Series of Crop Specific Biology Documents

BIOLOGY OF *SOLANUM TUBEROSUM* (POTATO)

Phase II Capacity Building Project on Biosafety

Ministry of Environment, Forest and Climate Change
Government of India

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Nature Protects if She is Protected

Ministry of Environment, Forest and Climate Change

Government of India

Biology of *Solanum tuberosum* (Potato)

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under UNEP/GEF supported Phase II Capacity Building Project on Biosafety

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Message

I am happy to learn that the Ministry of Environment, Forest & Climate Change (MoEFCC) as part of the initiative under the UNEP GEF supported "Phase II Capacity Building Project on Biosafety" has developed eight crop specific biology document on Chickpea, Mustard, Papaya, Pigeon-pea, Potato, Rubber, Sorghum, and Tomato.

I am happy to note that the documents have been prepared with support from seven research institutions namely Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research.

While Bt cotton is the only genetically modified (GM) crop approved for commercial cultivation in India, there are several crops under various stages of research, development and field trials. The present set of crop specific biology documents aims to provide scientific baseline information of a particular plant species that can be used as credible source of information for conducting safety assessment of GM plants.

I would like to congratulate all those who were involved in preparing these documents and those involved in steering this initiative.

I am confident that these biology documents will serve as a valuable tool for regulators, scientists, crop developers, policymakers, academicians and other stakeholders who are involved in the safety assessment of GM plants. I am also hopeful that baseline information provided in the biology document would further enhance awareness on biosafety aspects of GM crops.

(Prakash Javadekar)

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PREFACE

India is an agriculture based economy with abundance of genetic base, diverse agro-climatic zones and highly qualified manpower which provides a rich scope for technological advances in agricultural biotechnology. The shortage of healthy seeds/planting material, lack of disease resistant clones, crop damage by insects, pests etc. have often affected the Indian agricultural economy adversely and therefore the role of new technologies assumes significant importance for Indian economy.

With significant advances in the field of agricultural biotechnology the regulatory system has to deal with multiple crops integrated with multiple traits. In order to streamline the process of safety assessment, the Ministry of Environment, Forest & Climate Change (MoEF&CC) under the UNEP-GEF supported "Phase II Capacity Building Project on Biosafety" has prepared a set of crop specific biology documents namely Chickpea, Mustard, Papaya, Pigeon-Pea, Potato, Rubber, Sorghum, Tomato with support from six Indian Council of Agriculture Research (ICAR) institutions and Rubber Research Institute of India.

The biology documents provides an overview of baseline biological information of a particular plant species such as taxonomy, the centres of origin, its related species including wild relatives, general description of their morphology, reproductive biology, biochemistry, potential for gene introgression, biotic and abiotic interactions. Such species specific information is expected to serve as a guiding tool for use in risk assessment of genetically modified (GM) plants.

The documents has been prepared through a consultative approach and comments received from several organizations have been extremely useful in validating this document. I express my deep appreciation for the support provided by Indian Institute of Pulses Research, Directorate of Rapeseed and Mustard Research, Indian Institute of Horticulture Research, Central Potato Research Institute, Rubber Research Institute of India, Indian Institute of Millets Research and Indian Institute of Vegetable Research in preparing these documents. I would also like congratulate Dr. Ranjini Warrier, Advisor, (MoEFCC) and Dr O.P Govila (Former Professor, Department of Genetics, IARI) for their sincere efforts and the consultative approach adopted in finalizing the biology documents.

I am confident that these crop specific biology documents would be of immense value for researchers, regulators and industry in planning for the safety assessment of GM crops.

Hem Pande

CONTENTS

BIOLOGY OF *Solanum tuberosum* L. (POTATO)

1. GENERAL DESCRIPTION

Potato (*Solanum tuberosum L.*) is the most important non-grain food crop in the world, ranking 3rd in terms of total production with over 365 million tonnes per year (FAOSTAT, 2013), after rice and wheat. It is grown in around 150 countries spread across both temperate and tropical regions and at elevations from sea level to 4,000 m (Paul *et al.* 2012). More than half of the potato production takes place in developing countries including India, and over one billion people have potato as their staple diet. It has steadily expanded globally, with 35% increase in overall production since 1960. The increase in production is still higher in developing countries of Asia and Africa (Fig.1) indicating its growing importance as a staple food source.

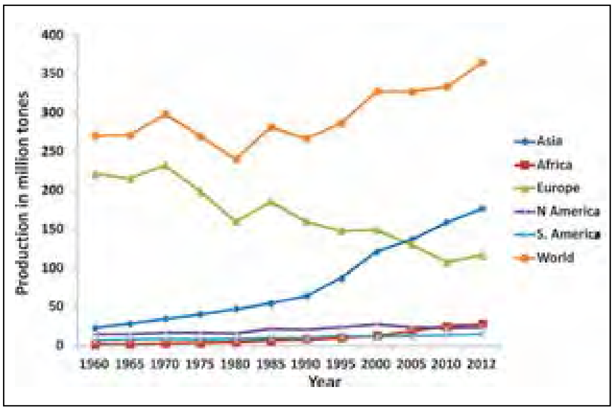

Fig.1: Trends in the world potato production from 1961-2012 (**Source:** FAOSTAT, 2014)

Nutritionally, potatoes are second only to soybean for amount of protein/ha, with the major storage protein being patatin, one of the most nutritionally balanced plant proteins known (Liedl et al. 1987). A single 150g tuber provides up to 45% of recommended daily allowance (RDA) for vitamin C, 10% vitamin B6, 8% niacin, 6% folate as well as significant amounts of other essential mineral nutrients required; however it lacks many other essential nutrients like vitamin B12, Biotin, Thiamin, Riboflavin, Alfa carotene, Lycopene, Retinol and Alfa tocopherol and important minerals like copper, iodine and molybdenum (Meredith, 2012) required for human consumption. A detailed nutritional content of potato is given in Table 1.

Table 1: Nutritional composition of potato (Source: Lister and Munro, 2000)

Substance	Range (%)	Mean (%)
Dry matter	13.1-36.8	23.7
Starch	8.0-29.4	17.5
Reducing sugars	0.0-5.0	0.3
Total sugars	0.05-8.0	0.5
Crude fibre	0.17-3.48	0.71
Pectic substance	0.2-1.5	-
Total nitrogen	0.11-0.74	0.32
Crude protein	0.69-4.63	2.00
Lipids	0.02-0.2	0.12
Ash	0.44-1.87	1.1
Ascorbic acid	21.7-68.9*	-
Glycoalkaloids	0.2-41**	3-10
Phenolic compounds	5-30**	

*mg/100g, **µg/100g

2. TAXONOMY AND GEOGRAPHIC ORIGIN

2.1 Taxonomy

Potato (*Solanum tuberosum L.*) belongs to the *Solanaceae*, a family of about 90 genera and 2,800 species. *S. tuberosum* is divided into two, only slightly different, subspecies: *andigena*, a diploid which is adapted to short day conditions and is mainly grown in the Andes; and *tuberosum*, a tetraploid potato now cultivated around the world, is believed to be descended from a small introduction of *andigena* potatoes to Europe that later adapted to longer day lengths. The latest comprehensive taxonomic treatment of section Petota was published by Spooner et al., 2014; it recognizes eight cultivated species and 228 wild species, divided into 21 taxonomic series, including 19 series for tuber-bearing species and two series of non-tuberous species.

Systematic classification of potato (Spooner *et al.*, 2014)	
Kingdom	Plantae
Subkingdom	Viridaeplantae
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Order	Solanales
Family	Solanaceae
Genus	*Solanum*
Species	*Solanum tuberosum L.*

The eight cultivated species in potato are provided in Table 2. Among these eight cultivated species of section Petota only *S. tuberosum* ssp. *tuberosum* is grown world wide others are restricted to the Andean countries where thousands of primitive cultivars are found.

Table 2: Cultivated potato species with their chromosome number and ploidy level

Solanum species	Chromosome number	Ploidy level
S. ajanhuiri *S. goniocalyx* *S. phureja* *S. stenotomum*	2n = 2x = 24	Diploid
S. chaucha *S. juzepczukii*	2n = 3x = 36	Triploid
S. tuberosum ssp. tuberosum *S. tuberosum ssp. andigena*	2n = 4x = 48	Tetraploid
S. curtilobum	2n = 5x = 60	Pentaploid

2.2 Geographic Origin and Distribution

Potato is not a native crop of India. The cultivated potato originated about 8,000 years ago near Lake Titicaca, which sits at 3,800 m above sea level in the Andes mountain range of South America, on the border between Bolivia and Peru. To the Andeans and later to the Incas, it was known as papa. The centre of diversity for wild tuber-bearing potatoes (subsection *potatoe*) lies in Latin America, which is also considered the centre of origin. For the series *tuberosa* (to which *S. tuberosum* belongs) and most other series within the subsection *potatoe*, there are two centres of diversity. One is a long-stretching Andean area in Venezuela, Colombia, Ecuador, Peru, Bolivia and Argentina. The other is in central Mexico. The distribution area of these wild potatoes is much larger: from the southwestern United States to southern Argentina and Chile (Child, 1990; Hawkes, 1990). By the 16th century potato was introduced into European countries by Spanish conquerors. The potato also received an unusually warm welcome in Ireland, where it proved suited to the cool air and moist soils. Irish immigrants took the tuber and the name, "Irish potato" to North America in the early 1700s. Generally the cultivated *Solanum* species are also found within the centres of diversity for wild potatoes. The exception is the cultivated diploid form of *S. tuberosum* subsp. *tuberosum*, which is only found in a constricted area of southwestern Chile. The cultivated tetraploid *S. tuberosum* subsp. *tuberosum*, as known in Europe and most other parts of the world, is considered to be a selection from a small introduction of *S. tuberosum* subsp. *andigena* potatoes from Colombia and Peru, and as such has a very narrow genetic basis. The arguments for this thesis are that plants of the original introductions into Europe are known to have been late flowering and tuberising, and that the morphological description of these potatoes matches the *andigena* type (Howard, 1970). Through selection, this introduction was adapted to the longer day lengths and different environmental conditions of Europe. Simmonds (1966) has shown that such transition can take place in a fairly short period of approximately ten years of selection. From Europe, this new type of potato has spread all over the world as a cultivated crop. An alternative theory is that, after the potato blight epidemic in Europe, new germplasm of *S. tuberosum* subsp. *tuberosum* originating from Chile (Hawkes, 1990) was introduced into Europe.

Fig.2: World Map showing journey of potato

European colonizers took potato to all corners of the globe. Colonial governors, missionaries and settlers introduced potato growing to the floodplains of Bengal and Egypt's Nile delta, the Atlas Mountains of Morocco, and the Jos plateau in Nigeria. Emigrant farmers took the potato to Australia and even to South America, establishing the potato in Argentina and Brazil. In the Asian heartland, the tuber moved along more ancient routes, finding its way from the Caucasus to Turkey's Anatolian plateau, from Russia to western China, and from China to the Korean Peninsula. In the mountain valleys of Tajikistan, some potato types have been grown long enough to be considered "old local varieties". The International Potato Centre's (www.cipotato.org) page on "Potato routes: a remarkable journey" provides an excellent account on global spread of potato from South America (Fig.2).

The 20th century saw the potato finally emerge as a truly global food. The Soviet Union's annual potato harvest reached 100 million tonnes. In the years following the Second World War, huge areas of arable land in Germany and Britain were dedicated to potato, and countries like Belarus and Poland produced - and still do - more potatoes than cereals. From the 1960s, cultivation of potato began expanding in the developing world. In India and China alone, total production rose from 16 million tonnes in 1960 to almost 120 million in 2010. In Bangladesh, potato has become a valuable winter cash crop, while potato farmers in southeast Asia have tapped into exploding demand from food industries. In sub-Saharan Africa, potato is a preferred food in many urban areas, and an important crop in the highlands of Cameroon, Kenya, Malawi and Rwanda.

2.3 Distribution in India

In India, potato was introduced by either Portuguese or British colonizers in the early 17th century. The earliest reference of potatoes in India is from the account of the voyage of Edward Terry, who was chaplain to Sir Thomas Roe, British Ambassador to the court of Mughal Emperor Jahangir from 1615-1619. The early potato introductions in India did not belong to *S. tuberosum* ssp. *tuberosum* but to *S. tuberosum* ssp. *andigena*. Those initial introductions eventually got established in India and further selections by Indian farmers resulted in several indigenous cultures known as *desi* varieties. Sixteen such "*desi*" varieties were later identified by Central Potato Research Institute (CPRI) with the help of Potato Synonym Committee, National Institute of Agricultural Botany, England. Among these, Phulwa, Darjeeling Red Round and Gola, were most popular. Though the *desi* varieties could be grown in Indian plains, their yield was very low and the seed stock was riddled with many viruses. The major boost in potato production came after the establishment of CPRI in the year 1949. The crop is presently being grown in 1.99 million ha spread over 26 states.

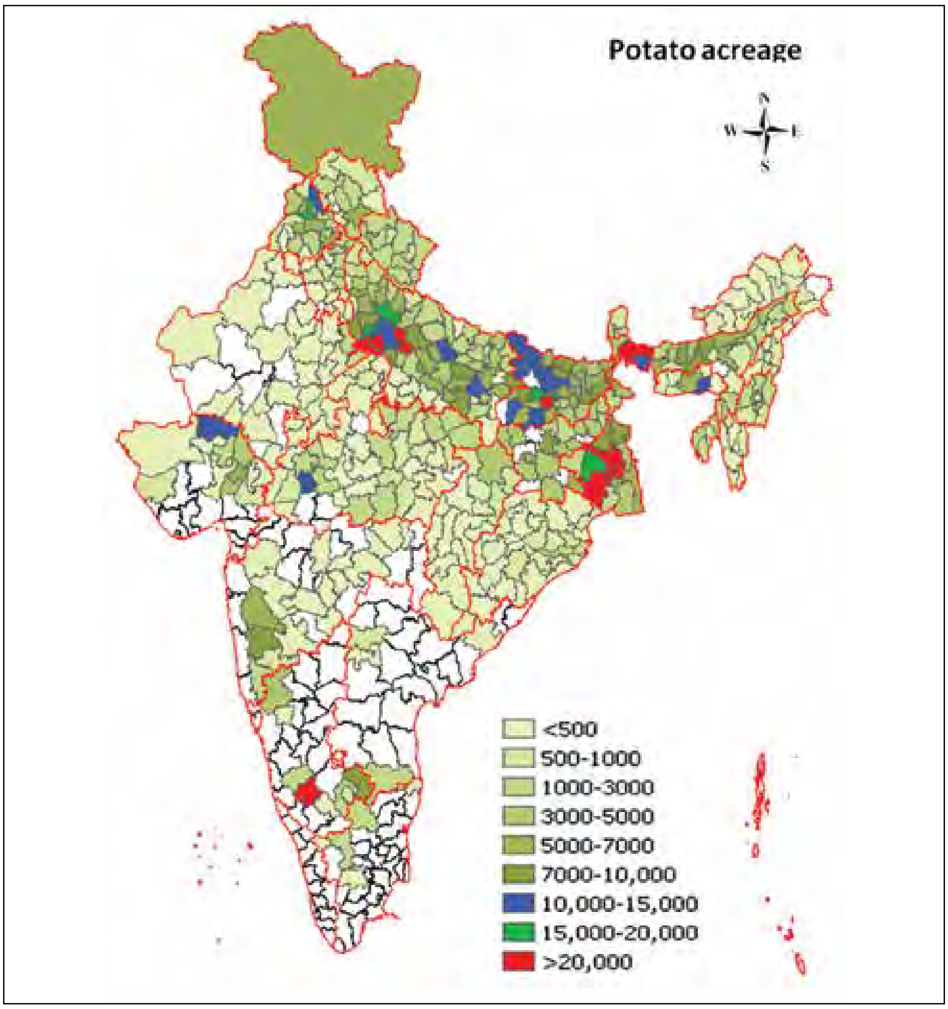

Fig.3:
Potato acreage

Important states/area under cultivation for the crop: In India, potato is grown during autumn/winter/spring seasons in the sub-tropical plains and during summer/autumn in the temperate/semi-temperate hills. The planting time depends on temperature and cropping pattern followed in the area. In plains, the ideal time of planting corresponds to maximum and minimum temperatures of 30-32^{0}C and 10-20^{0}C, respectively. In the hills, planting is done when the maximum temperature is about 20-22^{0}C and minimum temperatures are about 12-15^{0}C. In the Nilgiri hills, the temperatures remain mild throughout the year, and three consecutive crops are grown during summer, autumn and winter. On the basis of soil, climate and other agronomic features, India has been divided into eight potato zones. These zones lie in two major potato-growing areas, i.e., North Indian hills and North Indian plains, while Southern hills, North Bengal and Sikkim hills and plateau are three special areas.

North-western plains: This zone comprises states of Punjab, Haryana and Rajasthan. Potato is grown in three crop seasons i.e. early autumn (Sept.-Nov.), autumn (Oct.-Jan./Feb.) or spring (Jan.-April/May). Winter is severe, and sometimes frost is also noticed at the end of December. The temperatures during winter is not congenial for rapid multiplication of aphids vector, therefore this area is suitable for seed potato production. Day temperatures in September are higher, however, and an early crop of potato between September to November is grown in this area. Major characteristics of the varieties are short day adaptation, early bulking, tolerance to higher temperatures, slow rate of degeneration and late blight resistance. For the main crop, resistance to frost is an added advantage.

North-central plains: It consists of western-central Uttar Pradesh and North-western districts of Gujarat and Madhya Pradesh. A potato crop of 90-100 days duration is grown during winter under milder temperatures and short days (10 h day) from Oct.–Jan./Feb. The region, in general, is free from major potato diseases. Late blight does not follow a definite cycle of appearance in the region. Varietal features, namely adaptation to short-days, early bulking, moderate resistance to late blight and slow rate of degeneration are desirable for the zone.

Eastern plains: This zone comprises Assam, Bihar, Jharkhand, West Bengal, Odisha, eastern Uttar Pradesh, and north eastern and eastern districts of Madhya Pradesh and Chhattisgarh, respectively. This area in combination with West-central plains is aptly called the "potato bowl" of the country and accounts for three-fourth of Indian potato production. The crop herein is grown during short and mild winter during November-February/March. Beside adaptability to short days, early bulking/maturity and resistance to late blight are important desired features in the varieties. Some parts of eastern plains have a strong preference for red skin tubers.

Plateau region: This zone comprises central and peninsular India covering Maharashtra, Karnataka, and parts of Gujarat, Madhya Pradesh and Odisha. Two crops are raised both during *kharif* and *rabi* season. The former is rain-fed crop, planted in June-July and harvested in September-October, while the latter is irrigated, planted in November and harvested in January-February. The minimum temperatures (13-16^{0}C) during *rabi* season favour a low accumulation of reducing sugars and higher dry matter as compared to *kharif* crop. The important varietal requirements in this region are early bulking, ability to tuberize under higher temperatures, resistance to bacterial wilt and mites as well as potato tuber moth and a slow rate of degeneration.

North-western and central hills: This zone comprises hills of Jammu and Kashmir, Himachal Pradesh and Uttaranchal. Potato is cultivated in summer during April to September. Late blight is the most important disease appearing every year in epiphytotic proportion, while bacterial wilt is the problem in mid hills particularly of Uttaranchal. The varieties, therefore, are required to be adapted to long-days (14 h day) and resistant to late blight. In North-central hills, bacterial wilt is a disease of economic importance and, therefore, resistance to this disease is an additional requirement.

North-eastern hills: This zone comprising hills of Meghalaya, Manipur, Mizoram, Tripura, Nagaland and Arunachal Pradesh, grow potato either as a spring crop (between Jan./Feb.-May/June) or autumn crop (during August-Nov. /Dec.). Late blight and bacterial wilt are the two major diseases in this semi-temperate and high rainfall zone. Therefore, not only adaptability for long days but resistance to both the diseases is important.

Southern hills: The zone comprises hilly areas of Tamil Nadu, mainly the Nilgiris and Palni hills where potatoes can be cultivated round the year depending upon the elevation. The main crop is grown during summer crop (March/April-August/September), though suitable temperatures prevail through the year hence it is also possible to raise autumn (August/September-December/January) and spring (January-May) crops. Late blight and cyst nematodes are the two major problems. Early bulking, adaptability to long days and resistance to late blight and cyst nematodes are the essential varietal requirements.

Sikkim and North Bengal hills: The zone consists of Sikkim and hills of West Bengal. Potatoes are grown in spring (Jan./Feb.-July/August) and autumn (September-December). Late blight and wart are the two important problems of the area. Resistance to late blight and immunity to wart are major requirements of varieties suited to the zone. There is a distinct preference for red skin tubers.

2.4 Genomic Evolution

The basic chromosome number in the genus *Solanum* is twelve. *S. tuberosum* subsp. *tuberosum*

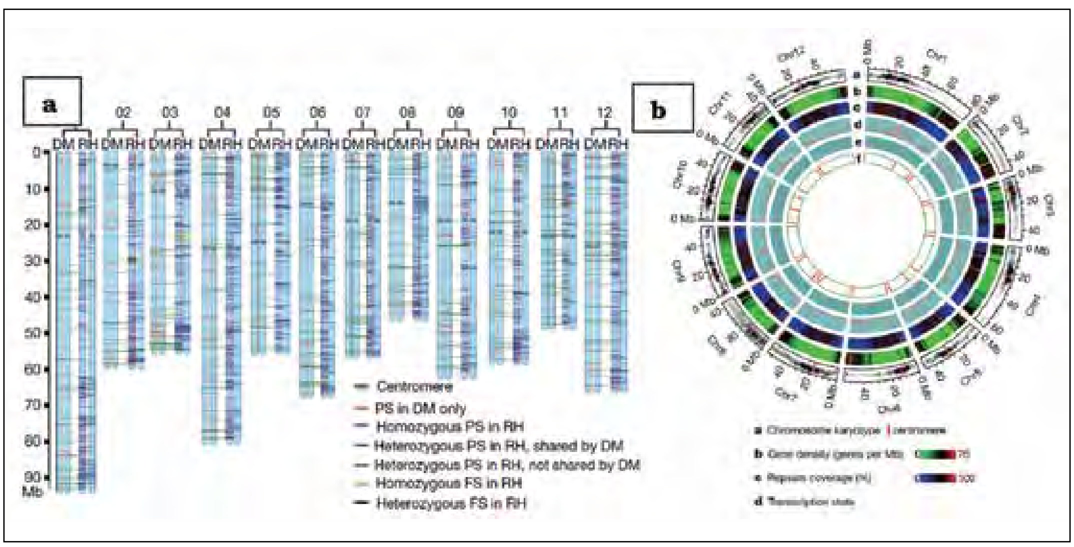

Fig.4: a. High density physical map used in assembling the potato genome sequence b. Assembled potato genome description (12 chomosomes)

is a tetraploid (4n=48). The diploid cultivated species are only found in South America, while the tetraploids are the most commonly cultivated all over the world. How the tetraploidy originated is unclear. The cultivated *S. tuberosum* subsp. *tuberosum* can be either an auto-tetraploid (doubling of the chromosomes of a diploid species) or an allo-tetraploid (doubling of the chromosomes of a diploid hybrid between two related species) (Hawkes, 1990). The phenomenon of unreduced gametes is common in *Solanum* species. In most *Solanum* species, next to the normal haploid gametes (n), unreduced gametes (2n) can be found, greatly extending the possible number of natural crosses (Hanneman, 1995). Watanabe and Peloquin (1991) reported that most of the 38 tuber-bearing *Solanum* species examined produced 2n pollen. The frequency varied from 2 to 10 per cent. It is also fairly easy to produce dihaploids from cultivated tetraploid *S. tuberosum*. This can be done by pollinating with, for example, *S. phureja*, which leads to the formation of parthenogenetic diploid plants. Anther culture is also in use to produce dihaploids (Howard, 1970; Caligari, 1992). It has been shown that, where *S. phureja* is used to produce dihaploids, minor chromosomal fragments are found in these dihaploids originating from *S. phureja* (Clulow *et al.*, 1991). The great value of these diploids is in breeding programmes: species that do not cross readily with the tetraploid potato can cross with a dihaploid (see section on crosses below). These dihaploids are often ovule fertile but pollen sterile.

Central Potato Research Institute, Shimla (Indian Council of Agricultural Research) as a part of global initiative - Potato Genome Sequencing Consortium (PGSC) joined hands with researchers from 26 international institutes belonging to 14 countries in cracking the complex genetic code of the non-cereal food crop potato, which was published in research journal Nature on 10th July, 2011 (Xu *et al.*, 2011). The PGSC has successfully completed the whole genome sequencing of potato (*Solanum tubersum* group Phureja) covering almost 86 per cent of its 844 Mb haploid genome. A total of 96.6 Gb sequence data was generated using Illumina Genome Analyser II and Roche 454 pyrosequencing as well as sanger sequencing technologies. Genome was assembled using SOAPdenovo resulting in final assembly of 727Mb of which 93.9% was non gaped sequence. Repetitive sequences account for at least 62.2% of the assembled genome (452.5 Mb) with long terminal repeat retrotransposons comprising the majority of the transposable element classes representing 29.4% of the genome. Using newly constructed genetic map based on 2,603 polymorphic markers in conjunction with other available genetic and physical maps developed across the world (Fig.4a), assembled genome was generated 623 Mb (86%) and constructed pseudomolecules for each of the 12 chromosomes which harbor 90.3% of the predicted genes (Fig.4b). Among the 31,039 total predicted protein coding genes of potato, 15,235 genes are predicted to be involved in tuberization, The Assembled sequence also contain 408 NBS-LLR genes, 57 Toll/interleukin-1 and 402 resistance (*R*) genes responsible for broad spectrum resistance against biotic and abiotic stresses. Apart from this highly regulated potato late blight resistance genes *R1, R2, RB, R3a, Rpi-blb2* and *Rpi-vnt1*.1 were present in the assembly. The potato genome sequence, the "genetic blueprint" of how a potato plant grows and reproduces, will assist potato scientists and breeders improve yield, quality, nutritional value and disease resistance of potato varieties, a process that has been slow in this genetically complex crop. The potato genome sequence will permit potato breeders to reduce the 10-12 years currently needed to breed new varieties. The potato genome is the first sequence of an Asterid to be published, a group of flowering plants encompassing around 25% of all plant species.

2.5 Morphology

The subsection Potato is distinguished from all other subsections within the genus *Solanum* by "true potatoes whose tubers are borne on underground stolons, which are true stems, not roots" (Hawkes, 1994). The series tuberosa is characterised by "imparipinnate or simple leaves, forked peduncle, rotate to petagonal corolla and round berries" (Hawkes, 1990). The species *S. tuberosum* is characterised by "pedicel articulation placed in the middle third, short calyx lobes arranged regularly, leaves often slightly arched, leaflets always ovate to lanceolate, about twice as long as broad, tubers with well marked dormancy period" (Hawkes, 1990).

2.6 Somaclonal Variation

Potatoes are very easily regenerated with the use of *in vitro* tissue culture techniques. This form of vegetative propagation normally leads to genetically identical individuals, but considerable heterogeneity is common after tissue culture in which a callus stage is included. This variation is called somaclonal variation. *S. tuberosum* subsp. *tuberosum* is, like all potatoes, quite prone to this kind of variation (Cutter, 1992; Hawkes, 1990).

3. REPRODUCTIVE BIOLOGY

3.1 Botanical Features

The potato is an herbaceous plant and growth habit varies between and within species. The plant has a rosette or semi-rosette habit (Fig.5). The potato tuber is an enlarged portion of an underground stem or stolon. Tuber eyes are the buds from which next season's growth will emerge. Eyes are concentrated near the apical end of the tuber, with fewer near the stolon or basal end. Eye number and distribution are characteristic of the variety.

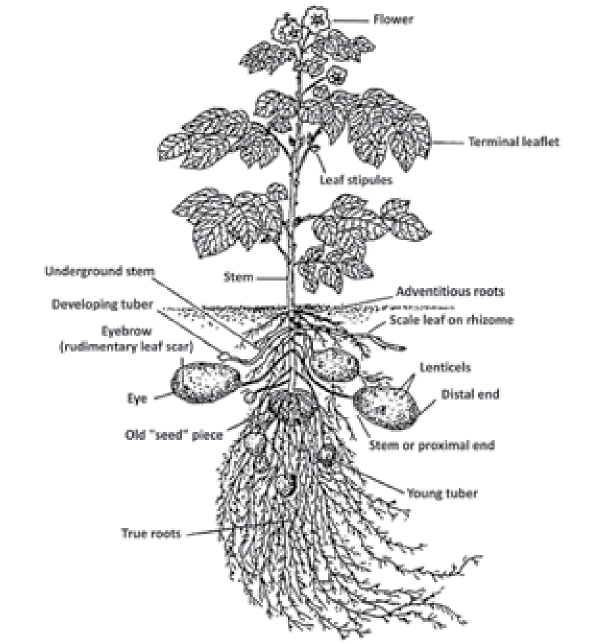

Fig.5: Schematic representation of potato plant

Potato is an annual herbaceous plant, mainly reproduced vegetatively by means of tubers and sometimes by botanical seeds, i.e., True Potato seeds. The tubers are underground stems and from that new shoots are produced. The stem is erect in the early stage but becomes spreading and prostrate

Fig.6: Botanical features of potato (Plant, Flower, Leaves and Tuber)

later on. The leaves are compound and alternate, irregularly odd pinnate.

Buds formed in the axil of the leaves produce rhizome which elongate rapidly and develop tubers at their extremities. The tuber is morphologically a fleshy stem bearing buds and eyes in the axil of small scale like leaves. The seeds are produced in a berry; flowers are self-pollinated but also cross pollination take place by insect (Fig.6).

3.2 Growth and Development

The development of potatoes can be broken down into five distinct growth stages (Fig.7).

Growth Stage I: Sprout Development (This stage begins with sprouts developing from the eyes and ends at emergence from the soil. The seed piece is

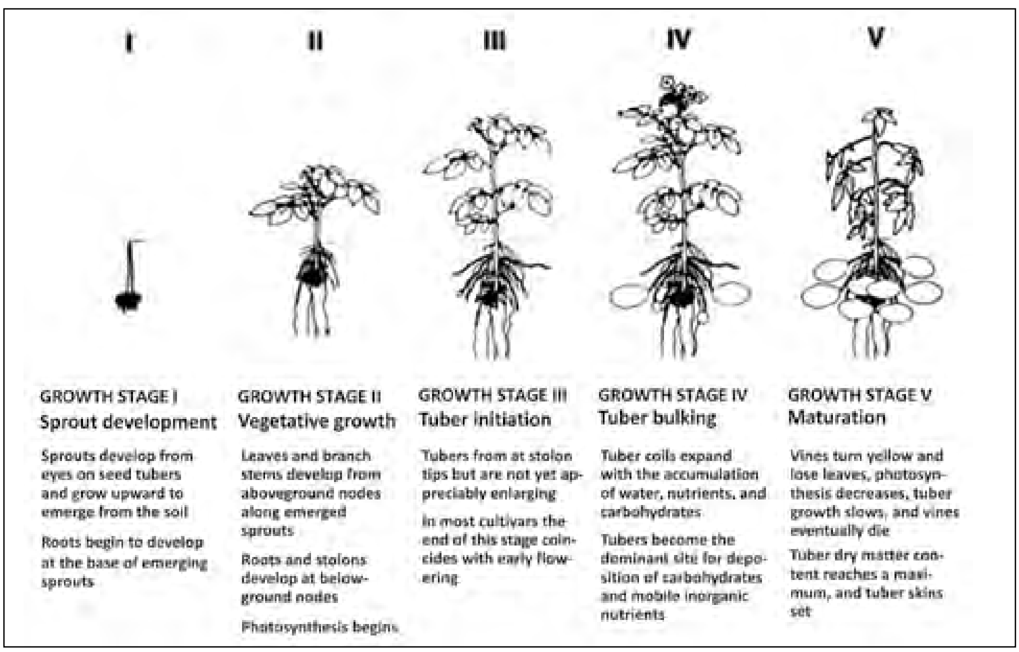

Fig.7: Different growth stages of potato

the sole energy source for growth during this stage).

Growth Stage II: Vegetative Growth (This stage, in which all vegetative parts of the plants (leaves, branches, roots and stolons) are formed, begins at emergence and lasts until tubers start to develop).

Growth stages I and II last from 30 to 70 days depending on planting date, soil temperature and other environmental factors, the physiological age of the tubers, and the characteristics of particular cultivars.

Growth Stage III: Tuber Set/Initiation (Tubers are forming at stolon tips, but are not yet enlarging. This stage will last approximately 2 weeks).

Growth Stage IV: Tuber Bulking (Tuber cells expand with the accumulation of water, nutrients and carbohydrates. Tuber bulking is the growth stage of longest duration. Depending on date of planting and cultivar, bulking can last up to three months).

Growth Stage V: Maturation (Vines turn yellow and lose leaves, photosynthesis gradually decreases, tuber growth rate slows and the vines die. This stage may not occur when growing a long season variety like Russet Burbank in a production area with a short growing season).

3.3 Floral Biology

Potato has a terminal inflorescence consisting of 1-30 (but usually 7-15) flowers, depending on the cultivar. The five petals give an open flower a star shape. A flower also has a pistil that generally protrudes above a cluster of five large, bright yellow anthers. A botanical description of the potato flower along with its diagram is given in Fig.8 and Table 3.

Table 3: Details of the *Solanum tuberosum* L. inflorescence

Inflorescence	Solitoryor cymose
Flower	Bisexual, actinomorphic
Calyx	Sepals five, united, persistent valvate aestivation
Corolla	Petals five, united, velvate aestivation
Androecium	Stamens five, epipetalous
Gynoecium	Bicarpellary syncarpoes, ovary superior bilocular, placenta with many vacuoles
Fruits	Berry or capsule
Seeds	Many, endospermous
Floral farmula	$\oplus$ ⚥ $K_5 \widehat{A_5 C_5} \underline{G_2}$

The corolla colour varies from white to complex range of blue, red, and purple (Fig.9). Flower opening starts nearest the base of the inflorescence and proceeding upward at the rate of about 2-3 each day. At the peak bloom, there are usually 5-10 open flowers. Flowers are open for only 2-4 days and the receptivity of the stigma and duration of pollen production is about 2 days. The peak time of pollination is early morning

Fig.8: Floral diagram of the potato flower

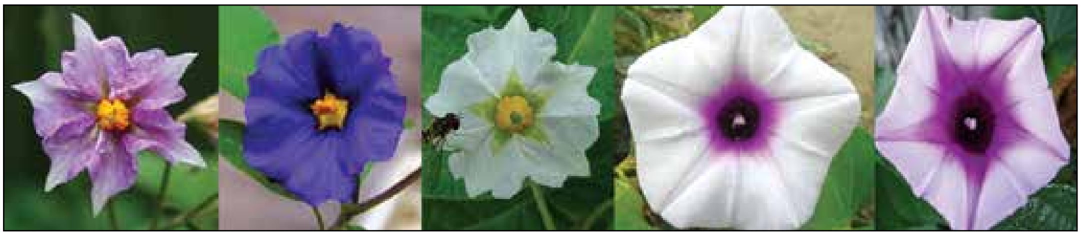

Fig.9: Diversity in flower colour of potato

3.4 Pollination

In general diploid wild species are insect-pollinating, cross-breeding in nature. To facilitate cross-breeding and selfing, the appearance of insects is necessary. In particular, bumblebees (e.g. *Bombus terrocola* and *B. impatiens*) are good pollinators for potatoes (White, 1983). Pollen dispersal is mainly limited by the distance pollinating insects fly. Bumblebees and bees do not fly much further than three kilometres (Reheul, 1987). Normal honeybees (*Apis mellifera*) and *Bombus fervidus* are not pollinators of potato, as the flowers are without any nectar (Sanford and Hanneman, 1981). White (1983) carried out some experiments to determine the importance of pollination by wind for potatoes. Flowers were emasculated, and therefore of no interest to insects. The seed set on these flowers was assessed. No seeds were found, and therefore it was concluded that pollination by wind was of no importance. Conner et al. (1996) collected outcrossing data from several field experiments with genetically modified potatoes, performed in New Zealand, the United Kingdom and Sweden. In each study the outcrossing rate was reduced to 0 per cent where the receiving plants were separated by more than 20 metres from the genetically modified ones. There are no detailed studies of pollination behaviour of potato in India

3.5 Methods of Reproductive Isolation

The cultivated tetraploid potato species (*S. tuberosum sub* spp. *tuberosum* and *S. tuberosum sub* spp. *andigena*) are photoperiodically long day plants and require long days and short nights for their flowering, but more than 90 per cent of the potato growing area in India is in plains and in rabi season (October planting) when the day lengths are shorter. Therefore, the flowering does not take place in the plains. Potato is also mainly propagated through tubers wherein tubers are used as seeds for planting. The seed certification standards for potato differ from other crops. The reproductive isolation required for producing the breeder seeds and certified seeds in case of potato are given bellow (Jai Gopal et al. 2006)

	Foundation seed (minimum distance required in meters)		Certified seed(minimum distance required in meters)
	Stage 1	Stage 2	
Fields of other variety	5	5	5
Fields of same variety but not confirming the varietal purity requirements of certification	5	5	5

4. CROSSABILITY BETWEEN SOLANUM SPP. AND HYBRIDIZATION

Potato is not native to India, so there are no naturally found wild species in India. Only one wild species of potato, *S. chacoense*, is present in India, that too only near CPRI, Shimla. It has a diploid genome and as such cannot be crossed with the tetraploid *S. tuberosum* ssp. *andigena* or *S. tuberosum* ssp. *tuberosum*. *S. tuberosum* ssp. *tuberosum*, however, can cross with ssp. *andigena* and also with wild species only in germplasm collection maintained under field condition.

5. ECOLOGICAL INTERACTIONS

5.1 Organization of Species Complexes and Gene Flow

There are around 220 tuber-bearing species in the genus *Solanum*. About 70% of them diploid and 15% of them, including the cultivated potato, are tetraploid, but most of them have disomic inheritance and are called disomic tetraploids (allotetraploid). The gene-flow among the wild potatoes is limited by internal hybridization barriers, difference in genomic structures and ploidy levels. These barriers can be classified into pre-zygotic and post-zygotic. On the basis of inter-specific crossing results, Johnston and Hanneman (1980) assigned the values, called Endosperm Balance Number (EBN). Crosses are compatible if the endosperm level between species with the matching EBN, but not between species with non-matching EBN (Richardo and Elsa, 1997) which means EBN should be 2:1 maternal to paternal ratio for normal endosperm development. The EBN has been determined for most of the *Solanum species* by crossing each with standard species of known EBN. Based on the results of such crosses, EBN values has been assigned to *Solanum species* (Hanneman, 1994). To overcome these barriers and to exploit the wild species, dihaploids (2n=2x=24) can be developed from tetraploids via parthenogenesis or anther culture (Peloquin *et al.* 1999). The dihaploids are then able to cross with most wild species for introgression of specific genetic traits. These traits can then be moved into tetraploids through the use of unreduced gametes (2n gametes) and used for further breeding. Colchicine treatment and in vitro tissue culture can also be used to move the dihaploid genome back into the tetraploid state (the process is called pre-breeding). As potato is not native to India, no wild species are found in India.

5.2 Potential for Gene Transfer from Potato

By definition this is the transfer of genes between plant species and between plant and non-plant species without sexual transmission. Naturally occurring vectors such as *Agrobacterium tumefaciens*, viruses, transposable elements and the degree of gene homology (causing recombination) are some of the factors that could have a role in these processes. It is theoretically possible for micro-organisms to incorporate DNA from transgenic potato plants in their own genetic material. However, such events have only been accomplished under optimized laboratory conditions and at a very low frequency. The probability of this kind of event occurring in nature are not recorded or systematically studied yet, and concerning the transfer of whole functional genes is extremely low.

There is also no evidence that the transferred genes from potato would be functional and hence would persist into the new host. In addition, processing of potato food is unlikely to maintain intact entire genes. Therefore, at this stage of our knowledge, the research on horizontal transfer of transgenes from plants to bacteria has not provided evidence that would qualify Horizontal gene transfer as a risk. Gene flow from potato varieties to wild relatives could occur via outcrossing (Celis *et al.* 2004). An extensive study (Jackson and Hanneman, 1999) confirms that crossability of wild potato species with cultivated species is highest in regions that are a major centre of diversity for the cultivated potato. These major areas of diversity of potato are the Bolivian and Peruvian Andes and the Northwest of Argentina, and Mexico. Under Indian conditions, this possibility is also negligible to nil as India is neither a centre of origin for potato nor any wild potato species naturally exists in the wild here except for in and around shimla where *S. chacoense* grows as weed naturally.

5.3 Volunteers

In the cultivation of Potato, plants from seeds from a previous crop can act as a volunteer weed. The tubers can also act as a volunteer weed in cultivation. In general these plants (from seeds and tubers) will be eliminated by normal agronomical practices. In addition, tubers will not survive for a long time in most of the areas of cultivation due to unfavorable environmental conditions (low temperatures). Outside the field, potato seedlings will have difficulty establishing themselves as they cannot compete with other plants. Love and Pavek (1994) reported that these seedlings are limited to cultivated areas for reasons of competition and adaptation. Potato tubers can be spread during transportation and use, but generally these plants will not be established for a long time due to unfavorable environmental conditions. In general, the potato is not known as a colonizer of unmanaged ecosystems. In climax vegetation it is not able to compete with other species such as grasses, trees and shrubs (Anonymous, 1996).

5.4 Weediness in Potato

Following characters are associated with weediness or invasiveness in a plant species. Although there is no weed that combines all these characteristics, a good number of these characteristics must be combined in order for a plant to develop a weedy nature.

- Seed production in a wide range of environmental conditions.
- Discontinuous germination (internally controlled) and great longevity of seeds.
- Rapid growth through vegetative phase to flowering.
- Continuous seed production for as long as growing conditions permit.
- Self-compatible but not completely autogamous or apomictic.
- Cross-pollinated by unspecialized visitors or by wind.
- Very high seed production in favourable environmental circumstances.

- Adaptations for short- and long-distance dispersal.
- If a perennial, vigorous vegetative reproduction or regeneration from fragments.
- If a perennial, plant should have brittleness, so not easily and completely drawn from ground.
- Ability to compete inter-specifically by special means (rosette, choking growth, other).

Potato is represented by a large number of wild species. Hawkes (1990) described 235 wild species of which 8 are cultivated as discussed earlier. The tetraploid potato cultivated in India is an exotic crop introduced in the late 19th centuries during colonial rule and as such except the cultivated S. tuberosum group tuberosum no cultivated or wild species of any ploidy exist in Indian fields and none of the cultivated species are known to behave as weeds.

5.5 Seed Dormancy

A dormancy value or duration gives insight into how long the potato will store before it initiates sprout development. Tuber dormancy keeps the potatoes from sprouting in the fall and therefore reducing chances of the species being killed by unfavourable winter conditions. We know this effective survival mechanism all too well when trying to control volunteer potatoes. Conversely, the tuber dormancy period provides great advantage in storage to allow for many months of storage with or without sprout control product application. Quality can be maintained when using a tuber's inherent dormancy traits to our advantage. A detailed study was conducted by Sharma *et al.* (2012) with major Indian potato cultivars to find their dormancy period using micro-tubers. The major Indian potato cultivars like Kufri Chipsona I, Kufri Surya, Kufri Badhsh, Kufri Anand, Kufri Pukhraj and Kufri Bahar had dormancy period upon storage as 114, 110, 107, 105, 98 and 98 respectively.

6. HUMAN HEALTH CONSIDERATION

Potato contains the glycoalkaloids alpha-solanine and alpha-chaconine (Maga, 1980), concentrated mainly in the flowers and sprouts (200 to 500 mg/100 g). In healthy potato tubers the concentration of the glycoalkaloids is usually less than 10 mg/100 g and this can normally be reduced by peeling (Wood and Young, 1974; Bushway et al. 1983). In bitter varieties the alkaloid concentration can go up to 80 mg/100 g in the tuber as a whole and up to 150-220 mg/100 g in the peel. The presence of these glycoalkaloids is not perceptible to the taste buds until they reach a concentration of 20 ma/100 g, when they taste bitter. At higher concentrations they cause a burning and persistent irritation similar to hot pepper. At these concentrations solanine and other potato glycoalkaloids are toxic. They are not destroyed during normal cooking because the decomposition temperature of solanine is about 243 C.

Levels of glycoalkaloids may build up in potatoes which are exposed to bright light for long periods. They may also result from wounding during harvest or during post-harvest handling and storage, especially at temperatures below 10°C (Jadhav and Salunkhe, 1975). Glycoalkaloids are inhibitors of choline esterase and cause haemorrhagic damage to the gastrointestinal tract as well as to the retina (Ahmed, 1982). Solanine poisoning has been known to cause severe illness but it is rarely fatal (Jadhav and Salunkhe, 1975).

Potato also contains proteinase inhibitors which act as an effective defence against insects and micro-organisms but are no problem to humans because they are destroyed by heat. Lectins or haemogglutenins are also present in potato. These toxins are capable of agglutinating the erythrocytes of several mammalian species including humans (Goldstein and Hayes, 1978), but this is of minimal nutritional significance as haemogglutenins are also destroyed by heat, and potatoes are normally cooked before they are eaten.

7. POTATO CULTIVATION IN INDIA

In India Potato was introduced by colonial rulers (Portuguese/British) and since then it was primarily being grown only in the backyards of the British people till independence (Luthra et al. 2006). Potato production in India has undergone a revolution since independence, as the total production has risen from 1.54 mt in 1949 to 45.35 mt in 2013 from an area of 1.99 m ha with an average productivity of 23.0 t/ha (Fig.10) (FAOSTAT, 2013). India is the second largest producer of potato next only to China in the world. At present India is not only self-sufficient in potato production but can also export seed potatoes to other countries as India has well-established seed production techniques to produce disease free seed potato.

Ninety percent of the potatoes in India comes from the Indo-Gangetic planes. Major potato growing states are Uttar Pradesh, West Bengal, Bihar, Madhya Pradesh, Punjab and Gujarat (Fig.11). In recent years potato processing industry has grown rapidly in India due to rapid urbanization and changing life style of the people. The present requirement is around 3.5 mt which accounts to 7.73% of the total potato production and is expected to increase rapidly in the coming years.

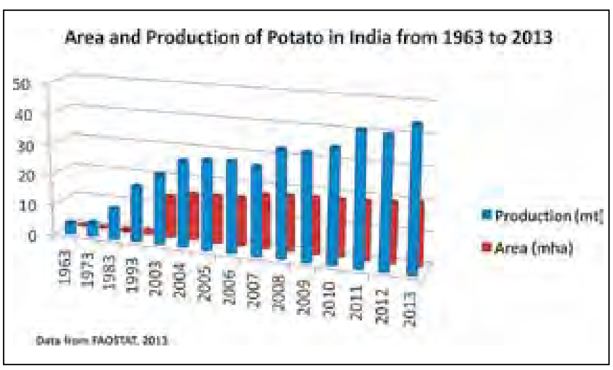

Fig.10: Area and production of potato in India since 1963

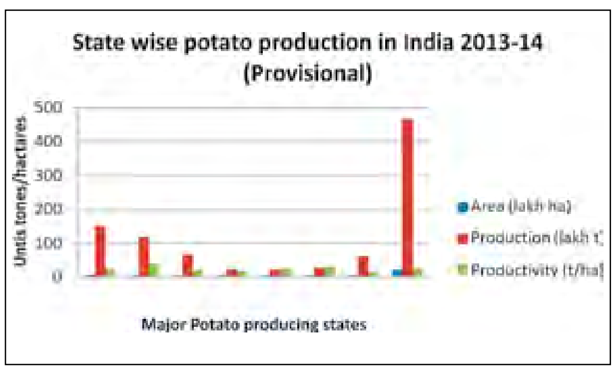

Fig.11: Major Potato growing states in India

* Data by Horticulture Statistics Division D/o Agriculture and Cooperation

Table 4: Agro-climatic peculiarities of growing potatoes in sub-tropics.		
Agro-climatic parameters	**Sub-tropical countries**	**Temperate countries**
Growing season	Winter	Summer
Temperature during Planting and harvesting	High (planting: 25-30°C; harvesting: 10-20°C)	Low (15-25°C at both)
Crop duration	90-100 days	150-180 days
Photoperiod during growth	10.3 hours/day	14 hours/day
Mid day water stress	Prominent	Absent
Day/Night temperatures	25-30°C/4-15°C	25°C/15°C
Frost	Common	Absent
Result	Low yields, less dry matter and more reducing sugars	High yield, high dry matter and low reducing sugars.

The potato crop thrives up to snow line. The hill areas because of almost virus free environment offer good scope for seed potato industry. Himachal Pradesh, U.P, hills and Sikkim provide the bulk of the Hill seed potato for the plains of India.

More than 80% potato in India is grown in sub-tropical regions during winter which differs than those prevalent in potato season of temperate countries. The Agro-climatic peculiarities of growing potatoes in sub-tropics is given in Table-4

7.1 Climatic and Soil Requirements

Potato Plant Growth

Growth and quality of potatoes are influenced by environmental factors such as temperature, moisture, light, soil type and nutrients. Many factors that influence potato growth are largely uncontrollable: length of growing season, air and soil temperatures, light intensity and duration, humidity, and wind. Other factors that influence growth of the crop can be controlled by the grower: variety of potato, size of mother seed tubers, seed-piece cutting, seed-piece types, cut-seed size, planter operation, plant stand, stem population, moisture, nutrition, pest management, planting date and harvest date. Only when all factors are at optimum levels can the most profitable yields of quality potatoes be attained.

The potato is a cool-season crop that grows well in certain areas of the Prairie Provinces. The rate of development of sprouts from seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C, elongation is slow at 9°C and is maximized at about 18°C. The optimum soil temperature for initiating tubers is 16-19°C. Tuber development declines as soil temperatures rise above 20°C and tuber growth practically stops at soil temperatures above 30°C. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favour development of large tubers. Yields are highest when average daytime temperatures are about 21°C. Cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances storage of starch in the tubers (Pandey *et al.* 2008 Potato seasonal outlook, 2013).

From the temperature information in the above paragraphs Physiological Days (P-Days) can be calculated. P-Days are a measure of the heat useful for the growth and development of potatoes. In the potato production areas of the Prairies, the highest average accumulation of P-Days, 850-950, occurs south of Lake Manitoba to the U.S. border and the lowest accumulation, 750-900, occurs in the seed production areas south of Edmonton and in Central Saskatchewan. The varieties currently grown on the Prairies require anywhere from 800-1000 P-Days to reach full maturity. An early-maturing variety such as Norland requires 800 P-Days, and later maturing varieties such as Russet Burbank require 1000 P-Days. Growing a potato variety in an area with insufficient P-Days will reduce yield and affect tuber quality factors such as accumulation of solids and fry colour. The average accumulation of P-Days is insufficient in many parts of the Prairies to produce late season varieties where the crop must be fully mature before harvest. These areas may be suitable for seed or table production, where the crop is killed or harvested before full maturity. The conditions required for the potato cultivation is mentioned in detail on CPRI web page (**www.cpri.earnet.in**)

Moisture

Potatoes require a continuous supply of soil water along with adequate soil aeration. Yields are greatest when soil moisture is maintained above 65% of the available soil water (ASW) capacity. Tuber set is particularly sensitive to moisture stress. There are generally fewer tubers set when available soil moisture is maintained below 65% of the available soil water (ASW) capacity. The amount of water needed by potatoes varies with the soil type, temperature, humidity, air movement, plant and stem populations, variety and cultural practices. Too much moisture generally causes more problems than too little moisture. Low or fluctuating moisture levels can contribute to common scab, early dying, hollow heart, knobby tubers, low dry matter, low tuber set, and low yield. Excessive soil moisture resulting in poor aeration, and water logging of the soil reduces yields and in extreme cases causes tuber rot. An excess of moisture may also lead to enlarged lenticels, which are openings of the epidermis. This detracts from their appearance and allows entry of disease organisms, causing tuber rot in storage (Pandey *et al.* 2008).

7.2 Varietal Testing System

New potato varieties are usually selected from the F1 progeny of a particular cross by successive clonal generations. Hybrids after F1C4 stage are considered as advanced hybrids. They are further selected through replicated trials. After 3-4 years of testing, promising selections are tested under multilocational trials of All India Coordinated Research Project (Potato). Multi-locational trials are conducted in all or selected centers of AICRP (Potato) depending on the targeted agro-climatic zone of the variety. Presently, AICRP (Potato) has the following 25 centres distributed in the distinct agro-climatic regions of the country (Fig.12 & Table-5).

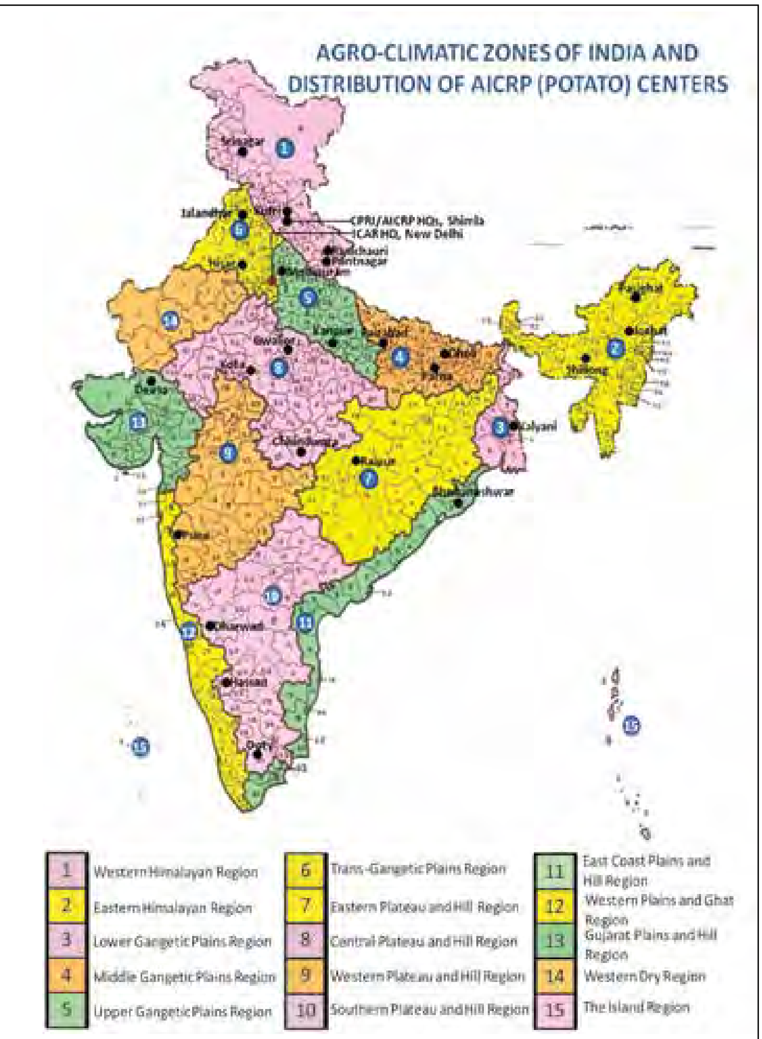

Fig.12: Agro-Climatic Zones of India and Distribution of AICPR (Potato) Centres.

S. No.	Table-5 : Central Potato Research Institute based AICRP centers
1.	CPRI Regional Station, Gwalior, Madhya Pradesh
2.	CPRI Regional Station, Jalandhar, Punjab
3.	CPRI Regional Station, Kufri, Himachal Pradesh (SPU)*
4.	CPRI Regional Station, Modipuram, Uttar Pradesh(SPU)*
5.	CPRI Regional Station, Ootacamund, Tamil Nadu
6.	CPRI Regional Station, Patna, Bihar
7.	CPRI Regional Station, Shillong, Meghalaya
8.	OUAT, Bhubaneswar, Orissa
9.	JNKVV, Jabalpur, Madhya Pradesh
10.	SDAU, SK Nagar, Deesa Gujarat
11.	UAS, Dharwad now shifted to UHS, Bagalkot, Karnataka
12.	RAU, Pusa, Dholi, Bihar
13.	NDUAT, Faizabad, Uttar Pradesh
14.	UAS, Bangalore now shifted to UHS, Bagalkot, Hassan, Karnataka
15.	CSS HAU, Hisar, Haryana
16.	AAU, Jorhat, Assam
17.	BCKV, Kalyani, West Bengal
18.	MPUA&T, Udaipur, Kota, Rajasthan
19.	GBPUAT, Pantnagar, Uttarakhand
20.	IGKV, Raipur, Chhatisgarh
21.	SKUAST (K), Srinagar, Jammu & Kashmir
22.	CSAUA&T, Kanpur, Uttar Pradesh
23.	MPKV, Rahuri, Maharashtra
24.	CAU, Imphal, Pasighat, Arunachal Pradesh
25.	GBPUAT, Pantnagar now University of Horticulture and Forestry, Ranichauri, Uttarakhand

7.3 Insect Pests of Potato

7.3.1 Insect pests (The information is also available on www.cpri.earnet.in)

i) Aphids (*Myzus persicae* and *Aphis gossypii*)

The potato crop is infested by more than 12 aphid species which are polyphagous in nature in India. The most dominant species are green peach aphid, *Myzus persicae* and cotton aphid, *Aphis gossypii*.

Fig.13: Aphids feeding on potato

Life cycle of the aphids is highly variable and is completed in 25-45 days depending upon weather conditions. Both nymphs and adults lie on the underside of tender leaves and shoots and suck the sap from phloem of potato stems, leaves (Fig.13) and roots using the stylets. Aphids are economically important on potato primarily because of their role as virus vectors although they cause direct plant damage at high densities (Sharma *et al.* 2013).

ii) Whiteflies (*Bemisia tabaci*)

Whiteflies are small milky white insects belonging to sap sucking group causing loss of plant cell sap with injection of toxic saliva which is also associated with virus transmission. Both nymphs and adults suck plant sap from the underside of the leaf during which virus acquisition and transmission takes place (Fig.14). Whiteflies gained economic importance in potato when it was identified as potential vector of Tomato leaf curl New Delhi virus-potato (ToLCNDV-potato) causing potato apical leaf curl disease in India (Sharma *et al.* 2013).

Fig.14: Whiteflies feeding on potato

iii) Leaf hoppers (*Amrasca biguttula*)

Potato leafhopper is a polyphagous pest and distributed worldwide causing major loss to potato. In India, the leaf hoppers are distributed in all potato growing regions of Indo-Gangetic plains.

Fig.15: Leaf hopper feeding on potato and hopper burn symptoms

Both the nymphs and adults of the leafhoppers suck the sap from lower side of the leaves causing extensive damage by direct feeding of the plants (Fig 15). The late instar nymphs are more harmful and cause almost twice the yield losses as compared to the adults. They also inject a toxin into the plant, which causes yellowing, browning, cupping and curling of leaves can be easily identified in the form of triangular mark of burn, starting from the tip.

The severely infested field gives a burnt look appearing in a circular ring commonly known as "hopper burn" (Sharma *et al.* 2013).

iv) Thrips (*Thrips palmi*)

T. palmi is the predominant species and most efficient vector of stem necrosis disease caused by *Groundnut bud necrosis virus* belonging to the Tospovirus group. Adults are pale yellow or whitish

Fig.16: Adult Thrips

in color and tend to feed on young leaves (Fig. 16). Eggs are deposited in leaf tissue, in a slit cut by the female, are colorless to pale white in color, and bean-shaped in form. Larvae resemble the adults and feed in groups, particularly along the leaf midrib and veins, and usually on older leaves. Thrips transmitted potato stem necrosis disease causes 15-30% yield loss in potato in northern Gujarat, parts of Madhya Pradesh and Rajasthan (Sharma *et al.* 2013).

v) White grub (*Holotrichia longipennis*)

White grubs are polyphagous and cosmopolitan in nature and are distributed in Asia, Africa, America and European countries. In India this pest causes serious damage to the potato production. The beetles emerge during month of May which coincides with onset of rainfall. The grubs are white in colour with dark brown head, and it becomes "C" shaped when disturbed (Fig.17a). The damage is done by second and third instar grubs which feeds on underground parts of the plant by making medium to large, shallow and circular holes on the tubers (Fig.17b) (Sharma *et al.* 2013).

Fig.17: a White grub, **b** Damage in potato tubers

vi) Cutworms (*Agrotis ipsilon*)

Cutworms are polyphagous, cosmopolitan and most destructive insects pests present throughout the world. In India, cutworms are more serious in northern region. *Agrotis segetum* is commonly

Fig.18: Cutworm larvae

found in hills and *A. ipsilon* in plains. The young larvae feed on leaves but mature larvae cut stems (Fig. 18) just near the ground and even make irregular holes in the tubers during the night. After tuber formation, they start feeding on tubers and roots resulting in a variety of holes which reduces tuber yield as well as market value (Sharma *et al.* 2013).

vii) Potato tuber moth
(*Phthorimea operculella* {Zeller})

The tuber moth occurs in all tropical and subtropical potato producing countries in Asia, Africa and North, Central and South America and is mainly a pest of stored tubers. The male and female moths are brownish grey in colour and wings are folded to form a roof like structure. The freshly laid eggs are white in colour and can be deposited singly or in small clutches resembling strings of

Fig.19: Tuber moth damage on potato plants and tubersa

beads. The larvae destroy the crop by injuring the leaves, boring into petioles and terminal shoots causing wilting of plants. The larvae enter into the tubers and feed on them causing mines in tubers (Fig. 19) (Sharma *et al.* 2013).

viii) Mite (*Polyphagotarsonemus latus* {Banks})

These are commonly known as yellow mites or broad mites and highly polyphagous in nature. The broad mite causes serious damage to potato crop during Kharif season in Maharashtra and Karnataka. It also affects early planted potato crop during Rabi season in Punjab and Western UP. Mites are usually found on the upper part of the plant. They feed on apical shoots and on abaxial surface of young leaves by sucking the cell sap. The typical symptoms are bronzing, curling and discolouration of leaves (Fig.20) (Sharma *et al.* 2013).

Fig.20: Symptoms of mite damage

7.3.2. Nematodes

i) Root knot Nematode (*Meloidogyne incognita*)

Root-knot nematodes are distributed worldwide, and are obligate parasites of the roots of potato plants. Small galls or knots are formed on potato roots but they often go unnoticed. Heavily infested plants are stunted and exhibit early maturity leading to reduction in tuber size and number and subsequently the yield. The warty 'pimple-like' outgrowths formed on tubers result in quality reduction in seed and table potato besides affecting seed health and transmission (Sharma *et al.* 2013).

ii) Potato cyst nematodes (*Globodera rostochiensis, G. pallida*)

In India the potato cyst nematode (PCN), also known as golden cyst nematode, was first detected during 1961 in Nilgiris, Tamil Nadu. Globally, *G. rostochiensis* has five pathotypes namely Ro1, Ro2, Ro3, Ro4 and Ro5 and four races (R_1A, R_1B, R_2A and R_3A) whereas *G. pallida* has three pathotypes (Pa1, Pa2 & Pa3) and seven races (P_1A, P_1B, P_2A, P_3A, P_4A, P_5A & P_6A). *G. pallida* field populations are however not uniform with respect to pathotype composition and populations containing mixtures of Pa2 and Pa3 (Pa2/3) are generally observed. In India, pathotypes Ro1 of *G. rostochiensis* and Pa2 of G. pallida are the most prevalent forms in the Nilgiris hills. The other prevalent pathotypes are Ro2 and Ro5 of the former and Pa1 and Pa3 of the later. The nematode infested root system of potato plant is poorly developed. Heavily infested plants remain severely stunted with dull and unhealthy foliage and as the disease advances, the lower leaves turn yellow and brown, and wither leaving only the young leaves at the top. The browning and withering of the foliage gradually extends and ultimately causes the premature death of the plant and significant reduction in yield (Fig.21) (Sharma *et al.* 2013).

Fig.21: Symptoms of nematode infested potato fields in Nilgiris

7.4. Major Diseases of Potato

7.4.1. Fungal diseases of Potato

i) Late Blight (*Phytophthora infestans*)

Symptoms appears as water-soaked irregular pale green lesions mostly near tip and margins of leaves which rapidly grow into large brown to purplish black necrotic spots.

Fig.22: Potato leaves infected with late blight (*Phytophthora infestans*)

A white mildew, which consists of sporangia and spores of the pathogen, can be seen on lower surface of the infected leaves especially around the edges of the necrotic lesions (Fig.22) (Sharma *et al.* 2013).

ii) Early Blight (*Alternaria solani*)

Causes small, round, oval or angular, dark brown to black, dry and papery necrotic spots on leaves limited by leaf veins. Concentric rings of raised and depressed tissue within the leaf spot give it a bull's eye or target board appearance. Leaf tissues around the spots often become chlorotic and yellow. The leaf spots may coalesce and the field may get severely blighted (Fig.23)

Fig.23: Potato leaves infected with early blight (*Alternaria solani*)

iii) Black Scurf (*Rhizoctonia solani*)

The most common symptoms of black scurf are on potato tubers as black irregular lumpy encrustations of fungal sclerotia. The other symptoms on potato tubers could be cracking, malformation, pitting and stem end necrosis. It also causes stem canker and formation of aerial tubers on stems in disease affected plants (Fig.24).

Fig.24: Black scurf of potato caused by *Rhizoctonia solani*

iv) Fusarium Dry rot (*Fusarium* spp.)

Dry rot symptoms appear as small brown lesions on surface of the affected tubers. The lesions

Fig.25: *Fusarium* spp. developing in dry rot affected tubers

subsequently enlarge, appear dark, sunken, and wrinkled, producing white, pink, or blue pustules. In later stages a cavity develops in the centre of the concentric ring and whitish, pinkish or dark brown growth of fungal mycelium may become visible (Fig.25).

v) Powdery Scab (*Spongospora subterranea*)

The disease appears on potato tubers as purplish brown sunken lesions which later turn to scab like lesions. However, unlike common scab the lesions of powdery scab are round, raised, filled with powdery mass of spores and surrounded by ruptured remains of epidermal layers (Fig.26).

Fig.26: Powdery scab lesions on potato tubers surrounded by ruptured remains of epidermis

vi) Charcoal Rot (*Macrophomina phaseolina*)

Symptoms on tubers developed around eyes, lenticels and stolon end where a dark light grey,

Fig.27: Charcoal rot of potato tubers

soft, water soaked lesion develop on the surface of the tuber. Subsequently, the lesions become filled with black mycelium and sclerotia of the pathogen. The lesions may shrink and develop symptoms similar to dry rots under low moisture conditions (Fig.27).

7.4.2. Bacterial diseases of potato

i) Bacterial wilt/ brown rot (*Ralstonia solanacearum*)

The disease initiates as slight wilting of youngest leaves during hot sunny days. The leaves show drooping due to loss of turgidity followed by total unrecoverable wilt. The cross-sections of stems show vascular discolouration. Bacterial wilt in field can be distinguished from fungal wilts by placing the stem cut sections in clear water (Fig.28).

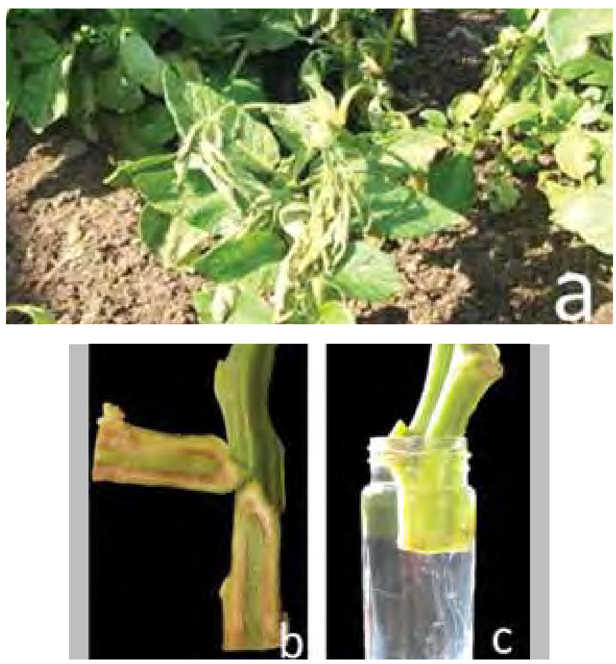

Fig.28: Symptoms of bacterial wilt (a); brown discoloration of stem tissues (b); bacterial streaming in clear water from stem cut section of potato (c) infected with *R. solanacearum*

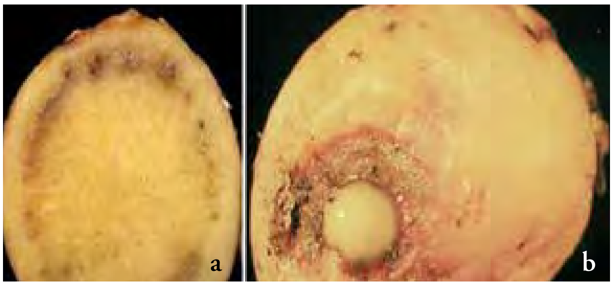

Fig.29: Brown rot symptoms on tubers; vascular browning of tubers (a) oozing of bacterial mass through an eye of tuber

The brown rot symptoms may appear in tubers at later stage of disease development. The vascular tissues of a transversely cut tuber show water soaked brown circles where dirty white sticky drops appear in about 2-3 minutes (Fig. 2). In advanced stages of wilt, bacterial mass may ooze out from eyes (Fig.29) (Virupaksh et al. 2012).

ii) Common scab (*Streptomyces* spp.)

Symptoms begin as small reddish or brownish spots on the surface of the potato tubers during juvenile period of tubers. Later, lesions become corky due to elongation and division of invaded cells (Fig.30). The symptoms range from a few superficial or raised brown spots on the skin to dark pits extending several millimetres into the potato tuber resulting in the reduced market value of the produce.

Fig.30: Various types of scab symptoms caused by Streptomyces species on potato tubers

iii) Soft rot and black leg (*Pectobacterium species*)

Initially a small area of tuber tissue around lenticels or stolon attachment point becomes water soaked and develops soft lesions. Under high humidity, the lesions may enlarge and spread to larger area. Tubers in advanced stages of decay are usually invaded by other organisms and the decaying tissue becomes slimy with foul smell and brown liquid ooze. Black leg symptoms appear in cooler regions. The affected haulms become black at collar region

Fig.31: Soft rot symptoms on tubers (a); black leg symptoms (b)

just above the ground. On stem and petioles, the lesions first enlarge into stripes, turn black and then invade the affected parts causing soft rot and toppling of the stem and leaves (Fig.31).

7.4.3 Viral diseases of potato

i) Potato virus Y (PVY)

PVY is a type member of the genus Potyvirus of the family Potyviridae. It is transmitted by aphids.

Fig.32: Stunted and mosaic symptoms on potato plants

Generally the symptoms vary with the strains of the virus and variety of potato. In general the affected plants are stunted with mild or severe mosaic and veinal necrosis. Original strain of PVYO causes mosaic, necrotic spots, mild rugosity and drying of leaves (Fig.32).

ii) Potato virus A (PVA)

PVA belongs to genus *Potyvirus*, family *Potyviridae* with single stranded positive sense RNA and is transmitted by aphids. It causes mild mosaic symptoms somewhat similar to those caused by *Potato virus* X. However, unlike PVX the mottles caused by PVA appear on the veins and the infected leaves look shiny. Infected plants show an open habit. Severe leaf crinkle may be produced in combination with PVX (Fig.33).

Fig.33: Mild mosaic symptoms of potato plants

iii) Potato virus X (PVX)

PVX belongs to the family *Alphaflexiviridae* and the order Tymovirales. It is the type species of the genus Potexvirus and it transmitted mechanically. In nature it is largely confined to members of the family Solanaceae. Plants infected with PVX often remain symptomless. When symptoms are expressed, there is a pattern of light and dark green on leaflets, the lighter, small, irregular blotches occur between the veins. PVX can interact with PVY and PVA to cause more severe symptoms such as rugose mosaic (PVX+PVY) and crinkle mosaic (PVX+PVA).

iv) Potato virus M (PVM)

PVM is a member of the genus Carlavirus of the family *Flexviridae* and it is transmitted by aphids. It causes mottle, mosaic, crinkling, rolling (Spoon-shaped leaves) of leaves and stunting of shoots (Fig.34). Severity of symptoms greatly depends on the combination of potato cultivars and PVM isolates.

Fig.34: Typical rolling and crinkling symptoms on potato plants

v) Potato leafroll virus (PLRV)

Potato leafroll virus is the type species of the genus Polerovirus, in the family *Luteoviridae* and transmitted by aphids. Primary symptoms are confined to top young leaves, which usually

Fig.35: Leafroll symptoms on infection potato plants

stand upright, roll and turn slightly pale in certain cultivars. Secondary symptoms develop when the plants are grown from infected seed tubers. Such symptoms are rather prominent in older leaves, i.e., absent or less pronounced on younger top leaves. Infected plants have characteristic pale, dwarfed, and upright appearance with rolling of lower leaves that turn yellow, brittle and are leathery in texture. In some cultivars, a reddish or purple discolouration develops on the margins and underside of the leaves (Fig.35).

vi) Potato virus S (PVS)

PVS belongs to the genus *Carlavirus*, family *Betaflexiviridae*. It is transmitted mainly by contact and by aphids. It is symptomless on the majority of potato cultivars, with occasional mild leaf symptoms of rugosity, vein deepening and bronzing. However, symptoms such as rugosity, mosaic, stunting, bronzing, vein deepening, early drop of leaves, and fine necrotic spots on lower leaves have also been reported occasionally in some cultivars.

vii) Tomato leaf curl New Delhi virus-potato

The apical leaf curl disease of potato is caused by a variant of Tomato leaf curl New Delhi virus (ToLCNDV), which is a bipartite geminivirus and transmitted by whitefly. The affected plants show curling / crinkling of apical leaves with a conspicuous mosaic symptom. In case of seed borne infection the entire plant shows the symptoms leaf distortion with mosaic accompanied with severe stunting of the plant (Fig.36). The symptoms are so severe that it can be identified easily, but such symptoms are expressed only when the concentration of virus is very high.

Fig.36: Symptoms of apical leaf curl disease on potato plants

7.5 Breeding Objectives

The early potato introductions in India were hybrids of *Solanum tuberosum* ssp. *tuberosum* and *S. tuberosum* ssp. *andigena*. Those initial introductions eventually got established in India and further selections by Indian farmers resulted in several indigenous cultures known as desi varieties. Among these, Phulwa, Darjeeling Red Round and Gola, were most popular. Though the desi varieties could be grown in Indian plains, their yield was very low and the seed stock was riddled with many viruses. Besides, 38 European varieties belonging to *S. tuberosum* ssp. *tuberosum* were identified from whatever was under cultivation in India before independence. These are referred to as exotic varieties. These exotic European varieties were long-day adapted and, therefore, their cultivation was restricted to the hills of the Indian sub-continent.

With the rapid expansion of potato cultivation to Indo-Gangetic plains after independence, absence of varieties suitable for sub-tropical agro-climates emerged as the major constraint. The potato breeding programme of ICAR was initiated under that backdrop. During earlier phase, varietal improvement of potato was a formidable challenge because: (i) the introduced European varieties were all long-day adapted, (ii) their multiplication in

Indian conditions was characterized by progressive accumulation of viral diseases resulting in concomitant decrease in yield, and (iii) limitations in tuber storage in hot and humid Indian conditions. The task was further complicated by the unique reproductive features of the plant since it flowers only under long days. Therefore, crossing work for potato had to be undertaken in the hills but their subsequent selection had to be done under short-day, winter months of Indian plains. This resulted in quick degeneration of hill-bred progenies in the plains during evaluation. As a consequence, initial attempt to breed sub-tropical potato varieties was a failure.

An organized potato breeding programme was initiated with the establishment of CPRI. The institute succeeded in establishing a strategy for crossing at its headquarter at Shimla and subsequent selection of potato hybrids at different stations located in plains. The strategy became more effective after perfection of another technology called "Seed Plot Technique" in the year 1963 (described below). With the introduction of this technique, it became possible to raise, maintain and evaluate segregating populations in the plains under disease-free, low aphid periods. This revolutionized potato breeding in India and till date, around 50 varieties have been released for cultivation under diverse agro-climatic conditions of the country. Presently, 21 varieties, viz. Kufri Sindhuri, Kufri Chandramukhi, Kufri Jyoti, Kufri Lauvkar, Kufri Badshah, Kufri Bahar, Kufri Lalima, Kufri Swarna, Kufri Jawahar, Kufri Sutlej, Kufri Ashoka, Kufri Pukhraj, Kufri Giriraj, Kufri Anand, Kufri Chipsona-1, Kufri Chipsona-2, Kufri Kanchan, Kufri Himalini, Kufri Chipsona-3, Kufri Arun, Kufri Surya are under cultivation (CPRI Tech. Bulletin No. 78). Currently these varieties occupy about 95% of the total potato growing area of the country. Prominent among them are Kufri Jyoti in the hills and state of West Bengal, Kufri Badshah in Gujarat and Kufri Bahar in Uttar Pradesh occupying nearly 80-90 % of the potato area of the respective states. The organized variety improvement programme of CPRI for over 60 years has been instrumental in fourteen-fold increase in total production and three-fold increase in yield per unit area in the country.

The emphasis in potato breeding in India had been on the development of high yielding varieties. Few cultivars with processing attributes have also been developed recently. Development of high yielding varieties by CPRI contributed largely for fast growth of potato cultivation during second half of 20th century. However, the momentum of yield gain has slackened considerably during last 10 years. The absence of varieties with specific desirable attributes like shorter crop duration, heat & drought tolerance, high input efficiency, cold-chipping, French fry preparation, and better nutritional quality is now posing a hurdle for extending potato in new areas.

7.6 Status of Biotechnological Interventions

Potato, being highly amenable to genetic transformation, attracts attention of researchers to assess the impact of development of transgenic potatoes harboring diverse traits. Genetic engineering in potatoes has a rather long history with the first transgenic potato developed about 25 years ago, and it is envisaged that many of the transgenic plant products to be commercialized in the present decade are likely to be potatoes with enhanced characteristics. In India, CPRI has initiated research on two priority traits namely durable late blight resistance and reduction of cold-induced sweetening for improvement by genetic engineering. Besides, transformation work on nutritional improvement, virus resistance and potato tuberization is being carried out by the institute.

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