CONTROL OF VEGETATIVE GROWTH AND FLOWERING IN HEDYCHIUM CORONARIUM KOENIG

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ABSTRACT

The study was undertaken with the following objectives:

i) To evaluate daylength treatments on flowering response in *Hedychium coronarium.*

ii) To produce compact flowering plants adaptable to containerized production using a growth retardant (paclobutrazol).

Daylength treatments of 8, 10, 12, 13, 14, and a natural daylength as a control was imposed on the plants between September 28 and December 20, 1997. The 13 and 14 hours provided adequate photo-inductive stimulus to elicit flowering response from the plants. No flowering occurred below 13 hours daylength. A subsequent night break (NB) treatment conducted between January 12 and May 10 1999 also induced flowering in the treatment plants, confirming that *Hedychium coronarium* is a long day plant. The NB consisted of 3.5 hours of light interruption from 11.30 pm – 3.00 am from two 100-watt tungsten filament lamps placed at 1.5 m apart and at 1.65 m above the pots.

Hedychium coronarium plants were subjected to paclobutrazol drench applications of 2, 4, 8 and 16 mg a.i./pot. All treatments exhibited pseudostem length suppresing activty on the plants. However the 4 mg a.i./pot treatment was the best, limiting pseudostem length to 71% of the non treated-control plants, with no adverse effect on the plants. The retardant did not impact other growth or reproductive parameters measured.

A study to compare the relative efficiencies of drench and pre-plant rhizome dip applications of paclobutrazol found the rhizome dip method ineffective at 16.6 and 33 ppm. The drench concentrations of 2 and 4 mg a.i./ pot were highly effective in suppressing pseudostem length to 62 and 50% of non-treated control.

The information generated by this study would be of practical value in scheduling an all year round flower production, as well as developing *Hedychium coronarium* for pot culture.

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CHAPTER 1. INTRODUCTION

The genus *Hedychium* was established by Koenig in 1783 based on *Hedychium coronarium* Koenig. The genus comprises approximately 80 species, distributed mainly in eastern Himalaya to South China, South India and South-East Asia (Sirirugsa and Larsen, 1995). The genus comes within the family Zingiberaceae. The Zingiberaceae are one of eight families of monocotyledons that make up the order Zingiberales. Four of these families form the monophyletic ginger group containing the Marantaceae, Cannaceae, Costaceae, and Zingiberaceae (Kress ,1990; Kirchoff ,1997).

In general, gingers are terrestrial (a few epiphytic) rhizotomous herbs, usually sympodially branched. The rhizome units bear reduced scale leaves and grow horizontally for a distance characteristic of the species before turning to become erect as foliage bearing shoots. In Zingiberaceae, the leaves tend to be arranged distichously, and their open leaf sheaths form a pseudostem through which the true stem elongates (hypoxanthic flowering) (Criley,1985).

The name *Hedychium* is derived from the words "hedys" meaning sweet and "chion" meaning snow. The leaves are green, or glaucous green, paler and glabrous or pubescent beneath, sessile or shortly petiolate on the sheath. The inflorescence is a bold terminal spike with conspicuous bracts arranged spirally on the rachis. The flower spikes are very attractive and heavily perfumed. The individual flowers are very short lived, lasting between 1-2 days, but the many flowered spikes produced over a period of several weeks provide a long flowering period (Schilling, 1982). *H. coronarium* plants attain heights of

1 - 2 m. Flowers are borne in cincinni within bracts (primary bracts), and from each up to 9 flowers have been observed to open in succession (Rao and Verma 1969). *Hedychium* have been grown in the U.S. for at least 50 years, probably longer (Chapman, 1995).

In Hawaii the more common species of Hedychium are *H. coronarium* (white ginger), *H. flavescens* (yellow ginger), and *H. gardnerianum*. Other lovely species occasionally seen are *H. thyrsiforme* (small curly white ginger), *H. coccineum* (orange/red ginger) *H. greenei* (red butterfly ginger) and *H. longicornutum* (epiphytic ginger) (Hirano, 1998) *Hedychium coronarium* is mainly used as landscape plant and for lei making in Hawaii, its use as a cut flower is also gaining popularity. There is a potential for using this species as a pot plant. However, its height (1 – 2 m) and weak stem which collapses without support are constraints that needs to be addressed.

The natural flowering period of *H. coronarium* is restricted to only 4 months (July – October) of the year. For the rest of the year the plants remain dormant and there is no flower production. Some growers had successfully used lighting to obtain flowering in the off-season. However, questions remained as to whether this was a true photoperiodic response and if it was, what were the daylength and duration, light intensity, and minimum number of expanded leaves etc. required for floral induction.

Thesis Objectives

The main objectives of this research are two fold.

i) To evaluate daylength treatments on flowering response of *Hedychium coronarium*.

ii) To produce compact flowering *H. coronarium* adaptable to containerized production using a growth retardant (paclobutrazol).

CHAPTER 2. LITERATURE REVIEW

2.1. Vegetative control

Excessive vigor may be undesirable in horticultural production for many reasons. To produce a compact attractive plant requires skillful manipulation of fertilizer, irrigation, temperature, light levels and pruning all adjusted for the specific growth characteristic of a given species or cultivar. Sometimes it may be extremely tedious or impractical to use this manipulative ability to achieve the desired growth control.

The discovery of plant growth retardants has provided a convenient tool to growers for the management of vegetative growth. Chemical growth retardants have been in use for over 40 years and have been particularly successful in improving the harvestable "agronomic" yield when applied to wheat and barley cultivars with long or weak straw, especially when soil fertility is high (Treharne et al., 1985). In fruit orchards growth retardants have been used to effectively reduce the number and length of vegetative shoots thereby allowing for efficient high-density orchards (Rademacher, 1988) and increased yields and improved fruit quality (Bangerth, 1983). According to Sterrett (1988), the high costs involved in the constant pruning of trees under power and telephone lines could be drastically reduced by use of growth retardants.

In ornamentals, retardants have been used commercially to produce compact, sturdy potted and bedding plants (Nickell, 1982). Some of the most widely used retardants are chlormequat chloride (CCC, Cycocel), daminozide (B-nine, Alar), and ancymidol.

The main disadvantages of these growth retardants are the restriction of their activity to certain plants. Their activity is especially low in woody plants, geophytes ("bulbs"), and foliage plants (Halevy, 1985).

[(2RS, 3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2- (1,2,4-triazolyl)-pentan-3-ol] (paclobutrazol or Bonzi) is one of the new generation of retardants having a significant advantage over those mentioned above (Goulston and Shearing, 1985). It has a wider range of activity than the other growth retardants. Its active concentrations are lower than those of most other retardants.

2.1.1 Mode of action of paclobutrazol

Paclobutrazol is a triazole compound, a gibberellin acid biosynthesis inhibitor. Triazoles inhibit cytochrome P_{450} mediated oxidative demethylation reactions, including those which are necessary for the synthesis of ergosterol and the conversion of kaurene to kaurenoic acid in the gibberellin biosynthesis pathway (Noguchi et al.1989).

2.1.2 Mobility of paclobutrazol in the plant

Most researchers have reported that translocation of paclobutrazol in the plant is exclusively through the xylem vessels. Sterrett (1985) found 23% of the paclobutrazol injected into apple trees to be translocated acropetally. According to Yau (1988), paclobutrazol is a xylem mobile plant growth retardant, which moves acropetally in the transpirational stream, accumulates in the apical shoots and foliage and is not remobilized in the reverse direction. Its uptake is mainly by roots, green stems and foliage. Intrieri et al. (1987) also noted that most paclobutrazol movement occurred apoplastically in the xylem. Hamid and Williams (1997) working with *Swainsonia formosa* confirmed that

paclobutrazol was readily translocated acropetally within a shoot (via xylem) but not basipetally (via phloem) However, Browning et al. (1992) found that xylem is not the only pathway for translocation of paclobutrazol in pear shoots. Witchward (1997) also reported that in castor oil plant, *Ricinus communis* L., paclobutrazol is transported in both the xylem and phloem.

2.1.3 Rates and Methods of application

Paclobutrazol has been effective as a height retardant on a wide variety of ornamental crops (McDaniel 1983) dicots and monocots inclusive. It can be applied as foliar spray, as soil drench, injection into woody plants (Sterrett, 1985), as well as by pre-plant bulb dip. The efficacy of paclobutrazol is influenced greatly by the rate and method of application and may vary among species.

2.1.3.1 Dicots

Vlahos and Brascamp (1989) achieved a 67% reduction in height of *Achimenes longiflora* with two foliar sprays of 100 ppm paclobutrazol.

Research on azaleas typically has found paclobutrazol foliar sprays of between 250 and 500 ppm to provide desirable control of shoot growth (Keever et al., 1990; Whealy et al., 1988). Joustra (1989) recommends foliar sprays of 50 - 125 ppm, noting that concentrations above 125 – 250 ppm can cause leaf deformation on some rhododendron cultivars. Brand (1993) reported that, foliar sprays of paclobutrazol at rates of as low as 10ppm provided effective shoot control on 'Roseum Elegans' rhododendron particularly if applied in April before the first flush of annual growth. On the other hand Ranney et al.

(1994) obtained only minimal control of shoot growth with foliar sprays of 200 ppm paclobutrazol on 'Roseum Elegans'.

Quality marketable plants of Butterfly bush (*Buddleia davidii*) were obtained with drenches of 10 mg a.i./ pot of paclobutrazol (Ruter, 1992). Geranium is very sensitive to paclobutrazol. Spray concentrations greater than 40 mg/ liter or drenches greater than 0.015 mg a.i./ pot caused excessive and undesirable reductions in height and leaf size of 'Smash Hit' geranium (Cox, 1991).

2.1.3.2 Monocots

Criley and Lekawatana (1988), obtained good height control of 'Dwarf Jamaican' heliconia with paclobutrazol soil drench of 2.0 mg a.i./ pot. McDaniel (1990), reported that paclobutrazol bulb soaks at 5.0 and 7.5 mg/liter for 1 hour produced commercially acceptable potted tulip heights that were similar to soil drench of 0.25 and 0.50 mg/15 cm pot. However, bulb soaks at 10 mg/liter caused excessively short plants.

Pre-plant bulb dip and drench methods of paclobutrazol application were tried on narcissus 'Grand Soleil d'Or' by Yahel et al. (1990). They observed that the drench was more effective than the dip method. The best treatment was 40 ml/liter. Tjia (1987) reported that foliar sprays of paclobutrazol were not as effective as drench application on *Zantedeschia rehmannii* hybrids.

Variation in reports of dose responses of paclobutrazol for both foliar sprays and root-zone drenches emphasize the potential for variation in efficacy as a function of growing conditions, timing and taxa being treated (Ranney et al., 1994). Undoubtedly, foliar sprays and drench are the most popular mode of application of growth retardants to

plants (Larson, 1985) However, to reduce costs, minimize pollution and applicator health risks (Sanderson et al., 1994) other application methods are being considered

2.2 Flowering

Flowering is a multistage process composed of sequences of events temporally and spatially ordered (Bernier *et. al.*, 1981). Most plant physiologists divide flowering into two major phases viz. flower initiation and flower development. Floral initiation is recognized as the phase, which results in the irreversible commitment of shoot meristem to produce inflorescence and or flower primordia. Floral development is the phase of production of flower primordia and floral organs by meristems and the development of the reproductive organs to anthesis. Both phases are affected by environmental, chemical and genetic factors that interact in a complex fashion.

2.2.1 Environmental factors

2.2.1.1 Temperature

Temperature acting independently or in combination with daylength greatly impacts flower initiation and development. In general, the optimum temperature requirement for flower initiation is different from the optimum for flower development (Moe and Hines, 1990). Increasing average daily temperature enhances flower development, but is inhibited or delayed by both too high and too low temperatures depending on plant species.

The difference between day and night temperatures (DIF) also influences flower initiation and development. According to Went (1953), a negative DIF (higher night and lower day temperature) alternation resulted in earlier flowering in *Saintpaulia ionatha* than constant temperatures. In *Fuchsia x hybrida,* Moe (1989), reported that more flower

and flower buds were formed with negative DIF than a positive. Whitton and Healy (1990) also observed that constant temperature promoted rapid flowering in *Aeschynanthus* but temperature fluctuation enhanced the flowering percentage (number of stems flowered per total number of stems) in cultivar Koral.

In many temperate plants a period of low temperature exposure varying from a few weeks to several months is critical for achieving reproductive development. Low temperature treatment is termed vernalization. The effective vernalization temperatures usually range from 0 – 15°C (Kinet, 1993). The effectiveness of the cold treatment is influenced by other environmental factors. In some species short days can substitute for cold treatment (Heide, 1990)

2.2.1.2 Light

2.2.1.2.1 Light Intensity

Light intensity, either independently or in combination with other factors, plays a critical role in the development of many species. Kinet et al. (1985) reported that in tomato, rose, many bulbous species and grapevine, low light levels may induce complete failure of the reproductive structure. Kinet and Sachs (1984) concluded from their shading experiment that, high photosynthetic activity in the source leaves is a major contributing factor to high light-induced promotion of development. Halevy (1984) reported increased or hastened flowering in roses as irradiance was increased whereas a low irradiance caused flower abortion.

Irradiance interacts strongly with daylength in photoperiodic species. High light may override the photoperiodic signal as shown in SDP Bougainvillea where it causes

flowering in long days (Kinet et al., 1985). In contrast, lowering the light intensity after flower initiation causes the development of vegetative inflorescences in the SDP *Kalanchoe blosseldiana* Poellniz and inflorescence reversion in the LDP *Sinapsis alba* (Bernier et al., 1981).

2.2.1.2.2 Daylength

In many species daylength is the main controlling factor for floral initiation and development. Vince-Prue (1975) classified plants into the following photoperiodic response types:

Day neutral plants (DNP) – Those that flower independent of daylength.

Long day plants (LDP) – Those that flower or flower most rapidly with more than a certain number of hours of light in each 24-hour cycle.

Short day plants (SDP) – Those which only flower or flower most rapidly with fewer than a certain number of hours of light in each 24-hour cycle.

The groups are further divided into:

- absolute or qualitative photoperiodic responses where a particular daylength is essential for flowering.
- quantitative or facultative photoperiodic responses where a particular daylength promotes but is not essential to flowering.

Some plants have dual photoperiodic response. In *Cestrum nocturnum*, flowering occurs in short days (SD) only after plants have previously received a sufficient number of long days (LD). In *Scabiosa succisa*, flowering occurs in LD only in plants that have previously received short days.

Salisbury and Ross (1992) stated that, before a plant can flower in response to its environmental stimuli (particularly daylength and temperature), the leaves that detect the environmental change must reach a condition called competence, and the meristems must be competent to respond to the stimulus from the leaves. There is a great diversity among species and plant organs as to the age at which they achieve these conditions.

2.2.1.2.2.1 Assessing Flowering Response

Vince-Prue (1975) listed a number of methods used in assessing flowering response after photoperiodic induction. They include:

- percentage of plants in any given treatment which has flowered within an arbitrary time limit.
- number of days from start of induction to appearance of flowers or flower buds.
- average number of flower buds per plant (used for *Pharbitis*)
- number of nodes on main axis which produce flower buds (used for *Glycine max*)
- node count to first flowers/inflorescence
- stages of floral development (used for *Xanthium*)
- dissecting of shoot apices and observing for presence of macroscopically visible flower buds.

2.2.1.2.2.2 Types of Photoperiodic Induction

Daylength extension by supplemental lighting as well as night breaks (NB) which involves interrupting dark period with a brief period of lighting have been used in the induction of plants. Night breaks promote flowering in LDPs and prevent them in SDPs. The effectiveness of the night interruption is dependent on the point in the cycle when the

NB is given (O'Neill, 1992). The relationship between the time of sensitivity to a night break and day and or night length is not a simple one. In experiments to determine the time at which a night break given in a 16-hour dark period has the greatest effect in *Xanthium*, *Lolium* and *Coleus* the following results were obtained. In *Xanthium*, the maximum effect was achieved after 6 hours of darkness at 18° C and after only 4 hours at 24°C. In *Lolium temulentum* and in *Coleus*, light had the greatest effect after the middle of the night. In two cultivars of sugar-cane, a light break given near the end of a 11.5 – 12 hour night delayed the initiation of branch and spikelet primordia more than light given near the middle of the night (Vince-Prue, 1975). With very long dark periods the time of the greatest sensitivity is not much altered, flowering is prevented in SDP and promoted in LDP, when light interruption is given a few hours after transfer to darkness (Thomas and Vince-Prue, 1997).

In most SDPs, a few minutes of light given as a night break (NB) will often prevent flowering completely and 30 minutes is usually adequate in plants such as *Perilla* (Carr, 1952) and *Xanthium* (Hamner and Bonner, 1938). Chrysanthemum is an exception and requires several hours from tungsten filament lamps (Cathey and Borthwick, 1953). However according to Lane et al. (1965), LDPs are usually less sensitive to a NB than are SDPs. They also require longer exposures and or higher intensities. The response of LDPs are frequently of semi-quantitative nature over a wide range of intensities and durations of light. Once flowering is inhibited in SDP, no further effect of light can be seen but, in LDP, the earliness in flowering or number of flowers often increases with increasing

amount of light. Night-breaks of 1 – 2 hours are usually sufficient to induce flowering in LDP but may not saturate the response (Hughes and Cockshull, 1965; Vince, 1965).

In some cases, flowering is most rapid when lighting treatment is continued throughout the whole night as in facultative LDP, carnation (*Dianthus caryophyllus*) (Harris, 1968).

When long periods of light are used to induce flowering in LDP especially when they are given as day-extension following a short day in the sunlight, a mixture of red plus far-red frequently has a much greater effect than red alone (Vince Prue, 1975).

2.2.2 Genetic control

An increasing number of genes have been identified that are involved in daylength and cold requirement as well as floral morphogenesis of various plants. In *Fragaria* a dominant allele of a single gene induces day neutrality in octaploids while recessive alleles of one to three genes confer it in diploids (Ahmadi, 1990). In pea (*Pisum sativum* L) at least 13 loci have been identified which affect flowering. Sn and Dne act in a complementary manner to confer a requirement for photoperiodic induction (Kinet, 1993).

At least two types of genes are expressed during flower morphogenesis. The first includes genes that assign an identity to organ primordia in the flower whorls and govern the proper placement of the floral appendages (Acquaah et al., 1992)

2.2.3 Chemical control (plant growth regulators)

Because plant hormones and plant growth regulators can influence virtually every aspect of plant growth and development, it is logical to investigate their effects on flowering. Work with hormones and growth regulators can lead to better understanding of the flowering process (Salisbury and Ross, 1992).

Auxin: Auxin at low doses is required for flower initiation but inhibits at high levels (Bernier, 1988).

Cytokinins: Exogenous application of cytokinins has promotive effect on flowering although inhibition was also reported especially when concentrations were elevated and with young seedlings as plant material (Bernier, 1988; Bernier et al., 1990)

Gibberellins: Gibberellins have been found to stimulate flower production in *Cordyline terminalis* (L) Kunth and various ornamental aroids, which are photoperiodically neutral and do not respond to cold (Halevy, 1990).

Ethylene: Depending on species, exogenous ethylene has opposite effects on flower initiation (Bernier, 1988). It promotes flowering in a variety of geophytes and bromeliads. Prevention of flower initiation by ethylene has been reported for several SD plants grown under inductive conditions (Bernier, 1988). This inhibition is associated with an increased production of sugar yield in sugarcane (Moore and Osgood, 1989). Ethylene is involved in reproductive structure failure. It has been implicated in the flower abortion of tulip, rose and tomato (Kinet et al., 1985).

CHAPTER 3. THE FLOWERING RESPONSE OF HEDYCHIUM CORONARIUM TO VARYING DAYLENGTHS

3.1 Abstract.

Hedychium coronarium plants were subjected to 5 daylength treatments of 8, 10, 12, 13, and 14 hrs with natural daylength (which ranged 12 – 10.50 hrs) as control. The treatment period lasted for 83 days (12 weeks). One plant out of a total of six flowered in the 13 –hour daylength treatment, whilst 3 out of 6 or 50% flowered in the 14-hour daylength treatment. The 8, 10, 12, and the natural daylength treatments did not produce any flowering plant.

3.2 Introduction

The genus *Hedychium* is mainly distributed in eastern Himalaya to South China, South India and South-East Asia (Sirirugsa and Larsen, 1995). Hedychiums are terrestrial or epiphytic herbaceous perennials with stout, fleshy creeping rhizomes. In the wilds of the Himalaya, *Hedychium* species can be found frequently growing in damp streamside and riverside situation or at the margins of mixed forest. The pseudostems, which are never branched, are enclosed by leaf sheaths and usually die down following the flowering season (Schilling, 1982)

Hedychium coronarium Koenig is widely cultivated in Malay Islands and Sri Lanka and throughout tropical and warm temperate regions. The flowers, which are heavily scented, emerge from a solid elliptical spike some 20 cm long. The natives of Malaya call this lovely species 'gandasuli' meaning queen's perfume. The flowers are much used in garlands or as a headdress throughout Asia.

In Hawaii *Hedychium coronarium* flowers are mainly used in making leis. The plants are also employed in landscaping. Their use as cut-flowers is also gaining popularity. Seasonality of flowering limits the availability of *Hedychium coronarium* flowers in Hawaii. The flowering season is from July to October (Criley, 1985). During this period there is a glut on the market however for the rest of the year there are no flowers. Indian botanists also noted that flowering of *Hedychium* is exclusively limited to summer months. Additionally, some growers have been successful in using lighting to obtain flowering in winter months. This led Criley (1985), to hypothesize that *Hedychiums* might be photoperiodic responsive.

Since the initial work of Garner and Allard in photoperiodism, daylength manipulation by the use of blackouts or supplementary lighting (Thomas and Vince-Prue, 1997) has been employed in the management of seasonal flowering in a wide range of ornamental species. By subjecting *Heliconia stricta* 'Dwarf Jamaican' to short day (SD) treatments (Criley and Kawabata, 1986) obtained increased flower production. Similarly Criley and Sakai (1997) were able to extend the production period of *Heliconia wagneriana* Petersen by the use of SD treatment.

This experiment was undertaken to evaluate the effect of six different daylengths on the flowering response of *Hedychium coronarium.*

3.3 Materials and Methods.

The experiment was conducted in the glasshouse of the Magoon greenhouse facility of the University of Hawaii. Rhizomes of *Hedychium coronarium* Koenig were collected from Lyon Arboretum on April 30, 1997. The rhizomes were trimmed of dead roots; dead rhizome portions were also removed. They were then thoroughly washed with water and divided into approximately 8-10 cm pieces. The pieces were placed in flat trays with a potting medium of perlite and vermiculite at a ratio of 1:1 by volume and placed under mist.

On June 4 1997, those pieces that had sprouted and or rooted well were transplanted into 4-liter containers with a potting mix of perlite, peatmoss and soil in a ratio of 2:2:1 by volume. There were 100 pots in total. The pot mixture was amended with dolomite, Micromax (minor elements) and treble superphosphate at rates of 6.0, 1.0, and 0.6 kg m^{-3}, respectively. Plants were irrigated with microsprinklers.

On August 5, the plants were divided and repotted into 8 liter pots. The potting medium and amendments were the same as described above. After the plants had established fairly good root systems and growth, 48 pots with healthy, fairly uniform plants were selected in September 1997. The pseudostems with more than 5 leaves were cut off leaving only a single plant of between 1 - 5 leaves per pot for the photoperiodic treatment.

The daylength treatment was commenced on September 28, 1997 and terminated on December 20, 1997 (12 weeks). The treatments consisted of 8, 10, 12, 13 and 14 hours and a natural daylength control (ranged from 12 hours at start of experiment to 10.57

hours at its termination). Five treatment compartments were made of a wood support framework with a covering of black plastic sheet (4 mil thickness); the sixth compartment, which housed the natural daylength, was not covered. Each compartment measured 170 x 150 x120 cm (h x l x w). The compartments were installed on benches in a glasshouse. Six pots were placed in each compartment. Six extra pots were added to the 8 hr and 14 hr treatment compartments; these extra plants were used for anatomical observation of apices for signs of floral initiation.

The compartments were covered up from 5pm - 9am. With the exception of the natural daylength and the 8 hour treatment plants, the rest were given supplemental lighting ranging from 2 hrs to 5 hrs. The source of supplemental lighting was a 60 W incandescent lamp placed at 1.65 m above the pots. The on and off time settings were 5 – 7 pm for the 10 hr, 5 – 9 pm for the 12 hr, 5 – 10 pm for the 13 hr and 5 – 11 pm for the 14 hr photoperiods. The plastic sheets were uncovered at 9 am and replaced at 5 pm to ensure plants received 8 hours of sunlight.

To ensure that each plant received equal amounts of supplementary light and also to eliminate the space advantage to plants near the walkways, plants were regularly rotated within each compartment. Plants were drip irrigated automatically with nutrient solution, at the rate of 2000 ml per pot per day. The fertilizer ratio in the irrigation water was 200 N-0 P-223 K (ppm). After 8 weeks of treatment, some plants showed severe tip burns and leaf necrosis. Excess salt was suspected, the plants were taken off the drip irrigation and leached, thereafter they were hand irrigated for 3 weeks after which they were returned to the drip irrigation.

The initial number of leaves per pseudostem, pseudostem length, base and neck diameters of pseudostems at the beginning of the treatment were recorded. Fortnightly measurements were taken of these same parameters and recorded. The number of leaves at floral initiation, number of leaves subtending the inflorescence, final length, base and neck diameter of pseudostems were recorded. Pseudostem length was measured from surface of medium to the junction of the youngest expanded leaf and its leaf sheath. Base diameter of pseudostem was measured at the rim of the pot. Neck diameter of pseudostem was measured at the junction of the youngest expanded leaf and its leaf sheath. A leaf was defined as a fully expanded leaf with leaf length 10 cm and greater.

Anatomical observation of shoot apices were made to:

1) determine floral initiation from the time of commencement of treatment

2) determine the minimum number of expanded leaves per pseudostem required for floral induction

For the former, pseudostem samples were collected every fortnight after commencement of treatment from the 8-hour and 14-hour treatments. A single sample was taken from each treatment each time.

For the latter objective, a separate study was conducted in late summer of 1998. Samples of pseudostems having between 0 and 2 fully expanded leaves growing under natural inductive conditions were collected on August 15, 1998 (daylength was 12.52 hrs.). The plants used for the study were offshoots derived from plants from the previous daylength experiment described above. Plants had been allowed to grow in the shade house of the Magoon facility under 30% shade. Five samples were collected for each leaf

number category. The samples were limited to 0 and 2 expanded leaves based on a preliminary result by the author, who had observed floral initiation in 3 – 6 fully expanded leaves.

FAA (Formalin - acetoalcohol) was used for fixation. After FAA treatment, specimens were subjected to ethyl alcohol-tertiary butyl alcohol dehydration series. Infiltration with Parowax and embedding in paraplast followed a standard paraffin embedding technique (Johansen, 1940). The thickness of the material cut with microtome was 10 μm. For slide preparation, Haupt's solution with formalin was used as an adhesive and safranin as staining agent. Photomicrographs of the apical meristem of selected samples were prepared to illustrate this portion of the study (Figure 3.1).

Data was analyzed as a completely randomized design. The response of pseudostem length as well as the number of leaves initiated was regressed against daylength using SAS PROC REG procedures (SAS Inst., 1990)

3.4 Results

No flowering was observed in plants under the 8, 10, 12 hours and natural daylength treatments (Table 3.1). However plants in the 13- and 14-hour treatments responded to the increasing daylength by initiating and producing inflorescences. One plant out of the 6 (17%) flowered in the 13-hour treatment, while 3 out of 6 plants (50%) flowered in the 14-hour treatment. The first morphologically visible sign of flower initiation and development was the swelling in the neck of the pseudostem as the developing inflorescence was emerging through the pseudostem; this occurred between 53 and 62 days after the imposition of light treatment (Table 3.1). Inflorescence bracts emerged from

the pseudostem 5 to 7 days after the appearance of the swelling. The emergence of the inflorescence is usually associated with the emergence of the last leaf which is normally much smaller than those that preceded it. Days from commencement of treatment to anthesis ranged from 81– 93 (Table 3.1) with the mean for the 14-hour treatment being 85 days. The blooming of individual spikes (inflorescence) lasted between 12 and 16 days producing a range of 12 – 29 flowers (Table 3.2). Between 9 and 12 cincinnal bracts (Table 3.2) subtended the flowers. The number of leaves below the inflorescence ranged from 12 – 15 with a mean of 13.7 for the 14-hour treatment plants (Table 3.2).

The number of leaves unfurled from non-induced plants during treatment period showed a significantly ($P \leq 0.0001$) linear response to increasing daylengths (Table 3.3) with the 13- and 14-hour daylength treatments having 3 more leaves unfurled than the 8-hour treatment. Within the 13- and 14-hour treatments, vegetative pseudostems developed 0.9 to 1.6 leaves more than pseudostems on which inflorescence developed (Tables 3.2 and 3.3). Similarly, there was a significant ($P \leq 0.0001$) linear response of pseudostem length to increasing daylength treatments (Table 3.3).

The results of anatomical observations of apices of *H. coronarium* are presented in Tables 3.4 and 3.5. Results for the 8-hour daylength treatment for November and December were not presented because good microtome sections could not be obtained. The first sign of floral initiation as was observed in the 14-hour treatment sample taken 8 weeks after the commencement of treatment. Two sterile bracts and 2 cincinnal bracts, which are inflorescence structures, were visible at this stage (Table 3.4).

No reproductive strucures were observed in samples of pseudostems with no expanded leaf. However floral structures were present in the single and 2 expanded leaf samples (Table 3.5). Photomicrographs showing vegetative and reproductive status of the pseudostem apices are presented in Figure 3.1.

Table 3.1 Effect of different daylength treatments on the initiation and development of inflorescence in *Hedychium coronarium* after 12 weeks of treatment.

Photoperiod (hrs)	Days to pseudostem neck swelling[a]		Days to anthesis[a]		Plants Flowered	
	Range	Mean	Range	Mean	No.	%
Natural dayl.[b]	-	-	-	-	0	0
8	-	-	-	-	0	0
10	-	-	-	-	0	0
12	-	-	-	-	0	0
13	59	59	86	86	1	17
14	53 - 62	56	81 - 93	85	3	50

[a]Days to pseudostem neck swelling and anthesis were calculated from the start of treatment.
[b]Natural daylength, ranged from 12 hrs at the start to 10.50 hrs at the end of the experiment.

Table 3.2. The effect of different daylength treatments on the inflorescence characteristics and the number of leaves subtending the inflorescence of *Hedychium coronarium* after 12 weeks of treatment.

Photoperiod (hrs)	Bracts		No. of flowers		Inflorescence length (cm)		No. of leaves subtending inflorescence	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Natural dayl.[a]	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	9	9	14	14	12	12	14	14
14	9 - 12	10	12 - 29	18.7	10 - 19	14.3	12 - 15	13.7

[a]Natural daylength, ranged from 12 hrs at the start to 10.50 hrs at the end of the experiment.

Table 3.3. The influence of different daylength treatments on pseudostem length, the number of leaves unfurled and total leaf number in *Hedychium coronarium* after 12 weeks of treatment.

Photoperiod (hrs)	Mean pseudostem length (cm)	Mean no. of leaves unfurled[a]	Total no. of leaves
Natural dayl.[b]	67.8	8.8	12.3
8	58.1	8.2	12.2
10	69	9.0	12.8
12	75.8	9.2	12.7
13	82.2	11.2	14.9
14	93.7	11	15.3
Significance[z]			
Linear	$P \leq 0.0001$	$P \leq 0.0001$	$P \leq 0.0001$

[a]Leaves unfurled, the number of leaves unfurled after the commencement of daylength treatment, only leaves from non-induced plants were included in leaf count.
[b]Natural daylength, ranged from 12 hrs at start to 10.50 hrs at the end of treatment. It was not included in the regression analysis

Table 3.4. Histological status of pseudostem apices of *Hedychium coronarium* maintained under 8 and 14-hour daylength treatments. Samples were taken every fortnight for anatomical observations starting two weeks after the imposition of treatment.

Date[a]	week	Daylength (hrs)	Number of leaves[b]			Status of apex
			Expanded	Inside	Total	
10/11/97	2	8	5	8	13	Vegetative
10/11/97	2	14	7	7	14	Vegetative
10/28/97	4	8	7	5	12	Vegetative
10/28/97	4	14	10	8	18	Vegetative
11/8/97	6	14	11	6	17	Vegetative
11/21/97	8	14	13	2	15	Reprod.[c]: 2 sb+2 cb
12/6/97	10	14	10	1	11	Reprod.: 2 sb+2 cb

[a]Date, Date on which sampling was made.
[b]Inside, total number of unfurled leaves and leaves covering the apex
[c]Reprod., sb = sterile bract, cb = cincinnal bract

Table 3.5. Histological status of pseudostem apices of *Hedychium coronarium* with varying expanded number of leaves growing under natural inductive conditions. Samples for anatomical observations were collected on August 15, 1998 (daylength was 12.52 hrs).

No. of expanded leaves	Sample[a]	No. of leaves inside[b]	Total no. of leaves	Status of apex
0	1	12	12	Vegetative
	2	9	9	Vegetative
1	1	9	10	Reproductive[c]: 2 sb + 2 cb
	2	8	9	Reproductive: 2 sb + 4 cb
	3	8	9	Reproductive: 2 sb + 3 cb
	4	8	9	Reproductive: 2 sb + 3 cb
2	1	7	9	Reproductive: 2 sb + 3 cb
	2	8	10	Reproductive: 2 sb + 5 cb
	3	8	10	Reproductive: 2 sb + 5 cb
	4	8	10	Vegetative

[a]Sample, each sample represents the apex of a single pseudostem
[b]Inside, total number of unfurled leaves and leaves covering the apex
[c]Reproductive, sb = sterile bract, cb = cincinnal bract

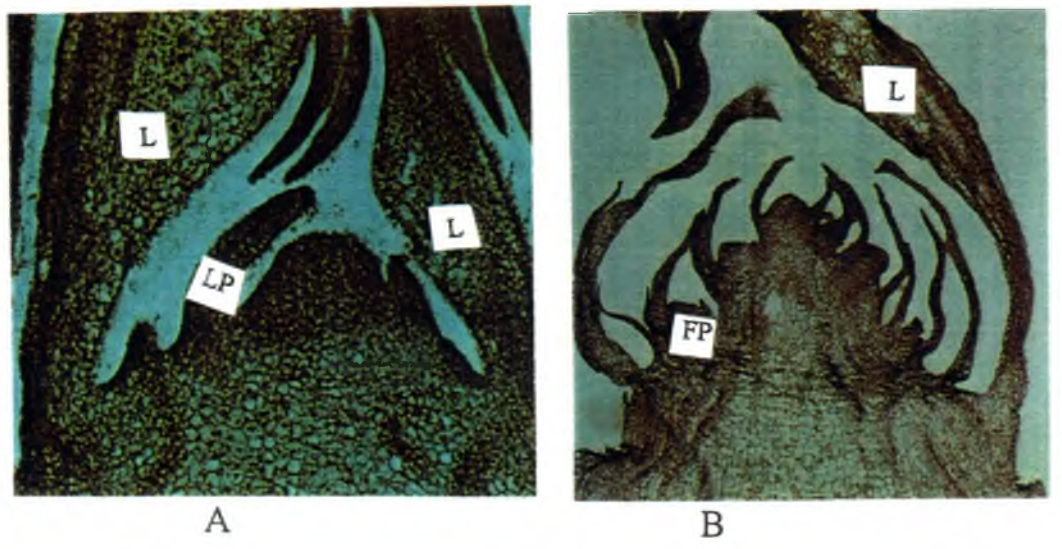

Figure 3.1. Longitudinal section of *H. coronarium* shoot apex. A is vegetative state and B is the reproductive state, all were maintained under photo-inductive conditions. L: leaf, LP: leaf primordium, FP: flower primordium.
Magnification, 10X for A, and 3.5X for B.

3.5 Discussion

Results from the experiment revealed that flower initiation in *Hedychium coronarium* is unresponsive to daylength treatments of 12 hours and less, whereas daylengths of 13 hours or more for 8 weeks induced flowering (Table 3.1). More flowering was induced in the 14-hour treatment (50%) than in the 13-hour treatment (17%). This is a typical response of light- dominant plants (plants in which there is positive enhancement of flowering by light as opposed to dark dominant plants where flowering is promoted by long uninterrupted dark period). *Hedychium coronarium* may well be one. According to Thomas and Vince-Prue (1997), the responses of light-dominant plants are frequently of a semi-quantitative nature over a wide range of irradiance and duration of light. Flowering response in these plants is usually a function of light integral. In the present experiment there was an increase in the number of plants flowering in response to the additional hour of lighting from 13 to 14 hours (Table 3.1). The increased flowering percentage may be due to the extra light integral.

It was observed that the blooming period (duration from first anthesis to anthesis of last flower) of the inflorescence spike is very much a function of the number of flowers in an inflorescence. Usually two flowers opened daily, one in the morning and one in the evening. Hirano (1998) also reported similar observation. The flowers are very short-lived, lasting for only a day. Thus for an inflorescence with 20 flowers the blooming period was normally be about 10 days. However, there were some days where no flowers were opened, or more than 2 flowers opened.

The number of leaves initiated during the treatment showed a trend of increasing number with increasing daylength. The result is similar to previous work done by Stevenson and Goodman (1972). They reported that the maize race 'Tehua' produced 28 more leaves under a long day than a short day.

The elongation of pseudostem appeared to be daylength dependent, with increasing daylengths eliciting longer pseudostem growth. However, the interpretation of the result must be done with caution. Because the light source used in the experiment under discussion was from incandescent or tungsten filament (TF) lamps which are rich in far red (FR), therefore the confounding of photoperiodic effect with light quality rather than light integral is a real possibility. TF lamps establish a low phytochrome fr:phytochrome total (Pfr/Ptot) ratio, typically about 0.5 (Thomas and Vince-Prue 1997). Any treatment, which reduces Pfr/Ptotal ratio in the range of 0 - 0.85 will cause increased stem elongation (Vince-Prue 1975). (Downs *et al.*, 1958) in *Lycopersicon esculentum* and *Glycine max* and (Zack and Loy, 1980) in *Curcubita maxima* have demonstrated greater internode elongation when short days were extended with TF light as compared to when they were extended with fluorescent light.

Anatomical examinations could not reveal the precise date of floral initiation. The date of first floral initiation was observed to be November 21 1997. However, this information was redundant, because macroscopic floral development as evidenced by pseudostem neck swelling had been noticed a day earlier (November 20), in one of the treatment plants; suggesting that floral initiation might have occurred at a much earlier date. Not every *Hedychium coronarium* shoot would eventually produce an inflorescence. Thus, a larger

sample size and more frequent sampling would have to be adopted in order to determine the precise time from start of treatment to floral initiation.

Pseudostems of *Hedychium coronarium* having even a single fully expanded leaf are capable of being induced for floral initiation during the natural inductive period. Two sterile bracts as well as cincinnal bracts ranging from 2 to 4 were evident in all four samples that were examined for pseudostems with a single fully expanded leaf. In the samples of pseudostems of 2 fully expanded leaves one of the samples was vegetative but the three remaining ones all had developed inflorescence structures. Two sterile bracts and cincinnal bracts ranging from 3 to 5 were observed. No inflorescence structures were seen in the pseudostems with no expanded leaves examined. However it cannot be emphatically concluded at this stage that pseudostems with no expanded leaf were not capable of being induced for floral initiation because only two suitable specimens were obtained for examination. The others had 4 samples each examined. More samples of pseudostems with no expanded leaf under inductive conditions need to be examined to arrive at a final conclusion.

Nonetheless, the result suggests that pseudostems of *Hedychium coronarium* with at least one fully expanded leaf are capable of responding positively to floral initiation stimulus under natural inductive period.

CHAPTER 4. THE FLOWERING RESPONSE OF HEDYCHIUM CORONARIUM TO NIGHT INTERRUPTION OR NIGHT BREAK (NB) TREATMENT

4.1 Abstract

A long-day (LD) treatment was imposed on *Hedychium coronarium.* The LD treatment was a night break of 3.5 hours daily from 11.30 pm – 3.00 am from January 12, 1999 till May 10, 1999. The light source was two 100-watt incandescent lamps at 1.5 m apart and at 1.65 m above the pots. A group of ten plants received the LD treatment; another group of ten plants was designated control and was allowed to grow under natural photoperiod conditions. Six out of the 10 plants (60%) in the LD treatment flowered, whilst there was no flowering in the control of the natural daylength treatment (photoperiod ranged from 10.57 hrs. at the start to 12.06 hrs. at the end of the experiment).

4.2 Introduction

Results from the experiment on the response of *Hedychium coronarium* to daylength treatments in Chapter 3 revealed that 8 hours of sunlight with a supplementary lighting of 5 or more hours from tungsten filament lamps induced flowering in the plants.

One distinction between a short-day plant (SDP) and a long-day plant (LDP) is that interruption by light of a non-inductive long dark period in LDP can lead to floral promotion. On the other hand only a few minutes of light interruption will prevent flowering completely in many SDPs under inductive conditions (Thomas and Vince-Prue, 1997). Whereas SDPs often show an all-or-none response to a night break many LDP are

increasingly promoted as the duration of the night break is increased (Kasperbauer et al., 1963)

Aside from utilizing the nightbreak (NB) technique to distinguish a LDP from a SDP, Thomas and Vince-Prue (1997) indicated that, in general, the same quantity of light is more effective when given as a night break than when added to the photoperiod as day extension for light dominant plants. For commercial purposes NB is more appealing than day extensions because it can be applied during off-peak period when electricity tariffs are much cheaper.

This experiment was therefore installed to confirm the results in chapter 3 and also to determine the true photoperiodic response of *Hedychium coronarium*.

4.3 Materials and Methods

The experiment was conducted at the Magoon facility of the University of Hawaii at Manoa. On September 20, 1998, *H. coronarium* plants, which had been growing in 4-liter pots, were divided and potted into 8-liter plastic pots. The potting mix was perlite, peat and soil in a ratio of 2:2:1 v/v. The pot mixture was amended with dolomite, Micromax (minor elements) and treble superphosphate at the rate of 6.0, 1.0, and 0.6 kg m^{-3}, respectively.

Plants were placed on benches in a shadehouse with 30% shade provided by saran cover. The plants were irrigated twice daily, with microsprinklers at the rate of 1000 ml per pot per day. Gaviota Foliar 60 (Brewer Environmental Industries, Honolulu, HI) fertilizer at the rate of 240N–105P–200K ppm was applied to plants as liquid feed once every 3 weeks.

On January 2, 1999, 20 pots with healthy, fairly uniform plants were selected. Pseudostems with leaves of between 5 and 7 leaves were retained; those with leaves outside this range were cut off leaving only a single pseudostem with 5 – 7 fully expanded leaves.

Plants were transferred to a glasshouse that same day. They were divided into two groups of 10 plants each and placed on two separate benches at a spacing of 2.5 pots m^{-2} in separate compartments of the glasshouse. A screen of black plastic was used to cover the glass wall separating the two chambers of the glasshouse to eliminate light filtering between the chambers.

A long day treatment in the form of night break (NB) was imposed on one group of plants. The NB was applied by providing 3.5 hours of light from 11.30 pm to 3.00 am daily from January 12, 1999 until May 10, 1999. The source of light was two 100 -watt incandescent lamps placed at 1.5 m apart and at a height of 1.65 m above the pots. The other group of 10 plants was allowed to grow under natural photoperiod. The length of the natural photoperiod ranged from 10.57 hours on January 12 1999 to 12.06 hours at the termination of the experiment on May 6 1999. Plants were drip irrigated automatically with nutrient solution, at the rate of 2000 ml per pot per day. The fertilizer ratio in this irrigation was 200N–0P–223K (ppm).

The number of leaves per pseudostem, as well as pseudostem length at the commencement and termination of the experiment were recorded. Pseudostem length was measured from surface of medium to the junction of the youngest expanded leaf and its leaf sheath. A leaf was defined as a fully expanded leaf with leaf length 10 cm and greater.

Other data recorded were, number of plants that flowered per treatment, days from treatment to anthesis, bract number, inflorescence length and number of flowers per inflorescence.

Data was analyzed as a completely randomized design. ANOVA was performed for the number of leaves initiated as well as the pseudostem length using SAS PROC ANOVA procedures (SAS Inst. 1990).

4.4 Results

No plants flowered during the evaluation period in the natural daylength control treatment. A total of 6 out of 10 plants (60%) flowered in response to the night break (NB) treatment (Table 4.1). The swelling in the neck of pseudostem was detected between 53 and 73 days after the commencement of the NB treatment (Table 4.1). Bracts emerged from the pseudostem between 59 and 78 days following initiation of NB treatment. The earliest time to anthesis was 85 days, with the mean at 98 days.

The rest of the reproductive parameters measured are summarized in Table 4.2. The minimum number of flowers produced per inflorescence was 16, whilst the maximum number was 42. The bracts subtending these flowers ranged from 9 to 12 with a mean of 11. The minimum number of leaves below the inflorescences was 12.

There was significant treatment effect ($P < 0.005$) on pseudostem length of *Hedychium coronarium*. Plants subjected to NB treatment had a mean pseudostem length of 122.9 cm, which was 17% more than the control mean of 101.8 cm (Table 4.3).

The mean number of leaves of 7.5, unfurled during treatment period for the LD maintained plants was 1.3 more than the natural day treatment (control) mean of 6.2

leaves (Table 4.3). However the difference in leaf numbers between treatments was not deemed to be statistically significant at the 5% probability level.

Table 4.1 The effect of night break (NB) treatment on the initiation and development of the inflorescence in *Hedychium coronarium* after 16 weeks of treatment.

Photoperiod	Days to pseudostem neck swelling		Days to anthesis		plants flowered	
	Range	mean	Range	Mean	No.	%
Long daylength (NB)	53 – 73	64	85 – 110	98	6	60
Natural daylength	-	-	-	-	0	0

Table 4.2 The effect of night break (NB) treatment on the inflorescence characteristics and the number of leaves subtending the inflorescence of *Hedychium coronarium* after 16 weeks of treatment.

Photoperiod	Bracts		No. of flowers		Inflorescence length (cm)		No. of leaves subtending inflorescence	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Night break (NB)	9 - 12	11	16 - 42	29.3	14 - 20	17.3	12 - 14	12.8
Natural daylength	-	-	-	-	-	-	-	-

Table 4.3 The influence of night break (NB) treatment on pseudostem length and the number of leaves unfurled in *Hedychium coronarium* after 16 weeks of treatment.

Photoperiod	Mean pseudostem length (cm)	Mean no. of leaves unfurled[a]
Long day (NB)	122.9	7.5
Natural daylength	101.8	6.2
Significance[z]	P≤ 0.005	NS

[a]Leaves unfurled, the number of leaves unfurled after the commencement of NB treatment
[z]NS, Nonsignificant at p ≤0.05

4.5. Discussion

The natural daylength, which ranged from 10.57 hours from the start of the experiment to 12.06 hours at its termination (mean of 11.10 hours) could not stimulate floral induction in *Hedychium coronarium* (Table 4.1). The night break (NB) treatment elicited floral induction response in plants on which the treatment was imposed. This confirms the result of the previous research in Chapter 3 where long day treatments of 13 and 14 hours induced flowering in the plants, while daylengths of 12 hrs and less did not. *Hedychium coronarium*, by virtue of its positive floral response to both day extension and NB treatment, can be termed a long-day response plant.

The flowering percentage of 60% in the current experiment is similar to the 50% obtained for daylength extension treatment in the previous experiment reported in Chapter 3. The days from commencement of treatment to first anthesis of 85 days compare well with the 81 days (Table 3.1) reported in the previous experiment in Chapter 3. Though the range of 85 - 110 days is 17 days beyond that reported in the Chapter 3 experiment (81 – 93), it is still considered comparable. This is because even within same treatments, it has been observed that the range for anthesis can vary as much as 30 days in *Hedychium coronarium*. Besides, only 3 plants accounted for the result in the earlier experiment (Chapter 3), while 6 plants, accounted for that of the latter study. Hence a greater chance of variability in the latter result.

A lot more flowers were produced in the current experiment (Mean of 29.3) than in the previous experiment (Mean of 18.7). The reason may be that the plants used in the current experiment were second generation plants derived from well-established mother plants.

These plants had good assimilate reserves and hence developed bigger pseudostems (data not shown) and were very vigorous in growth and able to support more flowers of an inflorescence. On the other hand plants used in experiment 3 were first generation plants (derived from single piece rhizomes) with probably less assimilate reserves which could not support vigorous growth and large number of flowers in an inflorescence. Light intensity in the light phase, was also greater in the latter study, since treatment plants received at least 10.57 hours (minimum daylength during the experiment) of sunlight. Treatments in the earlier experiment in Chapter 3, were limited to only 8 hours of sunlight in the natural light phase.

Results from this experiment indicate that NB treatment of 3.5 hours given between 11.30 pm – 3. 00 am from source light of two 100-watt incandescent lamp 1.5 m apart and 1.65 m above pots for 9 weeks (time from start of treatment to pseudostem neck swelling), could elicit floral induction in *Hedychium coronarium*. The information is of practical importance because growers can use the NB treatment to extend production into the traditionally off-season period.

CHAPTER 5. EFFECT OF PACLOBUTRAZOL DRENCH ON HEIGHT CONTROL OF HEDYCHIUM CORONARIUM

5.1 Abstract

H. coronarium was subjected to 5 levels (0, 2, 4, 8 and 16 mg a.i./pot) of paclobutrazol drench. All the treatments exhibited suppressive activity on height of the plants when compared to the non-treated control. The final pseudostem length ranged from 87.5% of the non-treated control for the 2 mg a.i./pot treatment plants to 63.4% for the highest concentration of 16 mg a.i./pot. The best treatment was 4 mg a.i./pot which was 71% of the control. There was no significant treatment effect on number of plants that flowered or on other reproductive parameters such as time to anthesis and flower number.

5.2 Introduction

Field grown *Hedychium coronarium* can attain heights of up to 2 m. (Schilling, 1982). To produce a compact container grown plant, an effective control of plant height is essential. Chemical control of plant height has been achieved for many herbaceous and woody species (Sachs and Hackett, 1972). According to McDaniel (1983), paclobutrazol has shown great effectiveness in growth controlling activity in a wide range of agronomic and ornamental plants. This experiment was undertaken with the objective of determining which rate of paclobutrazol drench would be effective in controlling the height of *H. coronarium*.

5.3 Materials and Methods

The experiment was conducted in a shade house at the Magoon facility of the University of Hawaii at Manoa. On March 10, 1998 *H. coronarium* plants were divided and potted into 8-liter plastic pots. The potting mix was perlite, peat and soil in a ratio of 2:2:1 v/v. The pot mixture was amended with dolomite, Micromax (minor elements) and treble superphosphate at rates of 6.0, 1.0, and 0.6 kg m^{-3}, respectively. Osmocote 18N-2.6P-9.9K (Grace Sierra and Co.) was applied as a top dressing at the rate of 429 g m^{-3}. Plants were irrigated twice daily with microsprinkers, at the rate of 600 ml per pot per day. Gaviota Foliar 60 (Brewer Environmental Industries, Honolulu, HI) fertilizer of nutrient content 240N-105P-200K ppm was applied to plants once every 3 weeks.

After plants had established well and developed a fairly good root system and growth, 35 pots with healthy, fairly uniform plants were selected on April 5, 1998. The pseudostems with more than 3 leaves were cut off leaving only single a pseudostem with 1 – 3 fully expanded leaves. The pots were divided into 5 groups of 7 pots each. Four treatments of paclobutrazol drench were imposed. One group was designated the control and received no paclobutrazol drench. The remaining groups were subjected to one of the following paclobutrazol drench levels: 2, 4, 8 or 16 mg a.i./pot. The drench was applied as 120 ml of solution to the pot media.

There were 7 replicates per treatment with each replicate being one pot of one plant. The treatments were placed on a bench at a spacing of 7 pots m^{-2} under a 30% shade. The experimental design was completely randomized. The initial number of leaves per pseudostem, the length, neck and base diameter of pseudostem were recorded fortnightly

until the termination of the experiment on August 5 1998. Pseudostem length was measured from surface of medium to the junction of the youngest expanded leaf and its leaf sheath. Base diameter of pseudostem was measured at the rim of the pot. Neck diameter of pseudostem was measured at the junction of the youngest expanded leaf and its leaf sheath. A leaf was defined as a fully expanded leaf with leaf length 10 cm and greater.

Other data recorded were number of plants that flowered per treatment, days from treatment to anthesis, number of bracts, number of flowers per inflorescence, and length of inflorescence. Inflorescence length was measured as the distance from the junction of the youngest expanded leaf and its leaf blade to the tip of the uppermost bract.

Hedychium coronarium pseudostem height was regressed against paclobutrazol concentration using a modified power function (Kawabata and Defrank, 1994) using SAS GLM and NONLIN procedures (SAS Inst., 1990). The dose response relationship between the other growth and reproductive parameters and paclobutrazol concentration was subjected to regression analysis using SAS linear procedures.

5.4 Results

The pseudostem length of *Hedychium coronarium* declined asymptotically with increasing concentration of paclobutrazol (Fig 5.1) yielding a dose response equation of $Y = (1.079*10^{-11} + 1.098*10^{-11} X)^{-0.168}$; where Y is pseudostem length in cm and X is concentration of paclobutrazol in mg a.i. All treatment levels suppressed pseudostem length. The final pseudostem length of the 2 mg a.i./pot treated plants was 87.5% of the non-treated control with the 4 and 8 mg a.i./pot being 71% and 69.5% respectively. The

greatest dwarfing effect was in response to the 16 mg a.i./pot which had a final pseudostem length of 63.4% of the control (Table 5.1).

The paclobutrazol growth suppressing activity was in effect within 2 weeks of commencement of treatment. This was evidenced by the much reduced length increment of all the treatments as compared to control (Fig 5.2). Length increment of treatments ranged from 54% to 22% of control within the period. The greatest period of stem elongation was from start of treatment to 4 weeks after treatment. This period also witnessed the most effective growth retardation activity of paclobutrazol. By the end of the 4th week, the range of length increment of treatments was 11% to 43% of the non-treated control.

Persistence of paclobutrazol appears to have lasted for close to 12 weeks for concentrations of 4 mg a.i./pot and higher. The retardation effect started waning thereafter. For the 2 mg a.i./pot treatment, persistence seems to have lasted for about 9 weeks. Mean number of leaves for the treatments ranged from 13.9 to 14.7 (Table 5.1), however, there was no consistent trend. There was no treatment effect on base diameter of the pseudostem. However, pseudostem neck diameter showed a trend towards decreasing size with increasing concentration but that was not statistically significant (Table 5.1).

The mean time from start of treatment to anthesis was between 96.7 – 102 days (Table 5.2). Regression analysis revealed no significant treatment effect. The effect of the growth retardant on other reproductive parameters is summarized in Table 5.2.

Table 5.1 Effect of paclobutrazol drench on the final length, neck and base diameters and the total number of leaves of the pseudostem of *Hedychium coronarium* at the end of 17 weeks of treatment.

Drench level (mg a.i./pot)	Length of pseudostem (cm)	% of control	Total no. of leaves	Neck diameter (cm)	Base diameter (cm)
0	69.6		14.7	0.8	1.3
2	60.9	87.5	14.6	0.7	1.2
4	49.4	71.0	13.9	0.7	1.3
8	48.4	69.5	14.6	0.6	1.4
16	44.4	63.4	14.0	0.6	1.4
significance[z]					
L[y]			NS	NS	NS
NONLIN	P[x]				

[z]NS, Nonsignificant at $p \leq 0.05$
[y]L = linear
P[x], the model accounted for 57 % of the variation in the dependent variable (pseudostem length)

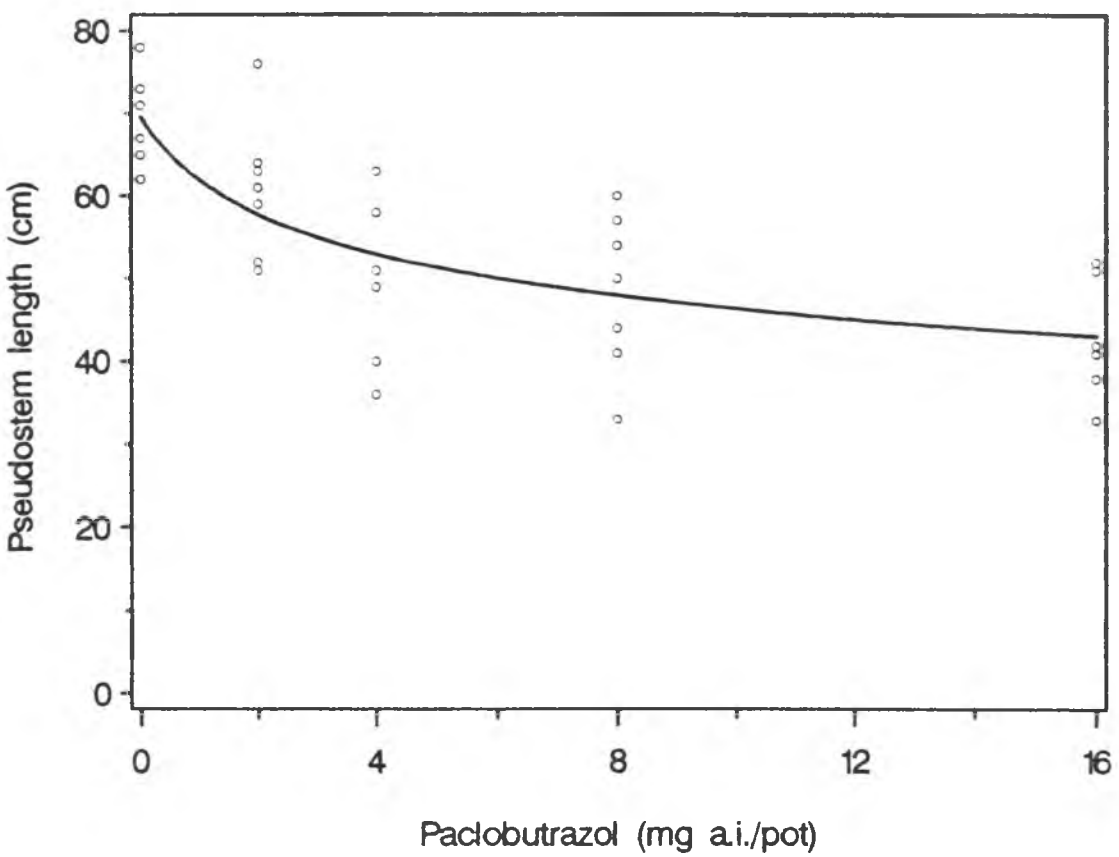

Figure 5.1 Computer generated model of final pseudostem length of *Hedychium coronarium* in response to paclobutrazol drench. The response was regressed with a modified power function.
Pseudostem length (Y) in cm = $(1.079*10^{-11} + 1.098*10^{-11}X)^{-0.168}$

Table 5.2 The effect of paclobutrazol drench on flower initiation, development and other inflorescence characteristics of *Hedychium coronarium*, at the end of 17 weeks of treatment. There were 7 plants per treatment.

Drench level (mg a.i./pot)	No. of plants flowered	Days to anthesis	Inflorescence length (cm)	No. of bracts	No. of flowers
0	4	100.5	8.3	8.3	8
2	4	99.3	8.5	8.3	9.8
4	4	102	10	8.3	9.8
8	3	98	10	7	13.3
16	3	96.7	9	8	4.7
significance[z]					
L[y]	NS	NS	NS	NS	NS

[z]NS, Nonsignificant at $p \leq 0.05$
[y]L = linear

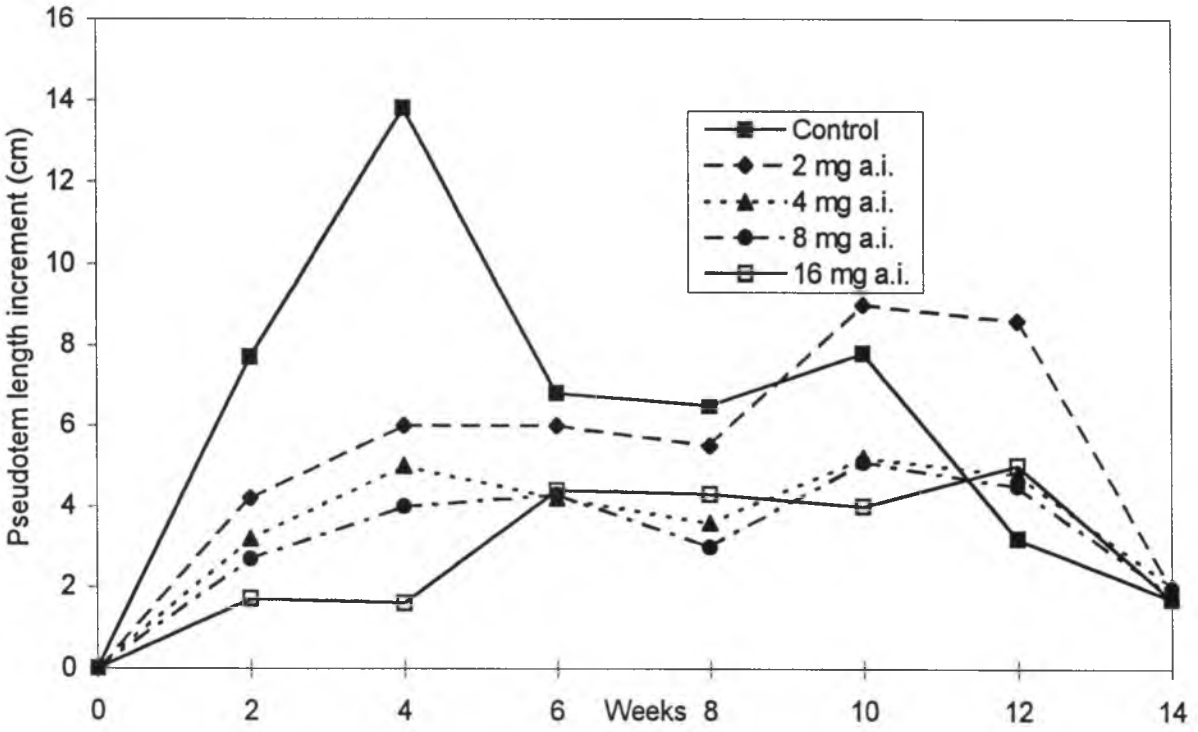

Figure 5.2 Fortnightly length increment of *Hedychium coronarium* pseudostem in response to different levels of paclobutrazol drench.

5.5 Discussion

The asymptotic response of pseudostem length to paclobutrazol is typical of plant growth response to growth retardants (Deyton et al., 1991; Kawabata and DeFrank ,1993, 1994). For concentrations greater than 4 mg a.i./pot, the response of pseudostem length to increasing paclobutrazol concentration was saturating. A two-fold increase from 4 mg to 8 mg a.i./pot in retardant concentration yielded only a 2% reduction in plant height over the 4 mg treatment plants; whilst a 4-fold increase to 16 mg a.i./pot yielded only 10.7% reduction.

Growth retardant treated plants showed short internodes retardation effect with severity increasing with increasing retardant concentration. The highest concentration of 16 mg a.i./pot produced plants with the pseudostem neck bent downwards. The malformation was more evident when plants resumed elongation as a result of weakening in suppressive activity of the retardant and compromised the visual appeal of the plants.

Paclobutrazol treatment did not affect leaf number (Table 5.1). This may be due to the fact that retardation of pseudostem length in this instance, was largely the impact of retardant on cell expansion rather than on cell division. This is consistent with earlier reports, that inhibitors of gibberellin biosynthesis have greater effect on cell expansion than on cell division at the shoot apex (Britz and Saftner, 1987; Nitsche et al., 1985).

Leaves of treated plants appeared darker green than the control in agreement with observations of Tukey (1981), Wample and Culver (1983), and LeCain et al. (1986). Archbold and Houtz (1988), reported increased leaf chlorophyll per unit area for paclobutrazol treated strawberry plants as compared to control. This may be the reason

for the intense greening of treated plants. However, confirmation of the result could not be made in the present work since no chlorophyll measurement was undertaken.

Flowering was not significantly affected by paclobutrazol treatment (Table 5.2). The number of plants that flowered were 3 out of 7 (43%) for the two highest concentration treatments (8 and16 mg a.i./pot), while there were 4 out of 7 plants (57%) for the lower paclobutrazol level and control plants. Likewise paclobutrazol treatment did not have any significant influence on days from treatment to anthesis. This result is similar to that of Corr and Widmer (1991) who observed no significant differences in flowering or days to anthesis of paclobutrazol treated calla lily (*Zantedeschia* spp).

Other reproductive parameters such as number of bracts, number of flowers and inflorescence length were not impacted by paclobutrazol treatment (Table 5.2).

Paclobutrazol drench at 4 mg a.i./pot can be used to produce compact plants adaptable to containerized production without adversely affecting the reproductive capacity of *Hedychium coronarium*.

CHAPTER 6. COMPARISON OF PACLOBUTRAZOL DRENCH AND DIP APPLICATION METHODS ON HEIGHT CONTROL OF HEDYCHIUM CORONARIUM

6.1 Abstract

Drench and pre-plant rhizome dip methods of application of paclobutrazol were compared. Paclobutrazol was applied either as a drench at 2 and 4 mg a.i./pot or as a dip at 16.6 and 33 mg/l to *Hedychium coronarium*. Rhizome dip was ineffective in controlling pseudostem elongation. On the other hand, drench was very effective in suppressing plant height. Pseudostem length of the 2 and 4 mg a.i./pot drench treatments were 62 and 50% of non-treated control respectively. The method and or rate of application did not affect other growth or reproductive parameters.

6.2 Introduction

The problem with many growth retardants has been finding an efficient application method that produces consistent results (Barrett et al., 1994). Commercially, paclobutrazol has been applied to plants in the form of foliar sprays, media drenches or pre-plant bulb or rhizome dips. Spray applications can result in nonuniform plant size if proper techniques are not used (Barrett and Nell, 1990). Generally, media applied retardants are more efficient than foliar sprays. However, unless the moisture status/absorption capacity of the medium is correctly assessed, any excess soil drench solution drips out of the pot and is wasted (Lewis and Lewis, 1981).

Improved efficiency of growth retardant application could reduce cost and minimize pollution and applicator health risks (Sanderson et al., 1994). Pre-plant bulb or rhizome

dips may be more cost effective when compared to drench since the cost of labor and plant growth regulator used was likely to be lower (Corr and Widmer, 1991). Furthermore excess solution, which drips from the bulbs or rhizomes, could be recovered and reused. (Lewis and Lewis, 1981).

The relative effectiveness of the application method is dependent on the plant species. Yahel et al. (1990) reported the superiority of paclobutrazol drench over bulb dip in the height control of narcissus 'Grand Soleil d'Or'. On the other hand, McDaniel (1990) found drench and dip equally effective on height suppression of 'Paul Richter' tulips. The objective of this experiment was to determine which application method, pre-plant rhizome dip or post-plant drench, was most effective in pseudostem length suppression of *Hedychium coronarium.*

6.3 Materials and Methods

This experiment was conducted at the Magoon facility of the University of Hawaii at Manoa. Preliminary results from the experiment described in Chapter 5 were used in this experiment. The two rates, which showed the most effective actions of growth retardation without any deleterious effect, on the *Hedychium coronarium* from the previous experiment, were selected. These rates were then used in the current experiment to determine which method of application, dip or drench, provides the most effective pseudostem length control. The selected paclobutrazol rates were 2 and 4 mg a.i./pot. For each of the selected rate, a drench and a dip solution of equivalent concentration was prepared and used for the respective treatments. The dip equivalent were 16.6 and 33.3 mg a.i/l.

On September 20, 1998, 200 *Hedychium coronarium* rhizome pieces of 5- 6 ins. (13-15 cm) in length were prepared. The rhizome pieces were randomly divided into 5 groups of 40 rhizomes apiece. Two groups were subjected to pre-plant rhizome dip treatments. Each group was soaked in either 16.6 or 33.3 mg a.i./l dip solution. The remaining 3 groups were bulked and soaked in deionized water at room temperature. The dipping time was 30 minutes. Thereafter the rhizomes were removed from solution and kept overnight at room temperature and planted the following day in metal flat trays filled with vermiculite. The two groups that were dipped were kept in separate flats from each other and from the rest, which had been treated with deionized water. The latter groups were however mixed together in other flats. The flats were placed under mist in a shade house (30% shade).

On October 30, 1998, after rhizomes had sprouted and developed a fairly good rooting system (about 6 weeks after planting), 10 plants were randomly selected from each of the dip treated group and potted into 8-liter plastic pots. From the deionized treated group, 30 plants were likewise randomly selected and potted into 8-liter plastic pots. The potting mix was perlite, vermiculite and soil in a ratio of 2:2:1 v/v. The pot mixture was amended with dolomite, Micromax (minor elements) and treble superphosphate at the ratio of 6.0, 1.0 and 0.6 kg m^{-3}, respectively. The plants were placed on benches in the shade house.

After 2 weeks (November 14, 1998) when plants had attained 1- 3 expanded leaves, pseudostems with more than 3 leaves or less than a leaf were cut off leaving a single pseudostem with 1 – 3 expanded leaves per pot. The deionized water treated batch of 30 plants was randomly divided into 3 groups of 10 plants each. Drench treatments were

imposed on two groups. Each group received a drench treatment of either 2 or 4 mg a.i./pot. The drench was applied as 120 ml of solution to the pot media. The third group, which was designated as the control, was drenched with water. The plants were then transferred to a glass house that same day and placed on benches at a spacing of 3 pots m^{-2}.

Treatment design was factorial, two application methods x 2 paclobutrazol levels, with 10 replications. Each replicate was one pot of one plant. The treatments were arranged in a completely randomized design.

The walls and part of the roof of the glasshouse had been painted white so the light intensity reaching plants was about one half that of outside. Plants were drip irrigated automatically with nutrient solution, at the rate of 2000 ml per pot per day. The fertilizer ratio in this irrigation was 200N-0P-223K. To induce plants to flower, long day treatment using night break was commenced on November 28, 1998. The plants were subjected to a night interruption of 3.5 hours daily till visible inflorescence initiation. Plants were lighted from 11.30 pm – 3.00 am, the source of light was two 60 watts incandescent lamp at 3 m apart at 1.65 m above the pots.

The initial number of leaves per pseudostem, as well as the pseudostem length was recorded fortnightly until termination of experiment on March 20, 1999. The initial and final neck and base diameters of the pseudostem were also recorded. Pseudostem length was measured from surface of medium to junction of the youngest expanded leaf and its leaf sheath. Base diameter of pseudostem was measured at the rim of the pot. Neck diameter of pseudostem was measured at the junction of the youngest expanded leaf and

its leaf sheath. A leaf was defined as a fully expanded leaf with leaf length 10 cm and greater.

Other data recorded were number of plants that flowered per treatment, days from treatment to anthesis, number of bracts, number of flowers per inflorescence and length of inflorescence. Inflorescence length was measured as the distance from the junction of the youngest expanded leaf and its leaf sheath to the tip of the uppermost bract.

Data were analyzed by analysis of variance and regression analysis using SAS GLM and PROC REG procedures (SAS Institute, 1990).

6.4 Results

The final pseudostem length of *Hedychium coronarium* was influenced by the application method of paclobutrazol as well as by the rate of application. However there was no interaction between application method and rate (Table 6.1). All the other growth and reproductive parameters measured were neither impacted by the rate nor method of application of the growth retardant (Tables 6.1 and 6.2).

Drench was superior to pre-plant rhizome dip in suppressing the pseudostem length elongation of *Hedychium coronarium* (Table 6.1) Within the drench treatment, pseudostem length declined with increasing concentration of paclobutrazol (Fig. 6.1). The dose response relationship is described by the equation:

$Y = 100 - 13X$; $r^2 = 0.74$. Where Y = length of pseudostem in cm and X is the concentration of paclobutrazol in mg a.i./pot.

The mean number of leaves for the treatments ranged from 15.9 to 17 (Table 6.1). No consistent trend was found regarding influence of method or rate of application on this parameter. Similarly, there was no treatment effect on neck and base diameters.

Only 1 out of 10 plants (10%) flowered per treatment with the exception of the 2 mg a.i./pot drench treatment, where 2 out of 10 plants (20%) flowered (Table 6.2). Analysis of variance did not reveal any significant treatment effect on this parameter. Days to anthesis ranged from 86 – 93 days (Table 6.2). The method and or rate of application of the growth retardant did not significantly impact the parameter. Paclobutrazol application method and or rates did not influence other reproductive parameters, such as number of bracts and flowers as well as inflorescence length (Table 6.2).

Table 6.1 Influence of paclobutrazol application method (pre-plant rhizome dip or drench) and rate of application on final length, number of leaves, neck and base diameters of pseudostem of *Hedychium coronarium.* Data was collected 18 weeks after imposition of light treatment to induce flowering.

Method of application	Rate[b]	Pseudostem length (cm)	% of control	No. of leaves	Neck diameter (cm)	Base diameter (cm)
Control[a]	0	104.6		16.3	0.6	1.3
Dip	17	102	97.5	16.4	0.6	1.5
	33	98.9	94.6	17	0.6	1.5
Drench	2	64.9	62	15.9	0.6	1.6
	4	52.2	49.9	16.5	0.6	1.5
Significance[z]						
Method		0.0001		NS	NS	NS
Rate		0.0093		NS	NS	NS
Method x Rate		NS		NS	NS	NS

[a]Control was excluded from the analysis of variance.
[b]Rate, Units for dip expressed as mg a.i./l and drench as mg a.i./pot.
[z]NS, Nonsignificant at $p \leq 0.05$

Table 6.2 Influence of paclobutrazol application method (pre-plant rhizome dip or drench) and rate of application on several reproductive parameters of *Hedychium coronarium*. Data was collected 18 weeks after imposition of light treatment to induce flowering.

Method of application	Rate of application[b]	No. of plants flowered	Mean days to anthesis	Mean inflorescence length	Mean No. of bracts	Mean No. of flowers
Control[a]	0	1	91	9	18	8
Dip	17	1	93	9	19	10
	33	1	89	9	13	10
Drench	2	2	86.5	10.5	23	10.5
	4	1	86	9	9	9
Significance[z]						
Method	NS	NS	NS	NS	NS	NS
Rate	NS	NS	NS	NS	NS	NS
Method X Rate	NS	NS	NS	NS	NS	NS

[a]Control, Control was excluded from the factorial analysis
[b]Rate, Units for dip expressed as mg a.i./l and drench as mg a.i./pot
[z]Significance, Nonsignificant at $p \leq 0.05$

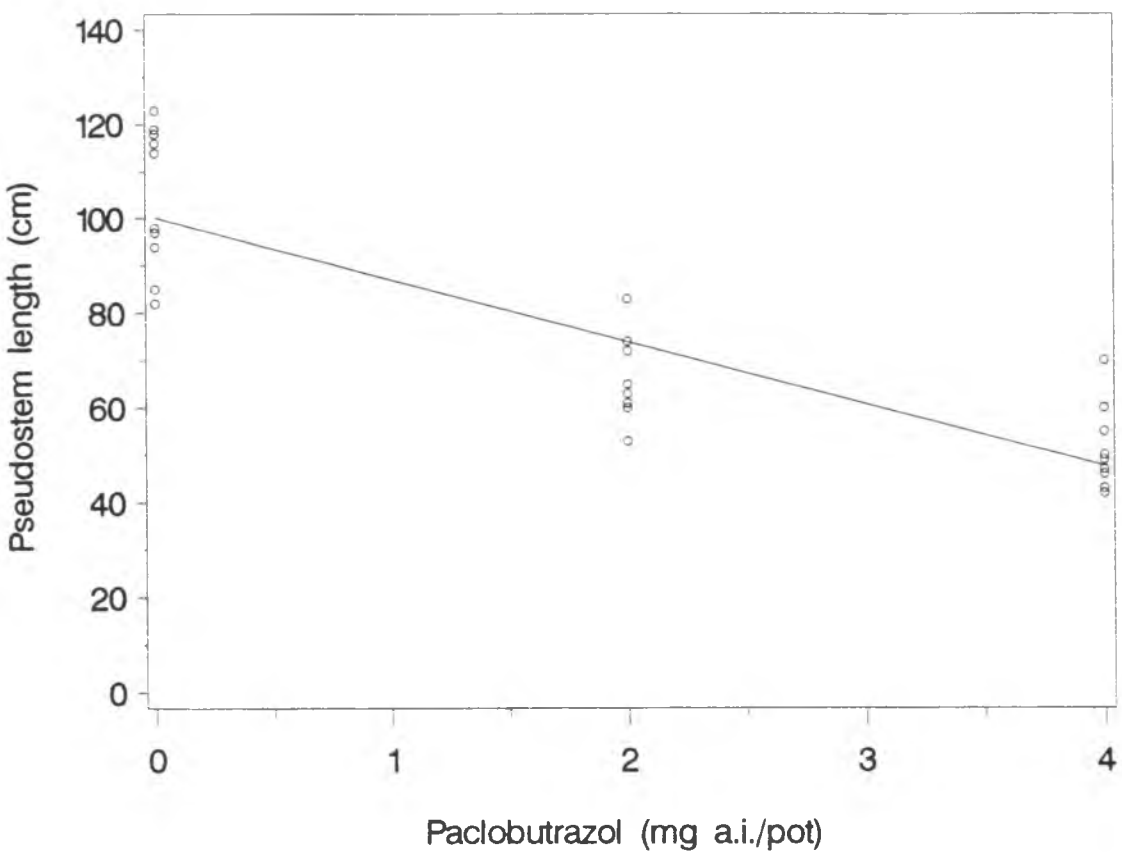

Figure 6.1 The response of *Hedychium coronarium* pseudostem length to paclobutrazol drench applications. The response of the length was regressed to paclobutrazol concentration. Pseudostem length (Y) in cm = 100 - 13X; X is conc. of paclobutrazol.

6.5 Discussion

The effect of paclobutrazol rhizome dip on pseudostem elongation suppression of *Hedychium coronarium* was insignificant (Table 6.1). The final pseudostem length of the highest concentration tested in this experiment (33 mg a.i./l) was 94.6% of the un-treated control, a mere 5.4%pseudostem length reduction over the control. The lower rate (17 mg a.i./l) was 97.5% of un-treated control. On the other hand the drench applications were highly effective in limiting pseudostem elongation (Table 6.1). The 2 mg a.i/pot and 4 mg a.i./pot treatments limited pseudostem lengths to 62 and 50% of non-treated control respectively (Table 6.1). These results are in contrast with those reported by McDaniel (1990). He subjected detunicated bulbs of 'Paul Richter' tulips to either pre-plant bulb soaks for 1-hour in paclobutrazol (2.5, 5.0, 7.5, or 10.0 mg/l) or paclobutrazol media drench treatment (0.25, 0.50, 0.75, or 1.0 mg/pot) in 200 ml/pot aliquots. He concluded that paclobutrazol bulb soaks at 5.0 or 7.5 mg/l for 1hour produced commercially acceptable potted tulip heights that were similar to soil drench treatments.

Perhaps, the effectiveness of height suppression for the bulb dip and soil drench was similar in the reported experiment because the bulb dip concentrations were much higher than those of the drench. They were two fold those of the drench whereas in the current experiment the concentration of the rhizome dip and drench were of similar concentration. Additionally, the longer soak time of 1 hour compared to the 30 minutes in the present experiment could also be a factor.

Other growth variables such as leaf number, neck and base diameter of pseudostem were not influenced significantly by paclobutrazol rate (Table 6.1). These results concur with those of the previous research reported in Chapter 5.

Flowering percentage across treatments including control was generally poor (10 – 20%) (Table 6.2). This may be a result of insufficient light intensity. As indicated in section 6.3 above, plants were lighted by two 60-watt incandescent bulbs spaced 3 m apart and at 1.65 m above the pots. Another experiment installed on an adjacent bench and lighted with two 100-watt bulbs spaced at 1.5 meters apart and 1.65 m above the pots achieved a 60% flowering.

The degree of height suppression achieved by the drench treatments in this experiment was much greater than for treatments of similar concentrations reported in Chapter 5. Whereas the final pseudostem length of the 2 and 4 mg a.i./pot treatments in the present experiment were 62 and 50% respectively of the non-treated control, similar treatments in the previous experiment reported in Chapter 5 were 87.5 and 71% of non-treated control respectively. The highly noticeable difference in response of treatment plants of the two experiments cannot be easily explained because there were too many factors involved. The numerous variables as well as their possible interaction certainly complicates any attempt to interpret the different plant response to the growth retardant.

Firstly, the 2 experiments were conducted under different seasons, the current experiment was conducted between November and May (short days). The previous experiment (Chapter 5) was conducted from April to July (long days). Secondly, the present experiment was conducted in a green house where light intensity, wind, and other

environmental conditions, as well as irrigation, and fertilizer amounts were completely different from those of the previous experiment. The experiment reported in Chapter 5 was conducted under shade house, where apart from the 30% shade, the plants were unprotected from the prevailing weather conditions.

The differing response of plants in the two experiments to similar growth retardant treatment is not unusual. Fisher et al. (1996), observed that, growth retardant efficacy can be affected by a range of environmental conditions, timing, nutrient status and temperature.

CHAPTER 7. CONCLUSION

From the series of experiments conducted the following conclusions can be drawn:

1) Photoperiodic response of *Hedychium coronarium*.

Daylengths of 13 hours or more for 8 weeks provided sufficient stimulus for floral induction. Daylengths shorter than 13 hours failed to induce floral response in the plants. The 14-hour daylength induced greater percentage of flowering in the plants than the 13-hour daylength. This parallels the semi-quantitative response of light–dominant plants to light irradiance and duration (Thomas and Vince-Prue, 1997). Night break of 3.5 hours given from 11.30 pm to 3.00 am for 8 weeks was equally as effective as 14 hour daylengths consisting of 6 hours incandescent lamp light extension of an 8 hour daily natural sunlight for 8 weeks. *Hedychium coronarium* could be classified as a long day plant. Plants are capable of responding to floral stimulus even when pseudostems have only a single fully expanded leaf.

2) Pseudostem length response to paclobutrazol

A paclobutrazol drench of 4 mg ai/pot limited pseudostem length of *Hedychium coronarium* to between 71 and 50% of non-treated control depending on time of season and growing conditions. The paclobutrazol treated plants had the compact appearance desirable for containerized production. Paclobutrazol treatment did not have adverse impact on other growth and reproductive parameters measured. Within the range of concentrations tested, pre-plant rhizome dip was ineffective in suppressing the pseudostem length of *Hedychium coronarium.*

The information generated from the series of experiment conducted would be of practical value in developing *Hedychium coronarium* for pot culture with an all year round flowering ability not limited by seasonality.

Recommended areas for further research

a) I could not establish the critical daylength for the plants; hence, this can be an area of further research.

b) Determination of the minimum number of days or weeks of LD treatment necessary for floral induction.

3) Since *Hedychium coronarium* appears to respond semi-quantitatively to the light integral, it would be interesting to examine the effect of various combinations of light intensities and duration on flowering percentage with the view to identifying the most effective combination. This could be applied to both day extension and NB treatments.

4) To determine whether pseudostems having no expanded leaf would respond to photo inductive floral stimulus. A reasonable amount of samples (at least 10) would have to be collected under photo-inductive conditions for anatomical examination.

5) It appears that the ability of *Hedychium coronarium* to flower is influenced by the size of the pseudostem. An investigation to determine the corelation of pseudostem size (neck, base as well as apex diameters) to flowering might provide some interesting clues.

6) The cost effectiveness of pre-plant rhizome dip over drench method of application, as well as its lower risk of environmental pollution, are too tempting to ignore. It is, therefore, suggested that higher concentrations as well as longer soak times should be evaluated. It may well be that these might yield concentrations, which would effectively

suppress pseudostem length of *Hedychium coronarium.* Paclobutrazol pre-plant bulb dips were effective in suppressing scape length in tulips (McDaniel 1990).

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