in still lower market arrival, which leads to higher increase in prices. Two, it could also be due to manipulation of market by wholesale buyers and big traders.

The WPI of onion in the country and prices in Maharashtra behave in a quite similar fashion. One may infer that the state price signals reach other markets too and affect prices in other markets.

The arrivals in Maharashtra started declining from January 2013, the trend continued (except April 2013) and the gap widened to a great extent in August 2013 as compared to the previous year (Fig.18.6). Further, a sharp decline in September 2013 added to crisis, and its impact on prices was clearly visible.

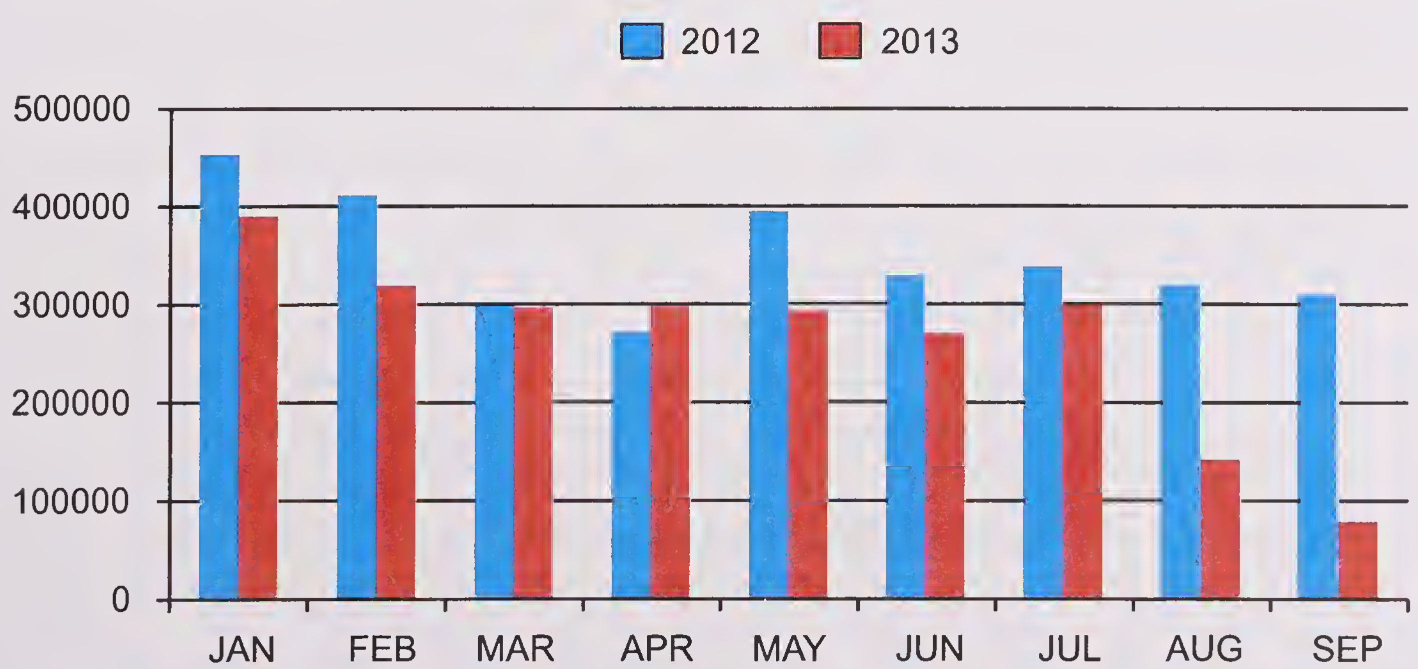

Fig. 18.6 Comparison in month-wise arrivals (tonnes) of onion in Maharashtra, 2012 and 2013

A peek into the present crisis reveals that adequate and clear signals were available as early as in the months of May–June ofthe coming price shock, and these have been exploited by onion traders under a clear strategy. Advanced estimate about onion production in March 2013 indicated that production in 2012–13 at the country level would be lower by 4% as compared with the previous year. Private traders could understand its implications and started procuring onion in a big way by offering higher price to producer-sellers. Market arrivals of onion in three post-harvest months of *rabi* crop (April to June 2013) in 32 markets of the country including those in Maharashtra were in fact 24% higher than the previous year. As the supply from farmers dried up, the market arrivals beyond June were to be determined by the stocks released by onion-traders. Market arrivals in July and August were lower by 17 and 22% compared to the previous year. This reduced supply, raised year on year market prices in 32 markets in July and August by 186% and 293%, respectively, compared to year 2012. It happened according to the expectation of the traders as well as what is implied by the price elasticity of demand. Then, it completely came in the hands of traders to dictate prices by calibrated release of stocks with them. Here, it is pertinent to point out that the decrease in production of onion was responsible for increase in price of onion only to a small extent; predominant part was owing to withdrawal of onions from the market by the traders.

It is ironical that India faces frequent and severe onion price shocks despite record growth in its production in the country. The present onion crisis is a consequence of our neglect of response to put in place effective mechanism to prevent the crisis or reduce its severity. Every time we face abnormal rise in onion price, we attribute it to unfavourable weather and exploitation of situation by traders and so called cartelization, hoarding etc. and forget about it when prices roll back to normal. We have been treating such shocks as inevitable rather than seeking a solution to avoid their recurrence.

Future Strategies

There are following three ways to stabilize supply and prices.

1. ***Stabilisation through stocks:***Stabilization through stock requires purchase of onion during normal or above normal production and liquidating the stock in the event of shortfall in production. This type of stabilization in supply requires market intervention by public sector parastatal like NAFED. Besides physical stabilization, it would also keep a check on exploitation and market manipulation by the private trade. There should be constant monitoring of prices and market arrivals by some agency of the Central Government, which should also give advance information to government about implications of supply fluctuation on prices, like early warning system of the FAO. This should be followed by appropriate and early action based on the market intelligence to regulate trade like liberalizing import, restriction on export and check on hoardings.
2. ***Stabilization through trade:*** It needs to be remembered that private trade is

benefited by price variations and volatility, and their interest is against price stabilization. One also cannot expect private sector, involved in domestic trade of onion, to arrange import to augment domestic supply as this would involve larger reduction in gains from domestic sales than gains from imports. The anecdotal evidence indicates as if Indian onion traders have tacit understanding and some sort of cartelization and they are involved in price discrimination, under which, they are charging lower price in overseas markets and higher price in domestic market like a monopolist. Therefore, public sector agency like the NAFED has a crucial role in price stabilization through domestic operations as well as through trade. Such institutions cannot be created at the time of crisis—they have to be there before the crisis.

3. ***Stabilization through regional or temporal spread of onion cultivation***: The third measure relates to seasonal spread in onion cultivation and technology. As the production of onion is concentrated in a few pockets, the instability in production can be reduced by diluting regional concentration of onion production and by extending its cultivation beyond present seasons and geographic areas. Both these options require technological interventions. The suitable varieties need to be developed to suit various agro-climatic conditions so that geographical and seasonal span of the onion- crop can be expanded.

If India doses not take the three measures listed above, it is going to face recurrent price crisis in onions.

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Subject Index

THE ONION

The name "onion" originated from the Latin name unio, meaning oneness or unity, or a kind of single onion. A native of Central Asia, onion is now grown in more than 140 countries under temperate to tropical conditions. In India, onions have been adapted from very early times, before Christian era. Maharashtra, Karnataka, Gujarat, Bihar, Madhya Pradesh and Rajasthan are the main onion-growing states in the country. Barring north-eastern states and Kerala, basically all states grow onion. A crop of high culinary importance in daily diet creates ripples in political circles when consumers face shortage of onion and market price goes high.

'The Onion' covers all aspects of the crop from its origin to marketing. In its eighteen chapters written by experts in the respective fields of onion, this monograph reviews status and prospects of onion research and development. It covers genetic resources, genetics, biotechnology, breeding, crop production, crop protection, seed production, physiology, biochemistry, processing and storage as well as price volatility aspects of onion. Each chapter presents complete information from historical aspects to latest times, supported by data, illustrations and references. Readers will find all information on onion in one spine in this book . This publication hopefully would be a source of rich information for students and researchers, and would be of great value for farmers and entrepreneurs alike.

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