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FLORAL BIOLOGY AND COMPATIBILITY STUDIES IN HELICONIA

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DEPARTMENT OF POMOLOGY AND FLORICULTURE
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Dedicated to

My Family

DECLARATION

I hereby declare that this thesis entitled "**Floral biology and compatibility studies in Heliconia**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

Vellayani,
27-06-2006.

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CERTIFICATE

Certified that this thesis entitled "**Floral biology and compatibility studies in Heliconia**" is a record of research work done independently by Mr. Sanjeev, S.J. (2003-12-11) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVATIONS

ANACOVA	–	Analysis of covariance
ANOVA	–	Analysis of variance
CD	–	Critical difference
cv.	–	Cultivar
df	–	Degrees of freedom
et. al.	–	And others
'	–	Feet
Fig.	–	Figure
g	–	Gram(s)
GCV	–	Genotypic coefficient of variation
h	–	Hour
%	–	Percent
PCV	–	Phenotypic coefficient of variation
i.e.	–	That is
µm	–	Micrometre
mg	–	Milligram
viz.	–	Namely
MSE	–	Error mean square
SS	–	Sum of square

Introduction

1. INTRODUCTION

Heliconia belonging to family Heliconiaceae are native to Central and South America, the Carribean Island and some of the islands of the South Pacific. Castro and Graziano (1997) have described the distribution of the heliconia species in Brazil. Their easy cultivation and spectacular presence have made them favourite garden subjects throughout the world. They are mostly grown for flowers and garden adornment. They are particularly desirable as cut flowers because of their long lasting characteristics. There is use of heliconia species for cut flowers and pot plant production (Criley, 1998). Heliconia last in the field for several days without losing their visual appeal and hence the harvesting time can be accordingly adjusted. Major heliconia producing nations include Barbados, Hawaii, Brazil and Venezuela. They are also cultivated in Netherlands and Germany. It is reported that India has an annual production of only one lakh stems which accounts for less than one per cent of the total floral production of the country and the major part of which is from Andhra Pradesh.

Heliconia are hailed as '*The flower crop of tomorrow*'. In most other flower crops of global importance, many new varieties are being released every year in all major growing countries. More over to have competitive value in international and national market novelty is a key factor for which, efforts to improve the existing varieties by releasing new varieties is needed.

A clear understanding of the floral biology of the plant is necessary for undertaking a breeding programme. Selected varieties with good combining ability can be used for further hybridization programme with desirable plant characters. Moreover there is

considerable genetic diversity available, which provides ample scope for intervarietial and interspecific hybridization.

Taking these factors into consideration the present study was undertaken with the objective of studying the floral biology and compatibility of heliconia.

Review of Literature

2. REVIEW OF LITERATURE

Heliconias are tropical plants of princely dimensions grown for their attractive foliage and brilliant flower spikes. There are about 89 species under the genus Heliconia and more than 350 varieties. They are banana like plants with rhizomes or under ground stems having distribution of nutrients and water like the true stems. They are propagated by bits of rhizomes as well as suckers or side shoots arising from the clumps and rarely from seeds (Tom, 1997).

When heliconias were first discovered, they were included in the Musaceae family along with bananas. But now they are included in the family Heliconiaceae. Heliconia is the only genus in the plant family Heliconiaceae, which is a member of a larger taxonomic order Zingiberales coming under the Monocots. There are two main types of heliconias, erect heliconia and pendent heliconia. Erect heliconias stand straight with bracts pointing up. Pendent heliconias hang with bracts pointing down. Their inflorescence have colourful bracts which curve upwards and downwards in alternate patterns along a thick stem (Endre, 1996). There are several characteristics by which they can be recognized, including large leaves and large colourful bracteaic inflorescences. Most taxonomists recognize eight separate families in the order Zingiberales which are Musaceae, Sterilitziceae, Lowiaceae, Heliconiaceae, Zingiberaceae, Costaceae, Cannaceae and Marantaceae.

The Heliconiaceae and Musaceae may be distinguished by characteristics of their lamina anatomy and by the fact that Musaceae blades have an irregular apex (Triplett and Kirchoff, 1991).

This review highlights the research on the various aspects of floral biology and compatibility in heliconias and other crops.

2.1 EVALUATION OF HELICONIAS

Some of the most important species of heliconia are described below.

Heliconia psittacorum

They originated from the Coast of Guyana. The psittacorum (or parrot's beak) heliconias are small, dainty and exotically tropical. It resembles the plant commonly known as Bird-of-Paradise. They bloom throughout the year. The flowers are greenish yellow with black spots near apex. The psittacorums rarely exceed 3'-6' in height. It grows well under tropical conditions (Juan, 1997).

Heliconia psittacorum **cv. Andromeda**

It possesses very attractive reddish-orange to pink bracts. Flowers are very long lasting. It grows up to a height of 4 'to 6'. Broschat et al. (1984) had given the following description about Andromeda. Height ranges from 1.0 to 1.8 m, and it produce 5 leaves/shoot followed by a terminal inflorescence with 3 or 4 bracts. The bracts are red, fading to light orange at their bases. The lower half of each bract and the upper 2 to 3 cm of the peduncle are covered with a waxy white bloom. The florets are orange with black tips and the main axis of the inflorescence is orange.

Heliconia psittacorum **cv. Lady Di**

Lady Di may be the most beautiful among the psiittacorums. It has dark rose red bracts and cream yellow sepals with dark green bands and white tips. Height of the plant ranges from 2'to 3' with an erect habit. It can grow well in full sun and up to 40 % shade. Peak flowering is during April to November (Juan, 1997).

Heliconia psittacorum cv. Choconiana

They bloom throughout the year and produces 4 to 6 orange bracts and orange sepals with distal black bands and yellow white tips. It can grow well in full sun and up to 50 % shade. Height ranges from 1' to 8'.Flowers are long lasting (Juan, 1997).

Heliconia psittacorum cv. Sassy

It is a dwarf variety. Bracts are pale green or cream at base and reddish pink distally. Sepals are orange with distal green-black bands and white tips. It blooms from April to November. It grows up to a height of 3'- 6' and in full sun to 40 % shade (Juan, 1997).

Heliconia psittacorum X *Heliconia spathocircinata* cv. Golden Torch

They have large golden boat-shaped bracts with golden yellow flower. It posses rigid flowers which were produced through the selective breeding for colour, longevity and durable texture. They are larger and sturdier than other psittacorums. Height ranges from 2.5' to 8'. It grows well in full sun to 40 % shade (Alan, 2004). Flower production peaked from July to September.

According to Broschat et al. (1984) Golden Torch plants ranges in height from 1.0 to 1.8 m, and produce 4 or 5 leaves/shoot followed by a terminal inflorescence with 3 or 4 bracts. The entire inflorescence is uniformly orange-yellow in colour. Trials conducted in South-Eastern Florida revealed that under higher dose of NPK application (3.6 kg of 18:6:12 NPK m-2 year-1) flower production was increased up to an average of 84 flowers m-1 year-1. The optimum temperature range for flower production was 210 to 35 ^{0}C. Growing plants under 63 % shade reduced flower production by about 50

%. The post harvest life of cut inflorescences placed in deionised water ranged from 14 to 17 days at 23 ^{0}C.

***Heliconia psittacorum* cv. St. Vincent Red**

It is a very attractive variety similar to Andromeda but without the bract frosting and deep red colour. It produces flowers year round on bright orange-red bracts. It grows to 2.5' to 6' height (Broschat *et al.*, 1984). It is originally from the Island of St. Vincent.

***Heliconia psittacorum* X *Heliconia spathocircinata* cv. Guyana**

These are perennial plants having a height of 1.0 to 1.4 m. It grows well in partial shade. It prefers moist soil. Bracts are wide and stout with orange-red coloured edges. Sepals are light yellow with emerald green tips. Bracts are arranged spirally around reddish-orange peduncle. It blooms throughout the year (Alan, 2004).

Heliconia latispatha

They are the native of Central and South America. The leaves are broad and oblong having 1m length and 30 cm width. It has erect inflorescence with well-separated boat shaped bract, 15 cm long and orange-yellow at base near axis and red towards the tip. They are tropical plants having green flowers (David, 1985).

Heliconia collinsiana

They are robust tropical perennial plants with lush growth. The inflorescence is pendent. The bracts are crimson-red and covered with waxy powder, yellowish towards tip. The flowers are cream in colour (David, 1985).

Heliconia collinsiana X Heliconia bourgena cv. Pedro Ortiz

These are natural hybrids between the pendent *H. collinsiana* and the erect *H. bourgena*. It produces erect inflorescence, but have the tendency to twist and hang down like a pendent. Bracts are pinkish-red coloured. It grows well in partial shade to full sun. Height ranges from 6' to 8' (David, 1985).

Heliconia rostrata

They are beautiful tropical herbs with banana like leathery green leaves, commonly known as hanging lobster claws. It is a native of Peru and generally distributed in tropical America. They have pendent inflorescence of alternating bracts each 6-10 cm long, scarlet red tipped with cream to yellow colour. The bract has deep red colour with yellow green tips, boat shaped. Each inflorescence has 6 to 20 bracts. It grows well at full sun to 50 % shade. Height ranges from 3' to 18'. It blooms throughout the year. It is one of the hardiest varieties (Goel, 2004).

Heliconia stricta

The strictas have exotic inflorescence with colour ranging from red, gold, orange, maroon and green singly or in combination. These exotic tropicals are ideal for small arrangements as their inflorescence range from 5 to12 inches long and are not too heavy (Charleston, 1997).

Heliconia stricta cv. Dwarf Jamaican

It is a small plant growing up to a height of 1.5' – 3'. It grows well in pots. The inflorescence is rose coloured and evenly graded from pale to deep hues. Each bract is ridged with green on its upper edge, matching the tiny green and white-stripped sepals. It blooms throughout the year. Peak

flowering is observed in winter. It adapts to variable temperatures and grows in full sun to 60 % shade (Charleston, 1997). Lekawatana and Criley (1989) studied various aspects such as propagation, general culture, temperature response and the use of growth retardants (ancymidol, paclobutrazol and flurprimidol) in the production programme for Dwarf Jamaican.

***Heliconia stricta* cv. Sharonii**

They have broad foliage, which is borne on stiff red stalks. Flowering starts from late July to February. It grows well at low light up to 80 % shade. It grows up to a height of 3' – 6'. It possesses red and yellow inflorescence that stands erect. The foliage is broad and has red vine colouration beneath it (Charleston, 1997).

Heliconia humilis

They are the native of Trinidad and Brazil. They have shiny green leaves, and erect flower heads. The bracts are boat shaped with salmon red colour changing to green towards tip. It has greenish yellow flowers (Timothy, 1996).

Heliconia wagneriana

These are erect heliconias, similar to *H. humilis*. But they are stouter than *H. humilis*. Their inflorescence is also stouter and paler in colour (Timothy, 1996).

Heliconia wagneriana red

The height of *H. wagneriana red* ranges from 3 to 4.5 m. They possess 5 to 10 red, yellow and green coloured bracts. It takes 10 months to flower and is having vase life of 15 days (Timothy, 1996).

Heliconia wagneriana yellow Peterson

These are erect plants having a height of 3 to 4.5 m. Bracts are 5 to 10 in number and are yellow and green coloured. It takes 10 months to flower and has a vase life of 15 days (Timothy, 1996).

Heliconia bihai

It is commonly known as Wild plantain or Fire bird. It is a large perennial herb having oblong smooth textured pointed green leaves. The bracts are crimson red with pointed tips and arranged in two rows on erect inflorescence (David, 1985).

Heliconia subgenus *Taeniostrobus* is redefined by Anderson (1992). This includes three species plus one placed there provisionally. Four sections are recognized in Heliconia subgenus Heliconia : H. section Episcopales, H. section Heliconia, H. section Tenebria, and H. section Tortex. Two new species are described, *H. darienensis* and *H. nubigena*. Two new combinations are made: *H. albicosta* and *H. undulate* .

The new species of Heliconia *H. fredberryana, H. litana* and *H. lutheri* having colourful, pendent inflorescences are described by Kress (1991). All are herbaceous with Musa -like habit, reaching 6 -7, 2 and 4 m in height, respectively. Also described is the new subspecies *H. obscura* subsp. *dichroma* (4-4.5 m tall). Two new species of Heliconia *H. colgantea* and *H. xanthovillosa* are mentioned by Atehortua and Adams (1992).

2.2 FLORAL BIOLOGY

A thorough understanding of the floral biology is an essential pre-requisite to any breeding programme. This background knowledge is of special significance in the breeding of heliconia.

Heliconias derive their beauty from highly modified leaves or bracts. The flowering bracts may be upright or pendulous depending on the variety and may exhibit the shape of a lobster claw, bird's beak or fan shape. Humming birds and bugs pollinates the flowers. However, some pollen may be carried from one flower to another by insects. These insects are not specialists, they feed from the flower for nectar and pollination rarely occurs. South East Asian heliconias are pollinated by bats (David, 1985).

Watson and Dallwitz (1991) had given the following descriptions about the floral biology of heliconia. Each inflorescence bract contains varying number of flowers upto 15 depending on the species. A small floral bract in turn subtends each flower. The floral bracts of some species are opaque and leathery and persists through fruit development to protect maturing ovaries. In other species they are plumpy and translucent and quickly decompose after the flower close. Flowers are hermaphroditic possessing both male and female sexual parts. Perianth is made up of three outer sepals and three inner petals united at the base and to each other in various phases. When the flower opens, a single sepal become free from the outer perianth part and allows pollinators to enter the flower. The colour of the perianth is species specific. The flowers are open only for a single day after which the perianth falls from the ovary. The flower contains high fertile stamens that produce viable pollens. A sixth stamen is replaced by a sterile stamenoid that does not produce pollen but may function in some species as a guide leading the pollinators tongue to the floral nectaries situated at the base of the style. Anthers are basifixed, tetrasporangiate. Ovary lies below the sepals and petals and can be variously coloured. It is usually smooth in most species, but is hairy in others. Gynoecium

is three carpelled, carpels rhizomerous with the perianth. The pistil is three celled. Placentation is basal to exile and there is one ovule per locule, which is anatropous. The mature fruit of heliconia is a drupe with a hard inner layer enclosing each of the four seeds, which are triangular (1 – 3 per fruit). The outer layer of fruit is fleshy and at maturity the surface layer becomes blue in American species or red to orange in South Pacific species. The colourful fruits are very attractive to the birds and mammals that disperse the seeds.

In heliconia thread-like structures connecting the pollen grains are described by Rose and Barthlott (1995). These threads are decay products of the walls separating the pollen chambers, and products of the rupture of the mature anthers in the stomium region. The pliable cell threads mix with the pollen and entangle individual grains to form aggregates. This ensures that the pollen becomes embedded in the feathers or attached to the smooth, unsculptured beak of pollinating humming birds (Trochilidae).

Six cultivars of *H. psittacorum* were selected by Lee *et al.*(1994) for studies on their natural fruit-bearing ability, pollen formation and pollination under the tropical climatic conditions of Singapore. Three of them, namely Tay, Andromeda and Lady Di, were partially fertile with a very low rate of fruit set, ranging from 2.8 to 4.7 percent. They were found to be diploid with $2n = 24$ chromosomes. The process of pollen formation (microsporogenesis) was normal, and pollen grains were all uniform in size and appeared normal. The poor fruit set of these 3 cultivars was attributed to poor pollen germination on stigmas rather than poor pollination or self-incompatibility. The other 3 cultivars, namely Petra, Sassy and Iris, were completely sterile. Their pollen grains were of variable sizes and appeared to be abnormally fragmented. Over 80 percent of the pollen grains aborted 1-2 days before pollination. These abnormal features were consistent with irregular distribution of chromosomes during meiosis in microsporocytes. All 3 cultivars were confirmed to be triploid ($2n = 3x = 36$).

Length of inflorescence has been pointed out as a character of prime importance in any orchid-breeding programme (Mc Donald, 1991).

2.2.1 Phenology of Flowering

The peak flowering period is from September to December in the first year of planting when planted in January. In the subsequent years it flowers in April and continues upto December. However flowers are produced almost throughout rest of the year. During winter partial shading of leaves occurs and flowering is arrested. The natural flowering season for heliconia species in their natural habitats may be influenced locally by rainfall and drought periods as well as by photoperiod and may not be reliable in indicating production periods elsewhere. With more than three dozen species of heliconia grown and exported in international trade, the seasonality of flowering is important to the supply and marketing of this bold tropical flower (Criley, 2000).

Most of the species of heliconias can be found in moist or wet regions, but some are found in seasonally dry areas. Although heliconias flourish in the humid lowland tropics at elevations below 1500', the greatest number of species is found in middle elevation rain and cloud forest habitats. Many of the heliconia species flourish well at open sites like roadsides, riverbanks and also in patches of light in the forest (Tom, 1997).

Heliconias grow well at a temperature range of 21 to 35 ^{0}C. Plants grown in full sun produce much more flowers than in partial shade. The influence of irradiance on photosynthesis under natural conditions was studied by Jie He *et al.* (1996) using *Heliconia rostrata*, *H. psittacorum* x *H. spathocircinata* cv. Golden Torch and *H. psittacorum* cv. Tay. When grown under full sunlight, all three taxa exhibited reduced photosynthetic capacities and chlorophyll content per leaf area compared with those grown under intermediate and deep shade. In heliconia, the top leaves (particularly leaf tips) experienced sustained decreases in PS II efficiency upon exposure to full sunlight. Although all 3 taxa exhibited sustained decreases in photosynthetic

capacity in full sunlight, the sun leaves of Tay showed higher photosynthetic capacity than those of the other 2 taxa. This could be due, at least in part, to the vertical leaf angle and smaller lamina area. When the upright leaves of Tay were constrained to a horizontal angle, they exhibited lower PS II efficiency, while horizontal leaves of Rostrata and Golden Torch inclined to near-vertical angles showed increased efficiency. Thus, an increase in leaf angle helps to achieve a reduction in the sustained decrease in PS II efficiency by decreasing the levels of incident sunlight and subsequently the leaf temperature.

Geertsen (1989) found that by increasing the minimum air temperature from 15 to 21 ^{0}C, the number of shoots emerging and the number of flowering stems produced per m^2 could be doubled in *H. psittacorum* cv. Tay. Also, stem length was increased and the quality was noticeably improved. Photoperiod had only a slight effect on growth and flowering.

A seasonal pattern of flowering was observed in field production of *Heliconia stricta* cv. Dwarf Jamaican by Criley and Kawabata (1986). This seasonality could be photoperiod-related because greater yields for plants were obtained when grown under 8 hour daylengths for 6 weeks than those plants grown under natural day lengths (about 13.5 h). Depending on the capacity of the plant to respond to photoperiod, 3 or 4 weeks of short daylength (SD) were sufficient for flower initiation. Geertsen (1990) observed that by exposing plants to a photoperiod of 8 hours, flowering was more advanced and more abundant. Raising the temperature from 15 to 21 ^{0}C flowering percentage increased by 20 %; the flowering stems were 40 cm longer and the number of leaves subtending the inflorescence increased by 2.5 cm.

Growth and development of *H. bihai* cv. Lobster Claw One and *H. latispatha* were studied under 3 shade levels (0, 40 and 60 %) for 20 months, during which 5 generations of shoots were developed. Plants without shade produced the maximum pseudostems. The number of shoots per clump was greater in *H. bihai* than in *H. latispatha* .In *H. bihai* the first 3 generations

flowered simultaneously, when the clump reached the age of 12 months. This flowering period lasted 6 months with a peak during March to June, when 95 percent of the flowers developed. In *H. latispatha* flowering began when plants were 10 months old and showed an irregular pattern during the cycle, with the peak (82 %) occurring in July and August (Maciel and Rojas 1994).

Flowering responses of *H. psittacorum x H. spathocircinata* cv. Golden Torch to temperature and photosynthetic photon flux (PPF) were studied by Catley and Brooking (1996) under controlled-environmental conditions. Temperature had no significant effect on new shoot production. An average of 9.3 shoots per plant were produced over the 248 days of treatment. More shoots, however, were produced at the higher PPF level (10.1 shoots, compared with 8.3 shoots at the lower light level). The proportion of shoots that initiated flowers (85%) was similar in all treatments. The time from shoot to inflorescence emergence was significantly shorter at 32/20 ^{0}C than at 24/20 ^{0}C (140 and 146 days respectively) and was unaffected by PPF combination. Acceptable flower quality with at least 2 opened, well-formed, well-coloured bracts was obtained in all treatments. Overall, temperature was more dominant than light in influencing production and quality of flowers. Cut flower production of Golden Torch should be feasible in temperature-controlled greenhouses in temperate regions where mean air temperatures can be maintained at approximately equal to 20 ^{0}C. Although year-round flowering of *H. chartacea* is potentially possible in Hawaii as new shoots develop regularly, flowering is low in the period from late March to early June. Floral initiation occurs after shoot emergence when 4 leaves have unfurled with 2-3 leaves still within the enclosing pseudostem. This places flower initiation in the October-December timeframe for these shoots. In contrast, autumn-winter shoots initiate flowers during January-March and they produce an average of one leaf less than the summer shoots. The greater leaf count and low flowering percentage of spring shoots suggest autumn conditions are favourable for leaf

initiation and unfavourable for floral initiation. An attempt to promote flower initiation during the autumn with light-break lighting was thwarted by disease (*Phytophthora)* according to Criley and Kawabata (1986).

It has been reported previously by Jie He *et al.* (1996) that *Heliconia* cv. Golden Torch leaves grown in full sunlight exhibit a sustained decrease in PS II efficiency as compared to those grown under shade conditions. It was also reported that full sunlight plus low levels of fertilizer application caused a further reduction in photosynthesis, chlorophyll content and F_v / F_m ratio while plants grown at high nutrient levels showed higher values of all these parameters. When plants were grown under intermediate or deep shade, there was no significant difference in any of the parameters irrespective of nutrient supply. In the recovery experiments, plants without fertilizer were refertilized weekly. Maximum photosynthetic rates, chlorophyll content, and F_v / F_m ratio increased gradually after refertilizing the plants grown in full sunlight. However, no significant changes in these parameters were observed in plants grown under intermediate or deep shade over the same period. Total leaf N was measured parallel with all the parameters. Photosynthetic rates, chlorophyll content and F_v / F_m ratio showed a clear linear correlation with total leaf N in plants grown in full sunlight while no clear relationship was observed in plants grown under intermediate or deep shade. These results suggest that high nutrient levels could achieve acclimatization of heliconia under full sunlight.

Heliconias do well at a temperature range of 21 to 35 ^{0}C. Plants grown in full sun produce much more flowers than in partial shade. The influence of irradiance on photosynthesis under natural conditions was studied in Singapore using *Heliconia rostrata*, *H. psittacorum* x *H. spathocircinata* cv. Golden Torch and *H. psittacorum* cv. Tay. When grown under full sunlight, all 3 taxa exhibited reduced photosynthetic capacities and chlorophyll content per leaf area compared with those grown under intermediate and deep shade. A marked decrease in the

chlorophyll fluorescence F_v / F_m ratio and an increase in photochemical quenching (1 - q p) and non-photochemical quenching (q N) were observed in upper leaves of plants grown under full sunlight. Increases in q N suggest that 'photoinhibition' (decreases in F_v / F_m) in heliconia grown under natural tropical conditions are probably due to photo protective energy dissipation processes. Quantum yield, maximum photosynthetic rate, F_v / F_m and chlorophyll content of upper leaves were lower than those of lower leaves on the same plants grown under full sunlight. Similarly, lower values were obtained for the tip (sun) portion than for the base (shaded) portion of the leaves. The changes in F_v / F_m and in the levels of (1 - q p) in leaves grown under intermediate and deep shade were negligible in plants during the course of the day. However, there was a steep decrease in F_v / F_m and an increase in the levels of (1 - q p), along with an increase in incident light in the sun leaves. The lowest F_v / F_m and the highest level of (1 - q p) indicated minimum PS II efficiency at midday in full sun. These results indicate that, in heliconia, the top leaves (particularly leaf tips) experienced sustained decreases in PS II efficiency upon exposure to full sunlight. Although all 3 taxa exhibited sustained decreases in photosynthetic capacity in full sunlight, the sun leaves of Tay showed higher photosynthetic capacity than those of the other 2 taxa. This could be due, at least in part, to the vertical leaf angle and smaller lamina area. When the upright leaves of Tay were constrained to a horizontal angle, they exhibited lower PS II efficiency (F_v / F_m ratio), while horizontal leaves of Rostrata and Golden Torch inclined to near-vertical angles showed increased efficiency. Thus, an increase in leaf angle helps to achieve a reduction in the sustained decrease in PS II efficiency by decreasing the levels of incident sunlight and subsequently the leaf temperature (Jie He *et al.*, 1996).

Criley *et al.* (1999) reported that although heliconia is a tropical genus, many species exhibit seasonal patterns of flowering. Some cases have been attributed to seasonal rainfall, but research has demonstrated that *H. wagneriana and H. stricta* cv. Dwarf Jamaican are short day (SD) species while

H. angusta initiates its flowers during long days (LD). *H. stricta* cv. Dwarf Jamaican initiates its flowers when its pseudostem has 3 unfurled leaf blades. Anthesis is reached 15-19 weeks after the beginning of SD. *H. angusta* initiates its flowers when daylengths exceed 13.3 h and requires 15-17 weeks of long days to reach anthesis. Grower shipping records have been used to identify other species with marked seasonality. Criley (2000) reported that the natural flowering season for heliconia species in their natural habitat may be influenced locally by rainfall, drought periods as well as by photoperiod. Strong seasonal flowering patterns were reported in *H. angusta*, *H. bihai*, *H.carribea* x *H. bihai*, *H. collinsiana*, *H. lingulata*, *H. rostrata*, *H. stricta* and *H. wagneriana*

It has previously been reported that *Heliconia psittacorum* cv. Golden Torch leaves grown in full sunlight exhibit a sustained decrease in PS II efficiency as compared to those grown under shade conditions(Jie He *et al.*, 1996).

Pattenshetty and Prasad (1972) from a detailed study of flowering pattern of the prostate type of cardamom under Mudigree conditions have stated that premonsoon showers encouraged the growth of panicle considerably. On these panicles, flowers started appearing from May onwards. Nearly 75 percent of the flowers were produced during the month of June to August. The total duration of flowering was six months from May to October. But, Parameswar (1973) and Parameswar and Venugopal (1974 a) reported that under Mudigree conditions, flowering was observed throughout the year on the panicles of current year as well as of the previous year. The buds required about 31 days from initiation to full bloom.

2.2.2 Morphological Studies

Detailed study of the morphological characteristics of heliconia helps in understanding the variability that exists among them. It also helps in the identification and classification of varieties.

Appreciable variation in vegetative and floral morphology was recorded in the population of single and double types of tuberose by Nambisan and Krishna (1983).

Nazarenko (1985) studied the floral morphology of oil-bearing rose types and observed greatest variation for number of flowers per plant. Slightly less variation in flower weight, the frequency of double flowers and essential oil content was noticed.

Tisdale *et al.* (1985) reported that plant height can be used as an index of plant growth and also distinguishing between varieties.

Komarova and Shasilova (1988) studied the morphological diversity occurred in *Anethum graveolens* belonging to eleven geographical regions of USSR and observed specific variation in leaf size, length and number of terminal segments of the leaves and in the structure of the seed and inflorescence.

Baghdadi *et al.* (1989) recorded inter and intra specific variation in morphological characters of the leaves, spines, flowers and in plant height of *Lycium schweinfurthis* and *L. shawii.*

Jagadev *et al.* (2001) observed a lot of variation in relation to plant height, colour of stem and inflorescence, leaf sheath and node in palmarosa.

2.2.2.1 Anthesis

According to Croat (1980) the modes of flowering behaviour had a direct influence on pollination biology and thereby on evolution. The processes related to anthesis varied with species and environment.

According to Synge (1947), anthesis refers to the flower opening, which brings about exposure of anthers and stigma to pollen vectors.

Berry and Kress (1991) has reported about *Heliconia solomonensis* in which the flowers are opening in the evening and at night.

Shankar *et al.* (1981) has described the sexual polymorphism in cardamom and have reported about a plant, which has non- opening flowers.

In Dendrobium, days to first flower opening from inflorescence emergence is primarily decided by the length of inflorescence and its rate of growth (Rani, 2002).

In *Annona reticulata* (Farooqi *et al.*, 1970) and in Bhindi (Mishra and Singh, 1988), the anthesis and anther dehiscence are favoured by low temperature of the day.

Pattanshetty and Prasad (1972) reported that, in cardamom three petals which enclose the labellum started separating at 4.30 a.m. From 5 to 6 a.m the folded labellum started stretching out to bloom into a full flower. Anthesis started soon after this and longitudinal splitting of anthers followed by release of pollen took place. By 9 a.m anthesis was completed. Parameswar (1973) reported in cardamom that maximum number of flowers opened during early hours of the day (6 to 8 a.m). Anthesis declined but continued for further six hours, while no anthesis was observed between 2 and 6 p.m. Parameswar and Venugopal (1974 a) reported that the flower buds of cardamom remain compact till the day of opening. The buds take a dome shape before the locus of the corolla start straightening up slowly followed by the straightening of the labellum. The full opening of the flower takes about 3 h. Anthesis commenced between 3.30 and 4.30 a.m and continued till 7.30 a.m and the peak anthesis was between 5.30 and 6.30 a.m. The dehiscence of anthers took place at 3.30 a.m and continued upto 7.30 a.m, with maximum bursting between 5.30 and 6.30 a.m. After 7.30 a.m there was no dehiscence. Jose (1980) reported that cardamom flower opening started by 4 a.m and attained a peak at 7 a.m in the Vandiperiyar region of Kerala.

Christenson (1992) in *Stelis argentata,* reported that in summer weather, new flowers opened primarily in the mornings and during rainy weather, in the late afternoons.

Mercy and Dale (1994) reported that in *Anthurium andreanum,* anthesis occurs on sunny days between 8 to 10 a.m and on cloudy and rainy days anther dehiscence is delayed. Sindhu (1995) observed that the interphase was prolonged with the suppression of male phase from March to August.

2.2.2.2 Stigma receptivity

Studies of Devi and Deka (1992) revealed that the stigma remained receptive for four consecutive days following anthesis in *Spathoglottis plicata,* for five days in *Aerides odoratum,* for six days in *Dendrobium amoenum* and for twelve days in *Phaius tankervilleae.*

2.2.2.3 Pollen Studies

Successful hybridisation in heliconia depends upon factors such as pollen viability. A brief summary of the review of salient research findings on these aspects is presented below.

The pollen in orchids forms compact, waxy masses termed pollinia, which is an important character for orchid taxonomy (Dressler, 1981). Two pollen masses or pollinia are contained in a cavity known as clinandrium and covered by a deciduous operculum(anther cap). The pollinia occur as two notched pollinia in *Vanda* to four pollinia applied to each other in pairs in *Arachnis, Phalaenopsis, Aerides, Renanthera* and *Angraceum* (Abraham and Vatsala, 1981).

Moore and Webb (1978) reported that the pollen in Orchidaceae are found as polyads. Individual pollen grains of the group are tightly pressed together in such a way that their outlines become angular.

Sheehan and Sheehan (1979) reported that the pollen in Orchidaceae is not powdery as in most angiosperms but agglutinated into masses called pollinia. Depending on genus, two to eight pollinia occur per flower. Abraham and Vatsala (1981) observed that pollen in Orchidaceae exists as tetrads. They are held together by means of elastic threads of tapetal origin giving rise to the condition termed mealy or granular and is seen in Neottieae and Epidendreae. In monopodials, pollinial tetrads are organised into many granular packets, prolongations of which form the caudicle. This is the situation termed sectile. In Vandeae, the pollen tetrads are collected into firm masses called waxy pollinia. In advanced subtribes like Oncidinae and Sarcanthinae, they have appendages like the stipe and the viscidium. Johnson and Edwards (2000) reported that cohesive masses of pollen known as pollinia have evolved independently in two plant families *viz.*, Orchidaceae and Asclepiadaceae. Although a single hard pollinium contains more than a million pollen grains, the pollen: ovule ratio in orchids is much lower than in families with powdery pollen. This is sufficient since pollinia ensure the efficient removal of pollen from anther, minimal pollen wastage during transit and the deposition of large pollen loads on stigma to enable fertilization of the large number of ovules in orchid flowers.

Venugopal and Parameswar (1974) have observed the fertility of pollen of cardamom by staining with acetocarmine and taking those that took stain deeply as fertile. The pollen fertility was observed to be the maximum at mid bloom and low at the beginning of the bloom and decreased towards the end of flowering period.

Pollen size was measured using Ocular stage micrometer in Anona by Thakur and Singh(1965).

Venugopal and Parameswar (1974) reported that perfect and mature pollen grains of the three cultivars of cardamom were round in shape and appeared as a creamy powder. The mean size of the normal pollen grain ranged from 85.69 to 104.23 microns. The smallest and the largest pollen were 78.00 and 121.68 microns respectively. Pollen grains of erect type were the largest and that of semi- erect the smallest.

2.2.2.4 Viability of Pollen

Devi and Deka (1992) observed that in terrestrial orchids like *Spathoglottis plicata* and *Phaius tankervilliae*, the pollen viability declined gradually after anthesis whereas in the epiphytic ones like *Aerides odoratum* and *Dendrobium amoenum* it showed an improvement, for three days after anthesis, before getting impaired.

Sobhana (2000) reported a low percentage of pollen fertility in *Dendrobium chrysanthum*.

Rani (2002) reported a high percentage of pollen fertility in *Dendrobium* Candy Stripe x Tomie Drake.

Pattanshetty and Parasad (1972) in cardamom reported that maximum germination of 75 to 90 percent of pollen was observed when the fresh pollen grains were dusted on a medium having 20 percent sucrose and 0.25 percent each of agar and gelatin. Emergence of pollen tube could be seen within 2 h of dusting. They concluded that pollen stored at room temperature lost viability after 24 h. The study was conducted in prostate cardamom variety. Parameswar (1974) reported that, though 85.2 percent of the pollen grains appeared fertile as observed by staining with acetocarmine, maximum

germination in artificial medium containing 20 percent sugar and 1 percent agar was only 70 percent. The testing of pollen viability may be done by their germination *in vitro*. Venugopal and Parameswar (1974) reported that cardamom pollen grain which could not germinate in distilled water germinated in coconut water (28 to 32 %). In 10 percent sucrose solution best result of 65 to 66 percent germination was obtained. Parameswar and Venugopal (1974 b) on an evaluation of the different methods of determining pollen viability in cardamom reported that it can be done either by the germination of pollen in artificial media or by observing fruit setting if six-hour –stored pollen is dusted on the fresh stigma. The acetocarmine method is not a dependable index of pollen viability in cardamom. Parameswar and Venugopal (1974 c) reported that the pollen of cardamom did not germinate in distilled water, but responded well in solutions containing sucrose upto 20 percent. The optimum level for the erect types differed from that of the prostate and semi- erect types. Pollen germination and tube growth were enhanced in all varieties when the solution containing 10 percent sucrose and 200 ppm boric acid is used.

Nair and Mathew (1986) reported that in Vanilla, pollen viability was reduced considerably one day after anthesis. Normal fruit set was noticed following self-pollination just prior to the natural opening of the flower.

2.2.2.5 Anthocyanin Content

Anthocyanin content was estimated in anthurium and based on it the probable spathe colour of five selected parents and their 10 F_1 hybrids have been worked out by correlating the total average anthocyanin content of the spathe of each varieties to the incremental effect of the two anthocyanin producing genes M and O (Mayadevi, 2001).

2.3 AGROTECHNIQUES

Habitats

Influence of habitat on physiological and structural characteristics was investigated by Rundel *et al.* (1998) in North-East Costa Rica in *H. imbricata, H. latispatha, H. pogonantha and H. wagneriana,* occurring in open sites, receiving full sunlight, *H. mathiasiae,* found at the forest edge under partial sunlight and *H. irrasa subsp. undulata and H. umbrophila,* occurring in the forest under storey under deep shade. Light response curves showed a clear gradient with respect to light saturation and rates of maximum net assimilation (A max). *H. latispatha* showed saturation at higher photon flux densities (PFD, 1400 micro mol m^{-2} s^{-1}) and higher A max (14-16 micro mol m^{-2} s^{-1}) than *H. mathiasiae* (PFD 1000 micro mol m^{-2} s^{-1}; A max 7.5-8.5 micro mol m^{-2} s^{-1}) and *H. irrasa* (PFD 250 micro mol m^{-2} s^{-1}; A max 3.5 mol m^{-2} s^{-1}). Leaf blade areas were greatest in open sites, and leaf specific mass was also significantly higher, but leaf support efficiency was highest in under storey species. Species in open sites had thicker leaves with more chlorenchyma, whereas deep-shade species had very thin leaves and low stomatal densities. These rapidly growing herbaceous perennials appear to allocate much of their aboveground biomass to leaf tissues and have a relatively low investment in support tissues, possibly as a result of the presence of belowground rhizomes.

Nursery practices

Heliconias are usually propagated by rhizomes, side shoots and suckers arising from the mother plant. Rhizomes produce both terminal and axillary buds. Therefore each division should contain at least one terminal or axillary bud. Increased interest in tropical cut flower export in developing nations has increased the demand for clean planting stock. Criley (1988)

determined tolerance of heliconia to high temperatures recommended for eradicating nematodes, rhizomes of heliconia survived treatment in 48 ^{0}C hot water for periods up to 1 h and in 50 ^{0}C up to 30 minutes.

Spacing

Heliconias of psittacorum cultivars are traditionally planted at a spacing of 40 x 40 cm for rhizomes. But most other species may require higher spacing. The effect of 2 spacing (20 and 40 cm) and 4 sizes of rhizome (10, 20, 30 and 40 g) on number of inflorescence/m^2, growth and other flower characters of *H. psittacorum* was studied by Lalrinawami and Talukdar (2000) in Jorhat, Assam, India. The wider spacing accounted for taller plants and larger inflorescence. The height of the plant increased with increase in size of rhizome. The 40 g rhizome exhibited the greatest plant height of 116.80 cm compared to 91.77 cm exhibited by the smallest rhizome (10 g).

Performance of two heliconia species (*H. stricta* and *H. rauliniana*) at different spacings (0.58×1m, 1.5×1m and 2×1m) was studied by Ibiapaba *et al.* (1997). The number of inflorescence per plant was highest at 0.5×1m spacing. Lalrinawmi and Talukdar (1999) reported the effects of rhizome size (10, 20, 30 or 40 g) and spacing (20 x 20 or 40 x 40 cm) on the rhizome production of *H. psittacorum* studied in Assam. The largest rhizomes (40 g) and wider spacing (40 x 40 cm) resulted in the highest values for girth, spread, number of rhizomes/clump and rhizome yield/clump. However, the number of rhizomes/m2 and rhizome yield/m2 was higher (343 and 7160 g, respectively) for the closer spacing. Ibiapaba *et al.* (2000) reported that in a field trial in Brazil, *H. psittacorum* cv. Sassy and Andromeda were grown at spacing of 0.50 x 0.25, 0.50, 0.75 and 1.00 m. In all spacings, the first shoots appeared 20-30 days after transplanting and the first inflorescences after about 120 days.

The inflorescences lasted about 14 days. Both cultivars produced the largest number of buds and inflorescences at a spacing of 0.25 x 0.50 m, with Sassy producing more than Andromeda. Treatments did not affect inflorescence length or width. Andromeda showed the best flower stem length at a spacing of 0.50 x 0.50 m, while there was no effect of spacing in Sassy. Flower stems were strong and resistant to handling.

Manipulation of growth and flowering by photoperiodic treatments, growth regulating chemicals etc.

Plants of *H. stricta* cv. Dwarf Jamaican were grown in 10 litre containers under full sun and 50 percent shade for 1 year, and plants of *H. caribaea* cv. Purpurea were grown in an open field for 2.5 years. Rhizomes were soaked for 1 h before planting or plants were sprayed with 30 µM DCPTA [(3,4-dichlorophenoxy) triethylamine] after 2 leaves had emerged. *H. stricta* plants grown under full sun produced more inflorescences than those grown under 50 % shade and DCPTA treated plants grown under shade produced more pseudostems and were taller than control plants under shade. DCPTA treated *H. caribaea* plants produced more pseudostems per plant than control plants during their first year, but differences in the number of pseudostems and inflorescences during subsequent years were not significant (Broschat and Svenson, 1994).

Manures and fertilizers

Heliconias need plenty of water and rich composting during active growing period. Well rotten farmyard manure at the rate of 4 kg/m^2 should be applied at the time of soil preparation and 20 g each of N, P_2O_5 and K_2O/m^2 at the time of planting rhizomes. A top dressing with N 20 g/m^2 is done two months after planting. Containerized plants of *Heliconia psittacorum x H.*

spathocircinata cv. Golden Torch were grown in a greenhouse for 8 months from early summer to winter under selected combinations of N, P, and K. Fertilizer rates ranged from zero to rates that exceeded those reported in the literature by 50-100 percent by Clemens and Morton (1999). Biomass variables (vegetative and inflorescence dry weight, and leaf area) were predicted to be maximized at high N and high N: P, and N: K ratios corresponding to N: P: K application rates of 1.2, 0.5, and 0.6 kg/m3, respectively (approximately equal to 2:1:1). However, the number of shoots and flowers produced per rhizome were highest at lower N: K ratios (1:1). Flower yield could therefore be optimized with appropriate fertilizer application, provided attention was paid to the N: K ratio so that the size of plants and their flowers was not compromised by efforts to increase shoot and flower number. The heavier the rhizome planted, the shorter the time for shoot emergence and flowering to occur, and the greater the number of flowers harvested. However, rhizome weight had no effect on number of shoots to emerge. The probability of shoots flowering declined markedly with order of shoot emergence, although this could be increased with appropriate mineral nutrition. The maximum number of leaves subtending the inflorescence was obtained at high N and P rates. Flower production was probably limited by declining solar radiation in autumn, and by within-plant competition for rooting space.

Harvesting and Postharvesting Technology

The flowers can be harvested with peduncles of 70 cm to one meter length. Harvesting of flowers is done by cutting the entire stalk at the ground level. The cut inflorescence lasts for 2 to 3 weeks. Cutting the flowers before 8.00 a.m. and immediately submersing the cut end in water along with recutting every few days extends their life. Zimmer and Carow

(1977) reported that when cut flowers of *Heliconia sp.* were kept at temperatures between 0 and 12 ^{0}C under reduced pressure, all species stored successfully for at least 4 weeks. According to Bredmose (1987) *Heliconia sp.* inflorescences lasted in water for 2-4 weeks, with no need for additives; vase life was shorter in winter than at other times. Paull and Chantrachit (2001) reported that the vase life of *Heliconia psittacorum* cv. Andromeda, *H. chartacea* cv. Sexy Pink and Red was increased by benzyladenine (BA, 100 mg litre^{-1}), applied as a dip or as a spray.

Insect Pests and Diseases

A few problems related to diseases or pests have been observed so far. However many disease causing organisms have been detected in heliconia plants which might be an indication that they may be acting as alternate hosts for the pathogens.

Cercospora heliconiae was isolated from *Heliconia caribaea* by Chowdhry *et al.* (1983). Bract liquid as a herbivore defense mechanism for *Heliconia wagneriana* inflorescences reducing the incidence of nectar robbing by chewing insects was reported by Wootton and Sun (1990). *Phyllosticta musae [P. musarum], Glomerella cingulata, Alternaria alternata, Gloeosporium musarum [Colletotrichum musae], Guignardia musae, Curvularia sp., Fusarium oxysporum, Mycosphaerella musicola, Drechslera musae-sapientum* and *Pestalotiopsis sp.* were isolated from lesions on leaves and inflorescences of *Heliconia sp.* grown in parks, gardens and indoors in Venezuela by Madriz *et al.* (1991). *Glomerularia heliconii* sp.nov. is described from *Heliconia sp.*, used primarily as an ornamental plant in Cuba by Herrera Isla (1994) .

2.4 COMPATIBILITY STUDIES

A thorough understanding of the compatibility relationships of the genera under consideration is essential for successful hybrid development.

Artificial hybridization among 14 species of neotropical heliconia was studied by Kress (1983) at two sites in Costa Rica. At Las Cruces Tropical Botanical Garden, individuals in cultivation were used as parents in crosses primarily between species with pendent inflorescences that are normally distributed allopatrically. At Finca La Selva normally sympatric species with either pendent or erect inflorescences were crossed in their natural habitats. Observation of pollen tube growth by means of fluorescence microscopy and seed set were used to determine the extent of crossability. Crossability barriers between the majority of species were strong and foreign pollen tubes were inhibited at the stigmatic surface, within the stylar tissue or within the ovary. The site of inhibition was consistent for each pair of species, and depended on the parentage and the direction of the cross. Although additional isolating mechanisms, such as pollinator specificity and phenological separation were present, pre-fertilization crossability barriers acted as the ultimate mechanism to prevent hybridization. The type of barrier (stigmatic, stylar or ovarian) that existed between two species was not dependent upon the geographical distribution of the parental species or the specific types of pollinators that visit them, but in some cases might indicate taxonomic relationships

According to Atehortua (1997) future objectives in breeding of heliconia will include plants adapted to a wider range of environments, smaller size and weight to facilitate transport, different flowering times to allow a year- round market, and longer vase and transportation life.

Number of flowers per inflorescence is a character of prime importance in orchid breeding, as has been pointed out by Kamemoto(1983), McConnel and Kamemoto(1983), Singh (1986) and Mc Donald (1991).

Singh (1982) has pointed out that in orchids, higher order hybrids show increased number of flower per spike. Bobisud and Kamemoto (1982) arrived at the same conclusion that flower production in Dendrobium hybrids was primarily influenced by parental genotypes. Several scientists have reported the inheritance of the character, number of blooms per inflorescence.

Shankar *et al.* (1981) have reported that there are different sex forms in cardamom, which have been evolved through the years of evolution from the purely vegetatively propagated form to completely sexually propagated form. It ranges from partially incompatible to completely compatible form.

Johansen (1990) demonstrated a unique incompatibility system in Dendrobium which also showed high incompatibility in interspecific pollination in contrast to any other orchid genus. Incompatibility response was initiated by auxin content in pollinia. The compatibility substance was specifically recognised by the eleutherocytes produced in the stigmatic mucilage.

2.4.1 Post Pollination Developments / Fruit Development

The high pollen sterility in the hybrids may be due to meiotic abnormalities resulting from the difference in the number of chromosomes. The disorganised disjunction in structurally heterozygous hybrids usually causes less than a full complement of chromosomes to be partitioned to each gamete in the meiotic process, and as a result, many or all gametes are non functional (Allard, 1960).

Post pollination phenomenon in orchids have been studied in detail by Arditti (1979). Working mainly with Cymbidium flowers, he reported the effects of ethylene, excised floral segments, water and dry- weight relations, abscissic acid and effect of auxin, kinetin and gibberellic acid and their interactions. Ethylene causes a number of phenomena in orchid blooms, including anthocyanin formation, fading, shortened flower life and dry sepal. Pollination or emasculation of flowers caused ethylene evolution, in addition to the transformation mentioned, and this can be autocatalytic in Vanda flowers (Arditti,1979 ; Chadwick *et al.*, 1986)

Emasculation of various floral segments in orchids indicated that most post pollination phenomena were controlled by the rostellar-stigmatic region (Arditti, 1966).

Harrison and Arditti (1972) have noted that wilting of sepals, petals and labellum (lip), swelling of the gynostemium (column) which subsequently becomes green and increase in the diameter of ovaries are among the most easily observable post pollination phenomenon in orchid flowers.

From further studies, Strauss and Arditti (1980) concluded that the additional chemical compounds produced by the pollinated flowers or obtained from the pollen were responsible for the changes following pollination in orchids.

Yadav and Bose (1989) and Slater (1991) explained in detail the post pollination phenomena in orchids. It was found to include stigmatic closure, swelling and increase in fresh and dry weights of ovaries and gynostemia, hormone production, new biochemical pathways, synthesis and/or destruction of pigments, deresupination, nastic movements, cessation of scent evolution, breaking apart of pollinia due to tetrad dissociation, progressive dehydration of pollen grains and germination of pollen from the outside of pollinium to the inside. Nadeau *et al.* (1993) observed that the activity of the ACC oxidase which catalyses the conversion of ACC to ethylene increased in

the stigma after pollination. Porat (1994) reported a rapid acceleration of the wilting process following successful pollination in several orchid genera. He also observed that wilting of flowers was accompanied by a loss of moisture from the cells of the upper layer of petals, leading to their upward folding.

Kuwada (1961) reported that the hybrid between *Abelmoschus esculentus* and *A. manihot* was partially sterile and he found that hybridisation between *A. tuberculatus* and *A. manihot* was successful only when *A. tuberculatus* was the female parent but the hybrid was completely sterile.

In a study on inter-specific hybrids of genus *Capsicum* Malhova and Fileva (1969) found abnormal development of embryo and endosperm in crosses between *C. pendulum* and *C. annum* and suggested this as one of the causes for their partial or complete sterility. Kumar *et al.* (1988) reported that crosses between the wild species *C. chacoense* and the cultivated species *C. annum*, *C. frutescens* and *C. chinense* were successful when *C. chacoense* was the female parent, but the reciprocal crosses failed. *C. chacoense* x *C. annum* F_1 hybrids were partially fertile but the other two F_1s were completely sterile. The F_1 plant formed mostly bivalents at meiosis, with a few multivalent and univalent.

In a study on inter-specific crosses of *Lycopersicon* involving *L. esculentum* and *L. chilense*, fruit set ranged from 20 to 59.6 %, although observations 20-40 days after fertilisation revealed abnormal and restricted embryo development, leading to eventual embryo abortion (Gavrilenko and Surikov, 1988). Chen and Imanishi (1991) observed normal seeds in ovules of ripe hybrid fruit from crosses between four *L. esculentum* cultivars and two lines of *L. chilense* or *L. peruvianum* line. However only few ovules had the potential for germination.

Several inter-specific hybrids involving *Solanum melongena* and the wild species *S. indicum*, *S. integrifolium* and *S. surattense*, were produced in the genus *Solanum* by Kirti *et al.* (1984) and found that formation

of twelve bivalent per pollen mother cell was common (2n=24), with some higher chromosome associations. Chiasma frequency was significantly lower in autotetraploids of *S. melongena* var. Insanum, *S. integrifolium* and *S. indicum* than the doubled values of the corresponding diploids. Autotetraploids showed irregular chromosome distribution at anaphase I, and had pollen sterility up to 50 percent. Amphidiploids were partially sterile despite regular chromosome behaviour.

Solanum melongena, S. khasianum and *S. sisymbrifolium* all (2n=24) were intercrossed, with reciprocals and also self pollinated. Pollen germination after 24 hours was more than 95 % in all self pollinated, but ranged from 27.3 to 73 % in the interspecific crosses (Sharma *et al.*, 1984). Singh and Roy (1986) reported that hybrids were produced from the cross *S. melongena* cv. Dorli X *S. surattense* only when the former was the female parent, while the cross *S. melongena* cv. Round Black X *S. surattense* was not successful in either direction. Meiotic analysis of hybrid plants revealed a higher univalent frequency than in the parents and the presence of laggards and chromosome bridges. However the hybrid had good pollen fertility (76.7 %). The meiotic behaviour of chromosomes was studied in inter-specific hybrids of *S. indicum* with *S. incanum* and *S. khasianum* and of *S. melongena* with *S. xanthocarpum* by Narkheda *et al.* (1987). They observed that bivalents were mostly ring shaped in species but in the hybrids, the bivalents appeared to be ring, V and rod shaped. Patil *et al.* (1990) reported that parents and F_1 hybrids between *S. macrocarpon* and *S. melongena* were subjected to cytological examination. It revealed that chromosome pairing was normal in both parents but in hybrids there was occurrence of quadrivalents and chromosome bridges in some cells. Several crosses were made between different *S. aethiopicum* genotypes and tropical varieties of *S. melongena*. Despite sterility problem encountered in the F_1, a recurrent selection scheme involving two backcrosses to *S. melongena* was performed, yielding families with a high level of wilt resistance and a wide range of fruit shape and colour.

Many of the cases of apparent self incompatibility and cross sterility commonly encountered among cultivated orchid hybrids can be attributed to one of the two causes, hybrid sterility or polyploidy (Lenz and Wimber, 1959).

Meshram and Dhapake (1981) reported high pollen sterility in the cross and *Abelmoschus esculentus* and *A. tetraphyllus*. High pollen sterility was recorded in the cross between *A. esculentus* and *A. radiatus* (Meshram and Narkhede, 1981). In interspecific hybrids high pollen sterility was reported in *Gossypium* (Omel'chenko and Abdulker, 1983; Gennur *et al.,* 1986).

2.4.2 Seed Setting

Heliconia fruit is a 1 to 3 seeded drupe, blue or red to orange at maturity. Seed is surrounded by stony, roughened endocarp (pyrenes), embryo is straight and endosperm present copiously (Wanger *et al.*, 1999).

Sauleda (1976) found that the pistillate parent was mainly responsible for determining the harvesting time when crosses were made between orchid parents with different harvesting time. Green capsules of *Paphiopedilum* harvested four months after pollination and that of *Cattleya, Cymbidium, Phalaenopsis* and *Eulophia* harvested eight to nine months after pollination germinated satisfactorily (Rosa and Laneri, 1977). Nagashima (1982) obtained the highest germination in orchid genera such as *Cymbidium goeringii* and *Paphiopedilum insigne* var. Sanderae, when the green capsules were harvested at 115-120 days and 195-200 days, respectively after pollination. Yadav and Bose (1989) considered capsules turning yellowish or brownish as a sign of maturity. Seaton (1994) suggested harvest of seed capsules just a few days prior to the onset of dehiscence, the stage at which seeds will be fully mature and highly viable.

Venkitaraman (1982) reported that for seed setting there is no parthenogenesis in cardamom as the seed setting on 'emasculation and covering' was zero in all the three cultivars studied.

Shankar (1979) has reported on the male cardamom which produces maximum number of flowers without any capsule set. This is because of the female sterility.

2.4.3 Nature of Pollination

Most species of Heliconia that have been tested so far are self-compatible; that is, a flower will produce seed following self-pollination. Seed set by transfer of pollen by pollinator is also seen (Berry and Kress, 1991).

Madhusoodanan *et al.*(1981) reported that although considerable amount of self pollination occur in cardamom by way of geitonogamy, it is principally a cross pollinated, entomophilious crop.

2.4.4 Agent of Pollination

Berry and Kress (1991) reported that Bronzy Hermit, Crowned Wood Nymph Humming Birds and Bats are pollinators of heliconia also some insects (e.g. Earwigs in Hawaii) and vertebrates (honey eater in Australia) are quite agile at transferring pollen especially within a heliconia flower.

Altshuler (2003) has reported that pollination in heliconia is mainly ornithophilous. Nectar feeding bat (*Melanycteris woodfordi*) are pollinator of green heliconia and 'The Bronzy Hermit'- Common Humming Bird (*Glaucis aenea*) and 'Crowned Wood Nymph Humming Bird '(*Thalurania colombica*) are the exclusive pollinators of red, yellow, pink and orange heliconia.

Pattanshetty and Prasad (1972) reported that honeybees are the principle agents of pollination. Bee free panicles had only 11 percent fruit

set as against 50.66 percent in the case of panicles open to bee activity. Parameswar (1973) also reported that insects, especially honeybees, pollinate cardamom. Jose (1980) reported that giant rock bees (*Apis domestica*) are the primary agents of pollination in cardamom and the Indian honeybees (*Apis indica*) are the secondary agents.

Bingham (1897) has described Stingless bees (*Melipona iridipennis*) to be a pollinator in many plants.

Grewal (1993) and Neelakandan (1996) has described Loten's Sun bird (*Nectarina lotenia*) of Family Nectariniidae which is restricted to Western Ghats from South Gujarat to Kerala to be feeding on flower- nectar, insects, spiders etc. which may be a possible pollinator in many plants.

Materials & Methods

3. MATERIALS AND METHODS

The investigation on "Floral biology and Compatibility studies in Heliconia" were carried out in the Department of Pomology and Floriculture at College of Agriculture, Vellayani during 2003-2005. The details regarding the experimental material used, methodology adopted and analytical techniques followed are described in this chapter.

3.1 FLORAL BIOLOGY OF HELICONIA VARIETIES

Floral Biology of 15 *Heliconia* species and varieties was studied to assess their floral characteristics. The experiment was conducted in the Department of Pomology and Floriculture, College of Agriculture, Vellayani, Thiruvananthapuram located at 8.5° N latitude and 76.9°E longitude and at an altitude of 29 m above mean sea level.

Materials

1. *H. psittacorum* L.f. cv. Lady Di
2. *H. psittacorum* x *H. marginata* cv. De Rooij
3. *H. psittacorum* L.f. cv. St.Vincent Red
4. *H. psittacorum* L.f. cv. Petra Orange
5. *H. collinsiana* x *H. bourgena* cv. Pedro Ortiz
6. *H. collinsiana* Griggs cv. Collinsiana
7. *H. psittacorum* L.f. cv. Andromeda
8. *H. psittacorum* L.f. x *H. spathocircinata* Aristeguieta cv. Guyana
9. *H. psittacorum* L.f. cv. Sassy
10. *H. psittacorum* L.f. cv. Pascal
11. *H. psittacorum* L.f. x *H. spathocircinata* Aristeguieta cv. Golden Torch

12. *H. psittacorum* L.f. x *H . spathocircinata* Aristeguieta cv.Alan Carle

13. *H. psittacorum* L.f. cv. Parakeet

14. *H. latispatha* Bentham cv. Distans

15. *H. psittacorum* L.f. cv. Deep Orange

Methods

3.1.1 Phenology of Flowering

3.1.1.1 Number of Inflorescence per Plant per Year

Monthly counts were made for estimating number of flowering shoots for a period of one calendar year. Total number of flowering shoots produced by each plant for one year was recorded and the mean value calculated. The counted plants were tagged for further observations.

3.1.1.2 Flowering nature- free flowering / seasonal

Flowering time was recorded, noting whether blooming occurred round the year or in specific season.

Average flower production per month, the non-flowering months if any and the seasonality of flowering were also recorded.

3.1.2 Emergence of Flower bud

3.1.2.1 Rate of growth of flower bud

Rate of growth of the inflorescence was recorded as per the method suggested by Rajamony and Mohanakumaran (1995a) in cocoa.

Inflorescence from each of the 15 genotypes were marked and labelled for recording the spike, pedicel and bract length. Observation commenced from the date on which the inflorescence just emerged and continued up to the date showing same value for five consecutive days. The

daily mean increase in the spike, pedicel as well as the bract length were recorded.

Morphological Studies

One year old plants in the field were used for taking observations. Observations on the following characters (phenological, quantitative and qualitative characters) of male (fourteen genotypes) and female parents (one genotype) were recorded and their mean values were taken.

3.1.3 Quantitative characters

3.1.3.1 Length of Inflorescence (cm)

Inflorescence length was measured from the junction of pedicel of the top most leaf to the tip of the axis of a fully opened inflorescence. The average of the inflorescence length was recorded.

3.1.3.2 Size of Bracts (cm^2)

The length and breadth of the second bract from base was recorded and the size of the bract was obtained by multiplying length by breadth and the mean calculated. In case of non- floral bracts (leafy bracts) the next bract to the non-floral bract was selected for recording the bract size.

3.1.3.3 Number of Bracts

Number of bracts in each spike was counted and the mean value calculated.

3.1.3.4 Number of Flowers per Bract

Second bract from below was selected as standard for counting the number of flowers per bract. The average was worked out and recorded for all the fifteen varieties.

3.1.3.5 Number of Flowers per Inflorescence

The total number of flowers produced per inflorescence will be noted and their average recorded for each of the fifteen varieties.

3.1.3.6 Number of Days from Emergence to full Opening of Bract

The plants selected and marked by tagging at the bud emergence stage were used for observation of days taken from the emergence to full opening and the number of days were recorded.

3.1.3.7 Number of Days for Full Unfurling of Bracts

The number of days taken from the first bract to last bract opening was recorded.

3.1.3.8 Number of days from first flower opening to last flower opening

Days from first flower opening to the last flower opening in an inflorescence was recorded.

3.1.3.9 Number of days from Emergence to Male phase

The number of days from the emergence of the inflorescence to the male phase was recorded.

The first anther dehiscence in a flower indicated by liberation of pollen grains when observed using 25X hand lens was taken as the initiation of male phase. The days taken from the emergence of inflorescence to male phase was calculated.

3.1.3.10 Duration of Male phase

Time in days for the emergence or dehiscence of the first anther in the first flower to the last anther in the last flower opened was recorded.

3.1.3.11 Number of days from Emergence to Female phase

The number of days from the emergence of the inflorescence to the female phase was recorded.

The number of days from the emergence of the inflorescence to the appearance of the first mature stigma was taken as having reached female phase. The days taken from the emergence of inflorescence to female phase was calculated.

3.1.3.12 Duration of Female phase

The number of days of stigmatic receptivity of the inflorescence, which is the period between the appearance of the mature stigmas in the first opened flower to the last opened flower in an inflorescence, were recorded.

3.1.3.13 Time of Anthesis

Fifteen flowers were tagged from each of the fifteen varieties and observed at one hourly interval for the time of bud splitting. Observations were made during July to September (Rainy season) and January to March (Summer season).

3.1.3.14 Stigma Receptivity

Stigma receptivity was assessed based on adherence of pollen grains to stigma as suggested by Heslop and Shivanna (1977) and Rajamony (1981) and Rajamony and Mohanakumaran (1995b) in cocoa. In this method, anthers from freshly opened flowers were rubbed on to the stigmatic surface. The stigmatic surface was then viewed through a hand lens (25X) to see whether the transfer of pollen has been effected or not. For this purpose fifteen flower buds were marked and divided into three lots of five each. The first lot was collected one day prior to opening and the stickiness of pollen to stigmatic surface was tested. The next lot was collected on the day of opening and the third lot one day after opening.

3.1.3.15 Pollen Studies

3.1.3.15.1 Pollen Morphology (Size and Shape)

Pollen size was measured using ocular stage micrometer as adopted by Thakur and Singh (1965) in Anona.

From fully opened flowers pollen grains were selected and stained in 1: 1 glycerin, acetocarmine solution (2 %). Diameter of ten normal shaped and well-stained pollen grains were measured at random using a standard occular micrometer after calibrating the occular divisions under the high power (10 x 40 X) of a microscope. The mean diameter was recorded in microns.

3.1.3.15.2 Pollen fertility (percentage)

Fertility of pollen grains was determined by the Acetocarmine staining method as adopted by Stanley and Linkens (1974), in cardamom .

3.1.3.15.2.1 Acetocarmine staining method

In Acetocarmine staining technique, pollen fertility was estimated by counting fertile and sterile pollen grains separately in the microscope. Pollen, which was fully stained, was considered as fertile. Unstained, partially stained or shrivelled pollen grains were considered as sterile (Zirkle, 1937). Three slides were prepared and five random fields from each slide were observed in each genotype. Fertility of each variety was estimated as percentage of the number of fertile pollen grains to the number of pollen grains scored.

The pollen fertility was calculated as,

$$\text{Pollen fertility} = \frac{\text{Number of well filled and uniformly stained pollen grains}}{\text{Total number of pollen grains}} \times 100$$

3.1.4 Qualitative Characters

3.1.4.1 Colour of Bract and Blending of Colours

The colour of bract and blending of colours of each of the fifteen varieties was recorded by visual observation when the inflorescence was in the harvest stage for cut flower purpose.

3.1.4.2 Colour of Flower and Blending of Colours

The colour of flowers and blending of colours were noted and recorded. Colour gradation and colour blending in the bracts and the flower were recorded.

Mature flowers were selected from the inflorescence in the harvest stage for cut flower purpose and the colour of flowers and blending of colour were recorded.

3.1.4.3 Estimation of Total Anthocyanin

Estimation of total anthocyanin was done as per the method described by Rangana (1977). The initial step was alcoholic extraction of the plant material (bract).

One gram of the bract sample from each variety was extracted with Ethanolic hydrochloric acid, filtered through a Buchner funnel using Whatman No.1 filter paper and the filtrate was then diluted with Ethanolic hydrochloric acid to 50ml to yield optical range of the Spectrophotometer (535 nm). The anthocyanin content was then calculated using the following relationship and the quantity was expressed as mg per 100 gm of the sample.

Total OD per 100gm of sample (x)= [(absorbance at 535 nm) X (volume made up of the extract used for colour development) X (Total volume) X 100] ÷ [Volume (ml of the extract) used X weight of sample taken].

The absorbance of a solution containing 1 mg of anthocyanin per ml is equal to 98.2 (constant).

$$\text{Therefore, Total anthocyanin in mg per 100 g of the sample} = \frac{X}{98.2}$$

3.1.5 Statistical Analysis

The data collected were subjected to the following statistical analysis for Randomised Block Design after testing the homogeneity of error variances.

Analysis of Variance (ANOVA) technique was used to test the significance of genotypic differences among the selected heliconia varieties. Mean, variance, standard error and coefficient of variation were estimated. The character associations were estimated through correlation coefficients using Analysis of Covariance (ANACOVA) technique (Panse and Sukhatme, 1967).

3.1.5.1 Coefficient of Variation

Phenotypic and genotypic coefficient of variation (PCV and GCV) for a trait x were estimated as

$$GCV = \frac{\sigma_{gx}}{\overline{x}} \times 100$$

$$PCV = \frac{\sigma_{px}}{\overline{x}} \times 100$$

Where,

σ_{gx} = genotypic standard deviation

σ_{px} = phenotypic standard deviation

$\overline{X}$ = mean of the character under study

3.1.5.2 Heritability and Genetic Advance

Heritability coefficient, (H^2) (in broad sense) = $\frac{\sigma_{gx}^2}{\sigma_{px}^2} \times 100$

Allard (1960) classification

<30 percent-Low

30-60 percent –Medium

>60 percent – High

Robinson (1965) classification

5-10 percent – Low

10-30 percent – Medium

>30 percent – High

Genetic advance as percentage of mean (GA) = $\frac{kH^2\sigma_{px}}{\bar{x}} \times 100$

Where k is the selection differential whose value is 2.06 if five per cent selection is to be practiced (Miller *et al.*, 1958).

3.1.5.3 Correlation Analysis

The correlation coefficients (phenotypic, genotypic and environmental) between two characters denoted as X and Y were worked out as follows

Genotypic correlation (γ_{gxy}) = $\frac{\sigma_{gxy}}{\sigma_{gx} \times \sigma_{gy}}$

Phenotypic correlation (γ_{pxy}) = $\frac{\sigma_{pxy}}{\sigma_{px} \times \sigma_{py}}$

Environmental correlation (γ_{exy}) = $\frac{\sigma_{exy}}{\sigma_{ex} \times \sigma_{ey}}$

3.2 COMPATIBILITY STUDIES

Crossing was proposed between one promising genotype of Heliconia with seed set as female parent and fourteen other genotypes used as male parents.

H. psittacorum L.f. cv. Lady Di was used as the female parent.

Fourteen varieties with commercially acceptable qualities were used as male parents.

1. *H. psittacorum X H. marginata* cv. De Rooij
2. *H. psittacorum* L.f. cv. St.Vincent Red
3. *H. psittacorum* L.f. cv. Petra Orange
4. *H. collinsiana X H. bourgena* cv. Pedro Ortiz
5. *H. collinsiana* Griggs cv. Collinsiana
6. *H. psittacorum* L.f. cv. Andromeda
7. *H. psittacorum* L.f. *X H . spathocircinata* Aristeguieta cv. Guyana
8. *H. psittacorum* L.f. cv. Sassy
9. *H. psittacorum* L.f. cv. Pascal
10. *H. psittacorum* L.f. *x H . spathocircinata* Aristeguieta cv. Golden Torch
11. *H. psittacorum* L.f. *x H . spathocircinata* Aristeguieta cv.Alan Carle
12. *H. psittacorum* L.f. cv. Parakeet
13. 13.*H. latispatha* Bentham cv. Distans
14. *H. psittacorum* L.f. cv. Deep Orange

The promising variety with seed set selected as female parent was selfed and crossed with other fourteen selected male parents to study the self and cross compatibility or incompatibility. Compatibility was studied using the percentage of fruit set.

3.2.1 Hybridisation Technique in Heliconia

The female parent was emasculated the previous evening by adopting the clipping method (John, 1980) and protected by covering with butter paper cover. The flowers selected for hybridisation should be mature and opening the next day. The next morning, pollen from the desired male parent was collected and dusted on the receptive stigmatic surface of the emasculated flowers between 4.00 and 7.30 hours. The crossed flowers were then tagged and again protected by butter paper cover. The flowers that have undergone assisted crossing were only retained in the inflorescence, clipping off the others (Plate 1).

3.2.2 Selfing Technique in Heliconia

For estimating the self-compatibility the mature inflorescence was covered using a butter paper cover (Plate 1). Inflorescence were tagged and the butter paper cover was retained till all the flowers in the inflorescence opened.

3.2.3 Pollination Studies

Pollination studies were carried out as per the method adopted by Devar *et al.* (1981) in Moringa.

3.2.3.1 Mode of Pollination

Fifteen inflorescences were merely tagged to assess the percentage of open pollination, second lot of fifteen inflorescences were bagged to assess the extend of selfing. Third lot was emasculated and kept open for assessing the extend of Natural Crossing. The fourth lot was emasculated, crossed and bagged to assess the percentage of fruit set from Assisted Crossing. The last lot was emasculated and bagged to prove the involvement of pollinator in pollination. The flowers were observed after ninety days and the percentage of fruit set was worked out in each case.

Selfing - Bagged inflorescence

Crossing - Cutting of Perianth

Crossing - Emasculation

Crossing - Dusting of pollen

Plate 1. Technique of selfing / crossing in Heliconia

3.2.3.2 Pollinators

Birds visiting the flowers were observed and photographed. The insects visiting the flowers were collected and identified. The photographs of the pollinators were taken.

Results

4. RESULTS

The experimental data were collected on various aspects of floral biology of 15 selected parents (1 female and 14 males) of Heliconia for the present study. The data were statistically analysed and the results obtained are presented here.

Evaluation of genotypes for their performance

The mean performance of each of the fifteen varieties for the sixteen floral characters (Tables 1 and 2) was studied. Analysis of variance revealed significant difference for all the floral characters studied (Appendix I and Plate 2).

4.1 Floral characters

4.1.1 Phenological characters

4.1.1.1 Number of Inflorescence per Plant per Year

The genotype Parakeet recorded the highest number of inflorescence per plant per year (105.34), which was on par with Lady Di (104.00) and Golden torch (91.92). The lowest mean number of inflorescence per plant per year was recorded in the variety Collinsiana (15.83).

4.1.1.2 Flowering Nature- Free Flowering/ Seasonal

Flower production was seen throughout the year for all the genotypes except for Distans with no flower production in the months of February to March. Very low flower production was seen in variety Distans during months of April to May (0.33), January to February (0.83) and March to April (0.83).

The genotype Lady Di recorded the highest flower production per month (21.17) in June to July followed by Andromeda and Parakeet (17.58 each) for the same month (Table 3 and Fig 1).

H. psittacorum L.f. cv. Lady Di

H. psittacorum x *H. marginata* De Rooij

H. psittacorum L.f. cv. St.Vincent Red

H. psittacorum L.f. cv. Petra orange

H. collinsiana x *H. bourgena* cv. Pedro Ortiz

H. collinsiana Griggs var. Collinsiana

Plate 2. Heliconia varieties used for the experiment

H. psittacorum L.f. cv. Andromeda

H. psittacorum L.f. x
H . spathocircinata Aristeguieta cv. Guyana

H. psittacorum L.f. cv. Sassy

H. psittacorum L.f.cv. Pascal

H. psittacorum L.f. x
H . spathocircinata Aristeguieta
cv. Golden torch

H. psittacorum L.f. x
H . spathocircinata Aristeguieta
cv. Alan Carle

Plate 2. Continued

H. psittacorum L.f. cv. Parakeet

H. latispatha Bentham cv. Distans

H. psittacorum L.f. cv. Deep Orange

Plate 2. Continued

Table.1 Floral character differentiation in Heliconia genotypes

Genotypes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lady Di	104.00	44.49	26.6	3.92	10.67	45.08	23.58	15	35.08	17.25	35.08	17.25	35.08	300.75	89.39	58.38
De Rooij	67.50	41.24	28.22	4.42	7.42	28.08	34.58	26.25	42	22.25	42	22.25	42	252	42.66	34.03
St.Vincent Red	58.75	41.44	14.61	4.33	9.58	41.5	18.58	10.67	29.42	18.75	29.42	18.75	29.42	289.5	81.81	35.56
Petra Orange	61.41	48.92	45.15	3.67	4.17	8.58	17.08	7.42	0	0	0	0	0	365.25	32.51	14.94
Pedro Ortiz	18.00	49.45	173.85	7.42	19.25	182.58	23.5	14.33	0	0	0	0	0	300.75	26.55	38.78
Collinsiana	15.83	57.6	133.65	7.75	15.42	110.33	29.17	18.83	47.42	17.75	47.42	17.75	47.42	286.5	28.22	25.29
Andromeda	51.67	52.48	20.03	4.25	7.83	20.67	16.83	7	23.42	16.75	23.42	16.75	23.42	287.25	71.61	27.66
Guyana	61.00	29.87	31.04	4.92	15.42	59.5	28.08	21.08	0	0	0	0	0	288	23.23	18.33
Sassy	46.08	34.92	26.09	5.08	7.67	22.5	31.92	23.33	29.42	30.5	29.42	30.5	29.42	281.25	82.09	14.77
Pascal	29.00	26.95	20.92	5.17	7.33	29.33	22	14.08	49.58	20	49.58	20	49.58	274.5	78.94	8.57
Golden Torch	91.92	52.92	77.91	4.42	15.08	62.83	22.58	12.08	0	0	0	0	0	264.75	44.52	9.08
Alan Carle	59.08	41.67	77.43	5.92	15.5	72.75	40.42	33.25	0	0	0	0	0	283.5	24.92	8.57
Parakeet	105.34	38.48	21.43	4.75	5.92	19	18.75	9.92	29.75	18.5	29.75	18.5	29.75	282	85.14	8.74
Distans	37.92	56.05	70.66	4.5	13.08	95.5	18.92	14.33	25.25	9.5	25.25	9.5	25.25	240.75	84.35	35.05
Deep Orange	54.67	42.35	37.15	2.83	5.5	15.50	20.75	11.5	28.5	19.75	28.5	19.75	28.5	285	79.2	7.47
Mean	57.48	43.92	53.65	4.89	10.66	54.25	24.45	15.94	22.66	12.73	22.66	12.73	22.66	285.45	58.34	23.01
F 14,28	29.17**	37.14**	214.38**	31.62**	569.86**	721.47**	2331.38**	268.91**	529.26**	1075.89**	2331.38**	1075.89**	2331.38**	252.24**	269.90**	1142.63**
SE	1.68	1.5	3.16	0.23	0.193	1.73	0.376	0.426	0.319	0.313	0.376	0.313	0.376	1.73	1.62	0.44
CD	4.88	4.33	9.16	0.67	0.56	5.01	1.089	1.234	0.925	0.906	1.089	0.906	1.089	5	4.68	1.29

1 Number of inflorescence/ plant/Year
2 Length of inflorescence (cm)
3 Size of bract (cm^2)
4 Number of bracts
5 Number of flower/ bract
6 Number of flower/ inflorescence
7 Days from bud emergence to full opening of bracts
8 Days for full unfurling of all the bracts
9 Days from first to last flower opening
10 Days from emergence to male phase
11 Duration of male phase
12 Days from emergence to female phase
13 Duration of female phase
14 Pollen size (μ)
15 Pollen fertility (%)
16 Anthocyanin content (mg/100g)

Table 2. Floral character differentiation in Heliconia genotypes-Rainy (R) and summer (S) season

Genotypes	1		2		3		4		5		6		7		8		9	
	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S
Lady Di	4.81	7.06	44.49	42.71	23.58	24.50	15.00	15.50	35.08	35.25	17.25	18	35.08	35.25	17.25	18	35.08	35.25
De Rooij	2.70	5.00	41.24	39.68	34.58	35.67	26.25	26.92	42.00	42.33	22.25	23	42.00	42.33	22.25	23	42.00	42.33
St.Vincent Red	2.61	6.36	41.44	39.34	18.58	17.92	10.67	11.25	29.42	30.17	18.75	20.5	29.42	30.17	18.75	20.5	29.42	30.17
Petra Orange	4.80	3.31	48.92	48.11	17.08	17.42	7.42	7.83	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Pedro Ortiz	0.72	1.58	49.45	48.52	23.50	24.75	14.33	15.08	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Collinsiana	0.72	0.94	57.60	57.58	29.17	30.42	18.83	19.83	47.42	47.50	17.75	19	47.42	47.50	17.75	19	47.42	47.50
Andromeda	3.03	2.03	52.48	50.64	16.83	17.83	7.00	7.75	23.42	23.58	16.75	17.75	23.42	23.58	16.75	17.75	23.42	23.58
Guyana	4.67	5.03	29.87	29.04	28.08	29.25	21.08	22.00	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Sassy	1.17	4.89	34.92	33.43	31.92	32.75	23.33	23.83	29.42	30.08	30.5	31.75	29.42	30.08	30.5	31.75	29.42	30.08
Pascal	1.03	3.06	26.95	26.39	22.00	22.42	14.08	14.42	49.58	49.92	20	22	49.58	49.92	20	22	49.58	49.92
Golden Torch	5.08	10.14	52.92	51.83	22.58	23.42	12.08	12.50	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Alan Carle	1.80	4.08	41.67	40.98	40.42	41.08	33.25	33.75	0.00	0.00	0	0	0.00	0.00	0	0	0.00	0.00
Parakeet	6.34	8.36	38.48	37.41	18.75	19.33	9.92	10.25	29.75	29.75	18.5	19.75	29.75	29.75	18.5	19.75	29.75	29.75
Distans	6.42	0.55	56.05	54.01	18.92	19.33	14.33	15.25	25.25	25.75	9.5	10	25.25	25.75	9.5	10	25.25	25.75
Deep Orange	3.83	2.00	42.35	41.33	20.75	21.83	11.50	11.83	28.50	29.42	19.75	20.5	28.50	29.42	19.75	20.5	28.50	29.42

1 Number of inflorescence/ plant/Year
2 Length of inflorescence (cm)
3 Days from bud emergence to full opening of bracts
4 Days for full unfurling of all the bracts
5 Days from first to last flower opening
6 Days from emergence to male phase
7 Duration of male phase
8 Days from emergence to female phase
9 Duration of female phase

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Table 3. Phenology of flowering in Heliconia

Genotypes	July-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-July	Average flower /Month	Total flower production/ Year
Lady Di	7.67	2.17	4.58	5.08	5.33	7.67	7.17	6.75	7.25	14.25	14.92	21.17	8.67	104.00
De Rooij	2.50	2.67	2.92	11.08	5.92	2.92	4.92	2.58	7.50	13.92	5.25	5.33	5.63	67.50
St. Vincent Red	1.33	4.17	2.33	2.33	2.25	4.67	3.75	7.00	8.33	4.33	7.17	11.08	4.90	58.75
Petra Orange	4.58	3.00	6.83	7.33	3.33	3.00	4.83	2.42	2.67	7.50	9.33	6.58	5.12	61.41
Pedro Ortiz	0.58	1.25	0.33	2.08	1.50	1.42	3.42	0.25	1.08	2.50	2.00	1.58	1.50	18.00
Collinsiana	0.25	0.92	1.00	1.83	1.25	0.83	0.58	0.92	1.33	2.25	2.17	2.50	1.32	15.83
Andromeda	4.08	2.42	2.58	4.58	1.42	0.25	0.75	0.92	4.42	3.08	9.58	17.58	4.31	51.67
Guyana	4.50	4.00	5.50	5.42	4.25	3.67	3.75	3.58	7.75	10.83	3.83	3.92	5.08	61.00
Sassy	0.75	1.50	1.25	1.00	1.17	1.25	2.33	7.25	5.08	4.75	6.33	13.42	3.84	46.08
Pascal	0.83	0.75	1.50	2.50	1.50	1.67	2.00	2.17	5.00	2.92	4.17	4.00	2.42	29.00
Golden Torch	6.42	3.08	5.75	6.33	4.25	8.75	4.17	12.67	13.58	7.50	9.08	10.33	7.66	91.92
Alan Carle	1.33	1.25	2.83	2.92	5.58	3.50	3.17	4.58	4.50	10.42	15.00	4.00	4.92	59.08
Parakeet	8.42	4.42	6.17	6.50	6.42	7.00	8.08	11.42	5.58	11.50	12.25	17.58	8.78	105.34
Distans	1.33	3.50	14.42	3.17	6.33	1.92	0.83	0.00	0.83	0.33	1.92	3.33	3.16	37.92
Deep Orange	5.58	2.42	3.50	7.75	3.17	4.17	2.50	1.83	1.67	3.58	9.08	9.42	4.56	54.67

4.1.2 Emergence of Flower Bud

4.1.2.1 Rate of Growth of Flower Bud

Genotypes Pedro Ortiz, Alan Carle and Distans took the longest number of days (27) for stabilisation of growth, followed by De Rooij (26 days). Variety St. Vincent Red took the shortest number of days (14) for stabilisation of growth (Table 4 and Fig. 2).

Morphological characters

4.1.3 Quantitative characters

4.1.3.1 Length of Inflorescence (cm)

The genotype Pascal recorded the lowest values of 26.95 cm and 26.39 cm in rainy and summer seasons respectively which was on par with Guyana. The highest inflorescence length was recorded for the genotype Collinsiana, which was 57.6 cm and 57.58 cm for rainy and summer seasons respectively.

4.1.3.2 Size of Bracts

The size of bract was the highest for the genotype Pedro Ortiz (173.85 cm^2) which was significantly different from others. The lowest value for size of bract was for the genotype St. Vincent Red (14.61 cm^2) which was on par with Andromeda (20.03 cm^2), Pascal (20.92 cm^2) and Parakeet (21.43 cm^2).

4.1.3.3 Number of Bracts

The lowest number of bracts per inflorescence was shown by the genotype Deep Orange (2.83) and the highest by the genotype Collinsiana (7.75) which was on par with Pedro Ortiz (7.42).

4.1.3.4 Number of Flowers per Bract

The lowest number of flowers per bract was observed for the genotype Petra orange (4.17) and highest was observed for the genotype Pedro Ortiz (19.25). The genotypes Alan Carle, Collinsiana, Guyana and Golden Torch were on par.

Table 4. Pattern of growth of flower bud in Heliconia genotypes (daily growth in cm)

	Lady Di			De Rooij			St.Vincent Red			Petra Orange			Pedro Ortiz			Collinsiana			Andromeda			Guyana		
Days	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B
1	12.5	6.1	12.5	10.5	9.2	10.5	11	5.6	11	13.7	2.1	13.7	19.9	4.2	19.9	25.1	14.5	25.1	12.1	5.3	12.1	14.4	2.7	14.4
2	12.5	9.7	12.5	10.5	12.3	10.5	11	9.5	11	13.8	7.7	13.8	20.7	4.4	19.9	25.1	15.2	25.1	12.1	9.4	12.1	14.5	6.3	14.4
3	12.5	12.6	12.5	10.5	15.4	10.5	11.2	12.4	11	13.8	12.2	13.8	21.4	4.9	19.9	25.1	15.4	25.1	12.1	15	12.1	15.1	6.7	14.4
4	12.6	16.6	12.5	10.5	18.6	10.5	11.2	15.5	11	13.8	18.2	13.8	22.2	5.7	19.9	25.1	15.4	25.2	12.1	19.9	12.1	14.3	7.8	14.4
5	12.6	20.9	12.5	10.8	22.3	10.5	11.2	17.6	11	13.8	22.1	13.8	23.1	7.4	19.9	25.3	15.4	25.2	12.1	22.7	12.1	14.3	10.1	14.4
6	12.6	24.6	12.5	10.9	23.3	10.5	11.2	18.8	11	13.9	23.6	13.9	23.9	7.4	19.9	26.1	15.4	25.3	12.1	23.8	12.1	16.3	10.6	14.4
7	12.6	28.5	12.5	11.2	25.1	10.5	11.2	.620	11	13.9	26.2	13.9	25.5	7.5	19.9	28.9	15.4	25.3	12.1	25.9	12.1	17	10.9	14.4
8	12.6	31.5	12.5	11.4	26.6	10.5	11.2	22.1	11	13.9	29.4	13.9	27.2	7.9	19.9	30.5	15.4	25.3	12.1	28	12.1	17.8	10.8	14.4
9	12.6	34.9	12.5	11.5	28	10.5	11.2	23.6	11	13.9	32.2	13.9	29.2	8.2	19.9	32.5	15.4	25.3	12.1	30.1	12.1	18.6	11.1	14.4
10	12.6	37.6	12.5	11.7	29.6	10.5	11.2	25.1	11	13.9	35.1	13.9	30.4	8.2	19.9	34.6	15.4	25.3	12.1	31.8	12.1	18.6	11.1	14.4
11	12.6	43.2	12.5	12	31.4	10.5	11.2	26.4	11	13.9	37.6	13.9	31.5	8.2	19.9	36.1	15.4	25.3	12.1	34	12.1	19	11.1	14.4
12	12.6	43.6	12.5	12.1	32.8	10.5	11.2	27.2	11	13.9	39.6	13.9	32.7	8.2	19.9	37.4	15.4	25.3	12.1	35.2	12.1	19.5	11.1	14.4
13	12.6	44.4	12.5	12.4	34.1	10.5	11.2	28	11	13.9	40.9	13.9	34.1	8.2	19.9	39.2	15.4	25.3	12.1	36.4	12.1	19.9	11.1	14.4
14	12.6	44.9	12.5	12.4	34.9	10.5	11.2	28.7	11	13.9	41.3	13.9	35.5	8.2	19.9	40.5	15.4	25.3	12.1	37.4	12.1	20.4	11.1	14.4
15	12.6	45.4	12.5	12.4	35.7	10.5				13.9	41.8	13.9	37.3	8.2	19.9	42.4	15.4	25.3	12.1	38.8	12.1	20.9	11.1	14.4
16				12.5	36.7	10.5				13.9	41.8	13.9	39.2	8.2	19.9	43.7	15.4	25.3	12.1	40	12.1	21.1	11.1	14.4
17				12.6	37.8	10.5				13.9	42.1	13.9	39.2	8.2	19.9	44.7	15.4	25.3	12.1	40.1	12.1	21.2	11.1	14.4
18				13	38.3	10.5				13.9	42.2	13.9	39.2	8.2	19.9	45.1	15.4	25.3	12.1	40.2	12.1	21.8	11.1	14.4
19				13.1	39.1	10.5				13.9	42.2	13.9	39.5	8.2	19.9	46.3	15.4	25.3	10.5	40.8	12.1	21.8	11.1	14.4
20				13.1	39.4	10.5				12.1	42.2	13.9	40.9	8.2	19.9	46.3	15.7	25.3	10.5	40.8	12.1	23.5	11.1	14.4
21				13.1	39.5	10.5				12.5	42.4	13.9	40.9	8.2	19.9	46.3	15.7	25.3	10.5	40.9	12.1			
22				13.1	39.7	10.5				12.5	42.4	13.9	40.9	8.2	19.9	47	15.7	25.3	10.6	41.2	12.1			
23				13.1	39.8	10.5				12.5	42.6	13.9	41.2	8.2	19.9	47.4	15.7	25.3	10.6	41.2	12.1			
24				13.1	39.8	10.5				12.5	42.7	13.9	41.4	8.2	19.9	47.9	15.7	25.3	10.7	41.2	12.1			
25				13.2	39.8	10.5							41.9	8.2	19.9									
26				13.3	39.8	10.5							41.9	8.2	19.9									
27													42.1	8.2	19.9									

(Data based on observations taken from emergence of spike to full opening) S-Spike P-Pedicel B-Bract

Table 4. Pattern of growth of flower bud in Heliconia genotypes (daily growth in cm) (Continued)

	Sassy			Pascal			Golden Torch			Alan Carle			Parakeet			Distans			Deep Orange		
Days	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B	S	P	B
1	11.5	4.3	11.5	10	2.4	10	16.2	1.4	16.4	21.6	19.3	15.9	12.1	7.2	12.1	22.7	16.6	16.5	9.6	2.7	9.6
2	11.5	9.3	11.5	10	5.1	10	16.2	3.5	16.4	21.6	19.3	15.9	12.1	9.9	12.1	23.2	16.6	16.5	9.6	4.8	9.6
3	11.6	12.9	11.6	10	6.9	10	16.3	6	16.4	22.3	19.3	15.9	12.1	14.3	12.1	21	16.8	16.5	9.6	9.2	9.6
4	11.6	17.5	11.6	10	8.9	10	16.3	8.6	16.4	22.7	19.5	15.9	12.3	17.2	12.3	21.1	16.8	16.5	9.6	12.8	9.6
5	11.7	21.7	11.7	10	10.8	10	16.3	10.9	16.4	23.3	19.5	15.9	12.3	20.4	12.3	22.5	16.8	16.7	9.6	29.4	9.6
6	11.7	24.9	11.7	10	11.2	10	16.4	11.9	16.4	24.2	19.5	15.9	12.3	21.6	12.3	22.5	16.8	16.7	9.6	30.2	9.6
7	11.7	27.4	11.7	10	12.1	10	16.4	14.1	16.4	24.5	19.5	15.9	12.3	23.7	12.3	22.9	16.8	16.7	9.6	32.2	9.6
8	11.7	30.2	11.7	10	13.4	10	16.4	16.1	16.4	25	19.5	15.9	12.3	25.8	12.3	23.5	16.8	16.7	9.6	33.6	9.6
9	11.7	31.9	11.7	10	14.2	10	16.4	17.9	16.4	25	19.5	15.9	12.3	27.7	12.3	23.9	16.8	16.7	9.6	35.1	9.6
10	11.7	33.8	11.7	10	14.9	10	16.4	19.6	16.4	25.4	19.5	15.9	12.3	29.3	12.3	25.2	16.8	16.7	9.6	36.6	9.6
11	11.7	34.9	11.7	10	15.6	10	15.8	21.3	16.4	25.4	19.5	15.9	12.3	31.2	12.3	26.7	16.8	16.7	9.6	38.1	9.6
12	11.7	35.3	11.7	10	16	10	16	22.7	16.4	25.6	19.5	15.9	12.3	32.9	12.3	27.5	16.8	16.7	9.6	39.3	9.6
13	11.7	35.9	11.7	10	16.1	10	16.2	24.3	16.4	26	19.5	15.9	12.4	34.1	12.4	28.3	16.8	16.7	9.6	39.7	9.6
14	11.7	36.4	11.7	10	16.1	10	16.2	25.7	16.4	26.7	19.5	15.9	12.4	35.3	12.4	28.3	16.8	16.7	9.6	39.7	9.6
15	11.7	36.7	11.7	10	16.1	10	16.3	27.3	16.4	26.8	19.5	15.9	12.4	36.1	12.4	28.6	16.8	16.7	9.6	39.8	9.6
16	10.4	36.7	11.7	10	16.1	10	16.3	29.1	16.4	27.1	19.5	15.9	12.4	37.6	12.4	29.7	16.8	16.7	9.7	39.9	9.7
17	10.5	36.8	11.7	10	16.1	10	16.4	30	16.4	27.2	19.5	15.9	12.4	38.1	12.4	29.8	16.8	16.7	9.7	39.9	9.7
18				10	16.2	10	16.5	30.8	16.4	27.6	19.5	15.9	12.4	38.9	12.4	30.5	16.8	16.7	9.7	40	9.7
19				8.5	16.2	10	16.5	31.9	16.4	28.5	19.5	15.9	9.7	39.3	12.4	31.4	16.8	16.7	8.6	40.3	9.7
20				8.6	16.2	10	16.6	32.4	16.4	28.3	19.5	15.9	9.7	39.6	12.4	31.8	16.8	16.7	8.7	40.5	9.7
21							16.6	32.5	16.4	28.5	19.5	15.9	9.8	39.9	12.4	32.2	16.8	16.7	8.7	40.5	9.7
22							16.6	32.5	16.4	28.5	19.5	15.9	9.8	39.9	12.4	32.2	16.8	16.7	8.9	40.5	9.7
23							16.7	32.5	16.4	29	19.5	15.9	9.9	40	12.4	34	16.8	16.7	9.1	40.5	9.7
24										29.4	19.5	15.9	9.9	40.2	12.4	34.1	16.8	16.7			
25										29.7	19.5	15.9				34.8	16.8	16.7			
26										30.1	19.5	15.9				35.3	16.8	16.7			
27										30.3	19.5	15.9				35.2	16.8	16.7			

(Data based on observations taken from emergence of spike to full opening) S-Spike P-Pedicel B-Bract

4.1.3.5 Number of Flowers per Inflorescence

The highest number of flowers per inflorescence was exhibited in the genotype Pedro Ortiz (182.58) followed by Collinsiana (110.33), Distans (95.5) and Alan Carle (72.75) and all were significantly different from each other. The lowest number of flowers per inflorescence was obtained for genotype Petra orange (8.58).

4.1.3.6 Number of Days from Emergence to full Opening of Bract

The lowest number of days from emergence to full opening of bracts was shown by the genotype Andromeda (16.83 days) which was on par with Petra orange (17.08 days). The highest number of days was taken by the genotype Alan Carle (40.42 days).

4.1.3.7 Number of Days for Full Unfurling of Bract

The lowest number of days for full unfurling of bract was taken by Andromeda (7 days) followed by Petra Orange (7.42 days), the highest number of days was taken by the genotype Alan Carle (33.25 days).

4.1.3.8 Number of Days from First Flower Opening to Last Flower Opening

The genotype Andromeda recorded the lowest mean value (23.42 days) for this character, which was followed by Distans (25.25 days). The highest mean value was recorded in the genotype Pascal (49.58 days). No flower opening was observed in the varieties Petra orange, Pedro Ortiz, Guyana, Golden Torch and Alan Carle.

4.1.3.9 Number of Days from Emergence to Male Phase

The mean number of days from emergence to male phase ranged between 9.58 for the genotype Distans (which was significantly different from others) and 30.83 for the genotype Sassy followed by De Rooij (22.08) and Deep Orange (20.25).

4.1.3.10 Duration of Male phase

The genotype Andromeda recorded the lowest mean value (23.42 days) for this character, which was followed by Distans (25.25 days). The highest mean value was recorded in the genotype Pascal (49.58 days).

4.1.3.11 Number of days from Emergence to Female phase

The mean number of days from emergence to female phase ranged from 9.58 days for the genotype Distans (which was significantly different from others) to 30.83 days for the variety Sassy followed by De Rooij (22.08 days) and Deep Orange (20.25 days).

4.1.3.12 Duration of female phase

The genotype Andromeda recorded the lowest mean value (23.42 days) for this character, which was followed by Distans (25.25 days). The highest mean value was recorded in the genotype Pascal (49.58 days).

4.1.3.13 Time of Anthesis

For all the varieties except Collinsiana, the peak anthesis time (Table 5) was found to be between 3 and 6 am. For the varieties Andromeda and Parakeet, peak anthesis time was found to be between 5 and 6 am. For Lady Di the peak anthesis time was between 4 and 6 am. For the variety Collinsiana, anthesis was observed from 8 pm to 7 am. The same trend was observed for all the varieties in summer season also, except for the varieties Parakeet, Distans and Deep Orange where it was 1 to 2 hours delayed and extended up to 6 to 8 am.

4.1.3.14 Stigma Receptivity

Stigma receptivity was the highest on the day of anthesis for all the varieties and not much difference was observed in the previous day also, but stigma receptivity was drastically reduced one day after anthesis (Table 6). There was high variation in structure between stigmas of different species of heliconia (Plate 3).

H. psittacorum L.f. cv. Lady Di

H. psittacorum x *H. marginata* De Roolj

H. collinsiana x *H. bourgena* cv. Pedro Ortiz

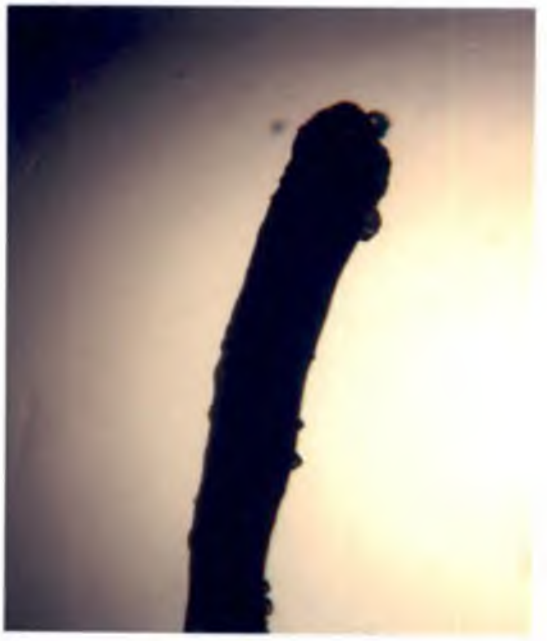
H. collinsiana Griggs var.Collinsiana

Plate 3. Stigma variations in Heliconia varieties

H. psittacorum L.f. x
H . spathocircinata Aristeguieta cv. Guyana

H. psittacorum L.f. x
H . spathocircinata Aristeguieta cv. Golden torch

H. psittacorum L.f. x
H . spathocircinata Aristeguieta cv.Alan Carle



H. latispatha Bentham cv. Distans

Plate 3. Stigma variations in Heliconia varieties
(Continued)

Table 5. Anthesis time of Heliconia genotypes for rainy and summer season

Time (hrs)	Rainy														
	Lady Di	De Rooij	St.Vincent Red	Petra Orange	Pedro Ortiz	Collinsiana	Andromeda	Guyana	Sassy	Pascal	Golden Torch	Alan Carle	Parakeet	Distans	Deep Orange
1-2															
2-3	1					2									
3-4	3	3	2			1			10	1				1	2
4-5	5	10	10			7	1		4	6			1	10	3
5-6	6	2	3			2	12		1	4			12	4	9
6-7						1				2			2		1
7-8							2			2					
8-9															
9-10															
10-11															
11-12															
12-13															
13-14															
14-15															
15-16															
16-17															
17-18															
18-19															
19-20															
20-21						1									
21-22															
22-23						1									
23-24															

Table 5. Anthesis time of Heliconia genotypes for rainy and summer season (Continued)

Time (hrs)	Summer														
	Lady Di	De Rooij	St.Vincent Red	Petra Orange	Pedro Ortiz	Collinsiana	Andromeda	Guyana	Sassy	Pascal	Golden Torch	Alan Carle	Parakeet	Distans	Deep Orange
1-2						1									
2-3						3									
3-4	2		1			2			6						
4-5	8	6	12			6			7	4					
5-6	3	7	2			2	13		2	10				9	3
6-7		1					1						14	1	11
7-8	1	1					1			1			1	5	
8-9	1														1
9-10															
10-11															
11-12															
12-13															
13-14															
14-15															
15-16															
16-17															
17-18															
18-19															
19-20															
20-21															
21-22						1									
22-23															
23-24															

Table 6. Stigma receptivity in Heliconia genotypes

Genotypes	Stigma receptivity from anthesis time		
	One day prior	On the day	One day after
Lady Di	4	5	1.9
De Rooij	3.5	4. 7	1.25
St.Vincent Red	4.4	5	2.3
Petra Orange	-	-	-
Pedro Ortiz	-	-	-
Collinsiana	-	-	-
Andromeda	4.3	5	2.4
Guyana	-	-	-
Sassy	4.3	5	2.3
Pascal	4.2	4.9	2.1
Golden Torch	-	-	-
Alan Carle	-	-	-
Parakeet	4.4	5	2.5
Distans	3.9	4.8	1.6
Deep Orange	4.3	5	2.4

4.1.3.15 Pollen Studies

4.1.3.15.1 Pollen Morphology (Size and Shape)

The pollen grains were spherical in shape with smooth exine. The mean diameter of fertile pollen ranged from 365.25, µm in Petra orange to 240.75 µm in Distans.

4.1.3.15.2 Pollen Fertility

Comparison of pollen fertility estimated using acetocarmine staining method revealed that, Lady Di had the highest pollen fertility of 89.39 per cent, which was on par with Parakeet (85.14 %). The lowest values were recorded for Guyana (23.23 %), Alan Carle (24.92 %) and Pedro Ortiz (26.55 %) genotypes.

4.1.4 Qualitative Characters

4.1.4.1 Colour of Bract and Blending of Colours

Dark red colour bracts were observed for varieties Lady Di, St.Vincent Red, Pedro Ortiz and Collinsiana. Blending of red and orange colour was seen in varieties De Rooij and Distans. White powdery coating over the bract was observed in variety Collinsiana. In variety Latispatha reddish pigment was observed in inflorescence stalk and shoot (Table 7 and Plate 1).

4.1.4.2 Colour of Flower and Blending of Colours

Homogeneous colouration was observed in sepal, ovary and rachis for varieties Deep Orange which showed continuous orange colour and Golden torch with golden yellow colour. Metallic black to dark green band on the sepal was observed in Lady Di, Andromeda, Guyana, Sassy, Pascal, Parakeet, Distans and Deep Orange (Table 7 and Plate 1).

4.1.4.3 Estimation of Total Anthocyanin (mg/100g)

The highest total anthocyanin was recorded for the genotype Lady Di (58.38 mg/100 g) followed by Pedro Ortiz and St.Vincent Red with 38.78 and 35.76 mg/100 g respectively and lowest for Deep Orange with 7.47 mg/100 g.

Table 7. Floral characteristics of selected parental varieties of Heliconia

Varieties	Bract	Rachis	Sepals	Ovary	Pedicel
Lady Di	Dark red with paler red towards cheek	Red, pink or pale pink	Light yellow with distal dark green band and white tip	Yellow, proximally cream	Light yellow or cream
De Rooij	Pink – red over most of keel and cheek	Yellow distally and pink below	Gold	Dark yellow distally and light yellow below	Light yellow
St.Vincent Red	Bright to deep red shading to orange proximally	Orange distally shading to reddish proximally	Orange with generally indistinct green-black area distally	Orange on top and distal 2/3 with pale orange or yellow proximally	Orange
Petra Orange	Outer surface orange to red, inner surface red shading to orange proximally	Orange	Dark orange with distal metallic black or green band and orange tip	Dark red	Orange
Pedro Ortiz	Dark red with pale red towards rachis	Dark to pale red	Golden with faint green stripe	Golden on distal 1/3 and top, yellow below	Yellow
Collinsiana	Dark red to orange red, younger bract with yellow at base and on proximal lip. Waxy coating present	Red on upper bract changing to reddish yellow or yellow at small lower bract	Yellow to orange-yellow or golden	Yellow	Yellow – pale gold, some with pink tint at base
Andromeda	Somewhat variable, outer surface orange – red with green tint, inner surface red shading to orange proximally	Orange with red infusion or green	Orange with distal metallic black or green band and orange tip	Dark orange distally and light orange or orange yellow below	Orange
Guyana	Red with dark orange infusion	Red with dark orange infusion	Golden to orange with distal green tip	Yellow distally and orange to yellow below	Orange to yellow
Sassy	Pale green or cream on proximal half and pink distally; basal bract with narrow green keel	Pale yellow or cream	Yellow with distal green to black metallic band and white to cream tip	Cream to yellow	Yellow to pale green

Table 7. Floral characteristics of selected parental varieties of *Heliconia* (Continued)

	Bract	Rachis	Sepals	Ovary	Pedicel
Pascal	Strawberry red – pink distally and cream proximally; with a thin distal green keel	Cream with green tint	Pale yellow with distal dark green to metallic band and white to cream tip	Pale yellow	Cream with light green tint
Golden Torch	Golden or yellow; basal bract with green keel	Golden, often with small red areas at base	Golden with faint green tip	Golden on distal 1/3 and top, yellow below	Yellow with green tint
Alan Carle	Reddish on most of cheek and keel, shading to yellowish on proximal cheek and along lip	Greenish to yellow	Dark green on distal 1/3 with light tip, yellow on proximal part	Yellow	Cream or yellowish
Parakeet	Dark red to pink distally with pale green or cream-yellow proximally	Pale green (with or without yellow tint) or cream	Yellow (sometimes orange) with distal dark green band and white or yellow tip	Green	Light green distally and cream proximally
Distans	Red on distal half and yellow or golden proximally, some with green or cheek; basal bract with green keel and usually with green leaf let; second and third bract often with green keel	Usually yellow, some with green tint or golden	Pale yellow – green with dark green stripe along distal margin and at base	Light green distally and pale yellow below	Pale yellow
Deep Orange	Orange with pale green on outer tip of basal bract	Orange	Orange with distal metallic black or green band and orange tip	Dark orange distally and light orange or orange yellow below	Orange

4.1.5 Statistical Analysis

4.1.5.1 Estimation of Variability Components

The genotypic coefficient of variation(GCV) and phenotypic coefficient of variation(PCV) are the relative measures of variation used for comparison among characters measured in different units. The genotypic and environmental components of phenotypic variance(Table. 8 and Fig.3) were estimated.

The highest variability for phenotypic component (97.97%) was observed for pollen fertility percentage, followed by anthocyanin content (86.76%). The highest variability for genotypic component (86.76%) was observed for anthocyanin content followed by number of flowers per bract with 85.66 percent.

Days from first to last flower opening and days from emergence to male phase also registered a high value of 80.14 percent and 80.19 percent for genotypic and 80.25 percent and 80.36 percent for phenotypic component.

The least variability was recorded for the size of bract as 19.45% for GCV and 19.67% for PCV.

The environmental influence was the highest for the number of flowers per inflorescence followed by size of bract, pollen size and pollen fertility.

4.1.5.2 Heritability And Genetic Advance

Robinson(1965) classified the heritability estimates in cultivated plants as low with 5-10 percent heritability, medium 10-30 percent heritability and greater than 30 percent as high. In the present study all the characters showed high heritability as per Robinson's classification. Allard (1960) classified heritability as low (less than 30%), medium (30-60%) and high (above 60%). According to this classification all characters except pollen fertility showed high heritability, highest was for days from first to last flower opening (99.87). Pollen fertility (55.15%) showed medium heritability.

Table 8. Components of total variance for different characters in Heliconia genotypes

Sl. No.	Characters	$\sigma^{2}p$	$\sigma^{2}g$	$\sigma^{2}e$	GCV (per cent)	PCV (per cent)
1	Length of inflorescence (cm)	255.58	248.88	6.7	28.52	28.68
2	Size of bract(cm^2)	6468.91	6438.88	30.03	19.5	19.67
3	Number of bracts	5.25	5.09	0.16	43.32	43.44
4	Number of flower/ bract	64.16	64.05	0.11	85.66	85.84
5	Number of flower/ inflorescence	6497.01	6488.02	8.99	65.27	65.36
6	Days from flower bud emergence to full opening of bracts	146.99	146.45	0.54	46.07	46.2
7	Days for unfurling of all the bracts	5.25	5.09	0.16	26.21	27.47
8	Days from first to last flower opening	989.66	989.24	0.42	80.14	80.19
9	Days from emergence to male phase	316.32	316.03	0.29	80.25	80.36
10	Days from emergence to female phase	316.32	316.03	0.29	20.46	21.29
11	Pollen size (μ)	2272.34	2263.37	8.97	45.45	45.7
12	Pollen fertility (percent)	2125.04	2117.2	7.84	72.75	97.97
13	Anthocyanin content (mg/100gm)	678.15	677.56	0.59	86.76	86.76

σ^{2} p –Phenotypic variance σ^{2} g–Genotypic variance σ^{2} e –Environmental variance
PCV-Phenotypic coefficient of variation GCV- Genotypic coefficient of variation

From the Table 9 and Fig. 4 it was found that high heritability was recorded for character days from first to last flower opening (99.87%) followed by number of flower per inflorescence (99.74%) and days from emergence to male phase (99.72%). Pollen fertility showed the least value (55.15%).

The highest genetic advance was obtained for number of flower per bract (95.53%) followed by anthocyanin content (94.55%).

The lowest genetic advance was obtained for the character days for full opening of bract (2.52%), number of bracts (9.48%) and length of inflorescence (14.29%).

4.1.5.3 Correlation Among Different Characters

The phenotypic, genotypic and environmental correlations (Table 10,11 and12 respectively) were estimated.

The significance for both phenotypic and environmental correlation was tested. However no test is available to detect the significance of genotypic correlation coefficient.

4.1.5.3.1 Phenotypic Correlation

Days from first to last flower opening were found to have significant positive correlation with days from emergence to male phase (+0.8533) and pollen size (+0.5564). It showed significant negative correlation with number of bracts (-0.4137) and size of bracts (-0.3730).

Days from bud emergence to male phase showed significant positive correlation with pollen size (+0.6867).

Days from bud emergence to full opening of bracts were found to have significant positive correlation with length of inflorescence (+0.9754).

Table 9. Heritability and genetic advance of different characters in Heliconia genotypes

Sl. No.	Characters	Heritability (Percent)	Genetic advance (5 percent)
1	Days from flower bud emergence to full opening of bracts	99.44	15.08
2	Days for full unfurling of all the bracts	91.08	2.52
3	Days from first to last flower opening	99.87	37.38
4	Days from emergence to male phase	99.72	21.1
5	Days from emergence to female phase	92.34	17.79
6	Number of bracts	99.48	9.48
7	Number of flower/ bract	99.58	95.53
8	Number of flower/ inflorescence	99.74	30.9
9	Anthocyanin content (mg/100g)	98.61	94.55
10	Length of inflorescence (cm)	98.90	14.29
11	Size of bract (cm^2)	98.32	29.77
12	Pollen size (μ)	98.89	54.32
13	Pollen fertility (%)	55.15	14.89

Days to full opening of bracts had positive and significant correlation with length of inflorescence (+0.39690), days from bud emergence to full opening of bract (+0.3639), number of bracts (+0.6786), number of flowers per bract (+0.7505) and anthocyanin content (+0.7463). It registered significantly negative correlation for pollen size (-0.5078) and pollen fertility (-0.4952).

Number of bracts showed significant positive correlation for length of inflorescence (+0.3570), number of flowers per bract (+0.8806) and anthocyanin content (+0.7502) but significant negative correlation for pollen size (-0.5575) and negative correlation for pollen fertility (-0.2756).

Number of flowers per bract showed significant positive correlation with days from emergence to female phase (+0.4072) and anthocyanin content (+0.9075) but significant negative correlation for pollen size (-0.4654). It showed negative correlation for size of bract (-0.0911).

Number of flowers per inflorescence showed no significant negative or positive correlation. It showed positive correlation with full opening of bracts (+0.0767) and number of bracts (+0.0767), but negative correlation with size of bract (-0.0236).

Size of bract showed significant negative correlation with first to last flower opening (-0.3730) and pollen size (-0.3581).

Pollen size was significantly related positively with days from first to last flower opening (+0.5564) and days from emergence to male phase and negatively for length of inflorescence (-0.4695), days from bud emergence to full opening of bracts (-0.4050), days for full opening of bracts (-0.5078), number of bracts (-0.5575), number of flowers per bract (-0.4654) and size of bract (-0.3581).

Pollen fertility was not significantly correlated to any of the characters. It showed negative correlation for all the characters. However, it showed positive correlation for characters like size of bract (+0.0776) and pollen size (+0.2297).

Table 10. Phenotypic correlation coefficients among different characters in Heliconia genotypes

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X2	0.8533**											
X3	-0.1366	-0.2537										
X4	-0.0270	-0.0014	-0.2283									
X5	-0.0251	-0.0145	-0.2774	0.9754**								
X6	-0.0071	-0.1828	0.1547	0.3969*	0.3639*							
X7	-0.4137**	-0.5771**	0.2956	0.3570*	0.3682*	0.6786 **						
X8	-0.2704	-0.4606**	0.4072*	0.1731	0.1872	0.7505**	0.8806**					
X9	0.2000	0.0941	0.3111	-0.1006	-0.0620	0.0767	0.2384	0.3474				
X10	-0.3038	-0.4773**	0.5353**	0.1854	0.1403	0.7463**	0.7502**	0.9075**	0.1335			
X11	-0.3730*	-0.3303	0.0347	-0.1900	-0.2732	0.0122	-0.1678	-0.0911	-0.0236	0.0925		
X12	0.5564**	0.6867**	-0.1648	-0.4695**	-0.4050*	-0.5078**	-0.5575**	-0.4654**	0.1552	-0.5886**	-0.3581*	
X13	-0.1301	-0.0757	-0.0118	-0.3148	-0.3465	-0.4952**	-0.2756	-0.3762*	-0.0431	-0.3345	0.0776	0.2297

*Significant at 5percent level **Significant at 1 percent level

X1-Days from first to last flower opening X2- Days from emergence to male phase X3- Days from emergence to female phase X4- Length of inflorescence (cm)
X5- Days from bud emergence to full opening of bracts X6- Days for unfurling of all the bracts X7- Number of bracts X8- Number of flower/ bract
X9- Number of flower/ inflorescence X10- Anthocyanin content (mg/100g) X11- Size of bract (cm^2) X12- Pollen size (μ)
X13- Pollen fertility (%)

4.1.5.3.2 Genotypic Correlation

Days from first to last flower opening were negatively correlated with all the characters except the number of flowers per inflorescence (+0.2010) and pollen size (+0.5595).

Days from emergence to male phase was positively correlated to days from first to last flower opening (+0.8557) and negatively correlated to days from emergence to female phase (-0.2632).

Length of inflorescence was negatively correlated to days from emergence to male phase(-0.0012) and days from emergence to female phase(-0.2493).

Days from emergence to female phase was negatively correlated to length of inflorescence (-0.2493), days from bud emergence to full opening of bracts (-0.2845), pollen size (-0.1763) and pollen fertility (-0.0356).

Length of inflorescence was positively correlated to days from bud emergence to full opening of bracts (+0.9811), days for full opening of bracts (+0.4262), number of bracts (+0.3589), number of flowers per bract (+0.1742) and anthocyanin content (+0.1899). It was negatively correlated to number of flowers per inflorescence (-0.1010) and size of bracts (-0.1891).

Days from bud emergence to full opening of bracts was negatively correlated to days from first to last flower opening (-0.0258), days from emergence to male phase (-0.0151) and days from emergence to female phase (-0.2845) and positively correlated to length of inflorescence (+0.9811). It was also positively correlated to days to full opening of bracts

(+0.3848), number of bracts (+0.3700) and number of flowers per bract (+0.1871).

Days to full opening of bracts was positively correlated to number of bracts (+0.7124), number of flowers per bract (+0.7951), number of flowers per inflorescence (+0.0820) and anthocyanin content (+0.7897) and negatively correlated to size of bracts (-0.0034), pollen size (-0.5347) and pollen fertility (-0.6717).

Number of bracts was positively correlated to number of flowers per bract (+0.8844), number of flowers per inflorescence (+0.2396) and negatively correlated to size of bracts (-0.1711).

Number of flowers per bract was negatively correlated to size of bracts (-0.0894), days from first to last flower opening (-0.2713) and days from emergence to male phase (-0.4624), and positively correlated to days from emergence to female phase (+0.4243), length of inflorescence (+0.1742) and days to full opening of bracts (+0.7951).

Number of flowers per inflorescence was positively correlated to days from first to last flower opening (+0.2010), days from emergence to male phase (+0.0935) and days from bud emergence to full opening of bracts (-0.0623).

Size of bract was negatively correlated to pollen size (-0.3658) and positively correlated to pollen fertility. It was also positively correlated to days from emergence to female phase (+0.0337) and anthocyanin content (+0.0959).

Pollen size was positively correlated to pollen fertility (+0.2765) and negatively correlated to number of bracts per inflorescence (-0.3734) and number of flowers per bract (-0.5132).

4.1.5.3.3 Environmental Correlation

Number of bracts showed significant positive correlation with days from emergence to female phase (+0.3815). Size of bract showed positive significant correlation with days to full opening of bracts (+0.3999).

Pollen fertility percentage was significantly positively correlated to pollen size (+0.3631). Pollen size and days from emergence to male phase (-0.4314) are significantly negatively correlated.

Anthocyanin content was significantly negatively correlated with number of bracts (-0.6096).

4.2 COMPATIBILITY/ INCOMPATIBILITY STUDIES

4.2.1 Cross Compatibility/ Incompatibility

Among the selected fifteen Heliconia genotypes, depending upon the availability of receptive stigma and fertile pollen crossing was done taking Lady Di as the female parent and other fourteen varieties as male parents. Selfing was done for the female parent Lady Di. This was done with the objective of studying the compatibility/ incompatibility relationship between genotypes.

4.2.1.1 Analysis of Cross Compatibility/ Incompatibility (15 flowers for each cross combinations):

The level of incompatibility were grouped under three heads as follows:

Table 11. Genotypic correlation coefficients among different characters in Heliconia genotypes

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X2	0.8557											
X3	-0.1411	-0.2632										
X4	-0.0276	-0.0012	-0.2493									
X5	-0.0258	-0.0151	-0.2845	0.9811								
X6	-0.0084	-0.1887	0.1900	0.4262	0.3848							
X7	-0.4148	-0.5784	0.3005	0.3589	0.3700	0.7124						
X8	-0.2713	-0.4624	0.4243	0.1742	0.1871	0.7951	0.8844					
X9	0.2010	0.0935	0.3283	-0.1010	-0.0623	0.0820	0.2396	0.3481				
X10	-0.3056	-0.4831	0.5637	0.1899	0.1436	0.7897	0.7627	0.9157	0.1346			
X11	-0.3766	-0.3321	0.0337	-0.1891	-0.2762	-0.0034	-0.1711	-0.0894	-0.0223	0.0959		
X12	0.5595	0.6939	-0.1763	-0.4743	-0.4085	-0.5347	-0.5605	-0.4678	0.1567	-0.5976	-0.3658	
X13	-0.1775	-0.0871	-0.0356	-0.4193	-0.4638	-0.6717	-0.3734	-0.5132	-0.0639	-0.4515	0.1054	0.2765

*Significant at 5percent level **Significant at 1 percent level

X1-Days from first to last flower opening X2- Days from emergence to male phase X3- Days from emergence to female phase X4- Length of inflorescence (cm)
X5- Days from bud emergence to full opening of bracts X6- Days for unfurling of all the bracts X7- Number of bracts X8- Number of flower/ bract
X9- Number of flower/ inflorescence X10- Anthocyanin content (mg/100g) X11- Size of bract (cm^2) X12- Pollen size (μ)
X13- Pollen fertility (%)

Table 12. Environmental correlation coefficients among different characters in Heliconia genotypes

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12
X2	-0.3394											
X3	-0.1064	-0.0738										
X4	0.1052	-0.0317	0.3410									
X5	0.2078	0.1246	-0.2297	0.3189								
X6	0.0822	-0.1869	-0.2366	-0.2413	-0.0997							
X7	-0.1156	-0.2671	0.3815*	0.1322	0.0355	0.0213						
X8	0.0666	0.0687	0.0142	0.0228	0.2016	-0.3459	0.0604					
X9	-0.3428	0.3142	-0.2819	-0.0484	0.0227	-0.0968	-0.0703	0.1431				
X10	-0.1391	0.2902	-0.0790	-0.1772	-0.2073	-0.0605	-0.6096**	0.0024	-0.0096			
X11	0.0426	-0.2126	0.0704	-0.2618	-0.0125	0.3999*	0.1565	-0.3063	-0.2379	-0.1256		
X12	0.0805	-0.4319**	0.1248	-0.0428	0.0169	-0.0110	-0.1998	-0.1669	-0.0752	0.1256	0.1872	
X13	0.0688	-0.3139	0.0735	-0.0726	-0.0618	-0.0959	0.0189	0.0948	0.1232	-0.0196	-0.0001	0.3631*

*Significant at 5percent level **Significant at 1 percent level

X1-Days from first to last flower opening X2- Days from emergence to male phase X3- Days from emergence to female phase X4- Length of inflorescence (cm)
X5- Days from bud emergence to full opening of bracts X6- Days for unfurling of all the bracts X7- Number of bracts X8- Number of flower/ bract
X9- Number of flower/ inflorescence X10- Anthocyanin content (mg/100g) X11- Size of bract (cm^2) X12- Pollen size (μ)
X13- Pollen fertility (%)

1. Instances where pollination attempted, but ovary dried before the onset of any visible post pollination changes.

Parents			Number of crossed flowers where ovary dried without any visible post pollination changes
Lady Di	×	De Rooij	5
Lady Di	×	St.Vincent Red	8
Lady Di	×	Petra Orange	15
Lady Di	×	Pedro Ortiz	15
Lady Di	×	Collinsiana	15
Lady Di	×	Andromeda	12
Lady Di	×	Guyana	15
Lady Di	×	Sassy	15
Lady Di	×	Pascal	15
Lady Di	×	Golden Torch	15
Lady Di	×	Alan Carle	15
Lady Di	×	Parakeet	10
Lady Di	×	Distans	12
Lady Di	×	Deep Orange	11

2. Instances where pollinated ovary dried within two months(after greening of ovary)

Parents			Number of crossed flowers where ovary dried within two months
Lady Di	×	De Rooij	6
Lady Di	×	St.Vincent Red	5
Lady Di	×	Petra Orange	0
Lady Di	×	Pedro Ortiz	0
Lady Di	×	Collinsiana	0
Lady Di	×	Andromeda	3
Lady Di	×	Guyana	0
Lady Di	×	Sassy	0
Lady Di	×	Pascal	0
Lady Di	×	Golden Torch	0
Lady Di	×	Alan Carle	0
Lady Di	×	Parakeet	4
Lady Di	×	Distans	3
Lady Di	×	Deep Orange	3

3. Instances where pollinated ovary dried up after two months growth

Parents	Number of crosses where pollinated ovary dried up after two months
Lady Di × De Rooij	4
Lady Di × St.Vincent Red	2
Lady Di × Petra Orange	0
Lady Di × Pedro Ortiz	0
Lady Di × Collinsiana	0
Lady Di × Andromeda	3
Lady Di × Guyana	0
Lady Di × Sassy	0
Lady Di × Pascal	0
Lady Di × Golden Torch	0
Lady Di × Alan Carle	0
Lady Di × Parakeet	1
Lady Di × Distans	0
Lady Di × Deep Orange	1

In 178 crosses attempted (84.76 %), flower and ovary abscission was observed without any visible post pollination floral changes. Incompatibility was of the highest degree in these combinations where even the initial swelling of ovary following pollination was not detected. The strength of incompatibility was of the highest degree with Petra Orange, Pedro Ortiz, Collinsiana, Guyana, Sassy, Pascal, Golden Torch and Alan Carle.

In 24 crosses (11.42%), ovary dried up within two months after pollination. The dried up ovary exhibited initial blue colour and swelling, which indicated a reduction in the strength of incompatibility from the first level. This was noted to the highest degree when De Rooij was used as male parent followed by St.Vincent Red.

In eight crosses (0.04%), berry dried up before maturity after two months of growth. This again indicated a lesser degree of compatibility reaction seen when De Rooij was used as male parent followed by Andromeda.

The extent and strength of compatibility/ incompatibility reaction varied among the selected fifteen heliconia genotypes (Table 13).

Table.13. Matrix showing compatibility relationship in fifteen Heliconia genotypes

♀ \ ♂	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
P1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1-Combination successful 0- Combination unsuccessful

4.2.2 Selfing

Selfing of female parent Lady Di yielded 1.48 percent well-filled blue colour berries (Plate 4 and Plate 5). Highest percentage of selfed seeds (Table 15) was for Parakeet (4.56%) and De Rooij (3.32%). The lowest percentage of fruit set was for St.Vincent Red (0.48%). Petra Orange, Pedro Ortiz, Collinsiana, Guyana and Alan Carle did not produce any berries.

4.2.3 Pollination Studies

4.2.3.1 Mode of Pollination

The data on mode of pollination are presented in Table 14. In open pollination Parakeet had the highest fruit set of 5.96 percent and the lowest was for Sassy (1.48%) other than genotypes Petra Orange, Pedro Ortiz, Collinsiana, Guyana and Alan Carle which yielded no berries. For selfing highest berry set was for Parakeet (4.56%). The genotypes Petra Orange, Pedro Ortiz, Collinsiana, Guyana and Alan Carle yielded no berries and the least percentage seed set was for St.Vincent Red (0.48%).

Natural crossing gave fruit set in varieties Lady Di(0.15%), Golden Torch(0.11%) and Distans (0.13%), respectively. Assisted crossing yielded no fruit set for any of the varieties. Emasculation and bagging to prove the involvement of pollinator in pollination did not yield any seeds even for the varieties Lady Di, Golden Torch and Distans, which gave fruit set when emasculated and kept open for pollination.

On the day of anthesis

One day after anthesis

Enlarged ovary

Blue coloured berry

Different stages of development - immature flower to viable blue berries

Plate 4. Pattern of seed setting in Heliconia

Lady Di

De Rooij

St. Vincent Red

Andromeda

Sassy

Pascal

Plate 5. Fruit set in different Heliconia varieties

Golden Torch

Parakeet

Distans

Deep orange

Plate 5. Fruit set in different Heliconia varieties (Continued)

Table 14. Mode of pollination in Heliconia varieties

Genotypes	Fruit set									
	Open pollination		Selfing		Natural crossing		Assisted crossing		Emasculation& Bagging	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Lady Di	13	1.92	10	1.48	1	0.15	0	0	0	0
De Rooij	15	3.56	14	3.32	0	0.00	0	0	0	0
St.Vincent Red	12	1.93	3	0.48	0	0.00	0	0	0	0
Petra Orange	0	0.00	0	0.00	0	0.00	0	0	0	0
Pedro Ortiz	0	0.00	0	0.00	0	0.00	0	0	0	0
Collinsiana	0	0.00	0	0.00	0	0.00	0	0	0	0
Andromeda	9	2.90	7	2.26	0	0.00	0	0	0	0
Guyana	0	0.00	0	0.00	0	0.00	0	0	0	0
Sassy	5	1.48	4	1.19	0	0.00	0	0	0	0
Pascal	9	2.05	6	1.36	0	0.00	0	0	0	0
Golden Torch	26	2.76	16	1.70	1	0.11	0	0	0	0
Alan Carle	0	0.00	0	0.00	0	0.00	0	0	0	0
Parakeet	17	5.96	13	4.56	0	0.00	0	0	0	0
Distans	47	3.28	28	1.95	2	0.13	0	0	0	0
Deep Orange	11	4.73	7	3.01	0	0.00	0	0	0	0

4.2.3.2 Pollinators/ Other Flower Visitors

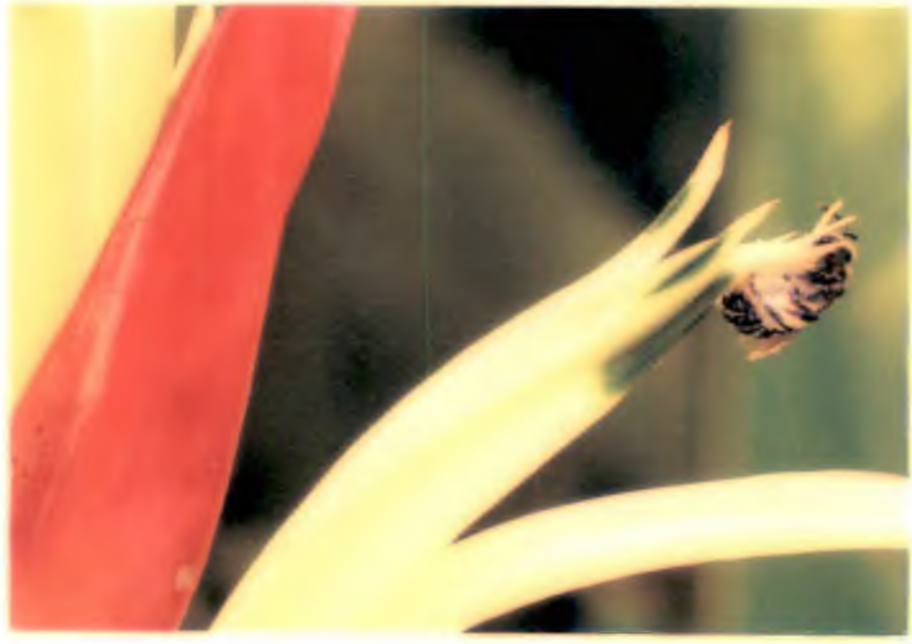
Three different groups of possible pollinators visiting the flowers (Plate 6) were identified as Lotens Sun Bird (*Nectarina lotenia*), Stingless Bees (*Melipona iridipennis* syn. *Trigona iridipennis)* and Ants. Also the flowers were intensively visited by Land Snail (Ariophanta) during night whose exact role was not known. Lotens Sun Birds were found to be more intensively visiting the flowers with bright colours (varieties like Lady Di, St. Vincent Red, Distans and Parakeet).

Male Lotens Sun Bird (*Nectarina lotenia*)

Female Lotens Sun Bird (*Nectarina lotenia*)

Plate 6. Pollinators / other flower visitors identified in Heliconia

Land snail and ant identified in Heliconia



***Melipona iridipennis* identified in Heliconia**

Plate 6. Pollinators / other flower visitors identified in Heliconia (Continued)

Discussion

5. DISCUSSION

Heliconia which are distinctive plants among monocotyledons have strikingly beautiful inflorescence with long lasting characters. Despite its potentiality, the crop still remains under exploited and only limited work has been done on its improvement.

The information on floral biology and analysis of compatibility are the prerequisite for any breeding programme. In this context the present study was conducted to analyse the floral biology of 15 heliconia genotypes and compatibility of the 15 genotypes by taking one promising variety as female parent and crossing with other 14 varieties. The salient findings in the course of their development are discussed below.

In heliconia, flowering was either throughout the year or seasonal. Climatic variables such as wind, rain, relative humidity, temperature, light intensity and spectral quality are the triggers for the time of flowering in plants. Continuity of flowering can be due to constancy of environmental conditions or insensitivity to environmental fluctuations.

The present study reveals that under South Kerala condition, there was no uniformity in flowering behaviour of different varieties. Considering the flowering pattern, some of the varieties showed continuous flowering throughout the year, whereas some others were significantly seasonal in their flowering behaviour. As per Fig.1, in the variety Distans there was no flower production during months of February to March and very low flower production in months of April to May (0.33), January to February (0.83) and March to April (0.83).

Genotype Lady Di recorded the highest flower production in month of June-July with 21.67, followed by Andromeda and Parakeet with 17.58 each for the same month.

The result obtained is signified by the report by Juan (1997) that heliconia especially the *H. psittacorum* species bloom throughout the year.

Criley *et al.* (1999) has reported that many species exhibit seasonal pattern of flowering. Also, according to Maciel and Rojas (1994) *H. latispatha* flowering showed an irregular pattern during the cycle of growth with the peak occurring in July to August, which was nearly in accordance with the result obtained in the study where the peak flowering in *H. latispatha* was seen in September to October (14.42). Criley (2000) reported that natural flowering season for heliconia species may be influenced locally by rainfall, drought periods as well as by photoperiod.

Criley (2000) also reported strong seasonal flowering pattern in *H. collinsiana*, which was not in accordance with the result obtained in the study even though there was a reduced flower production during month of July to September and December.

Peak flowering during April to November was reported by Juan (1997) in Lady Di. In the present study the highest flower production was during month of June–July and also flower production was high during month of April-May (14.2) and May-June with 14.92 flowers, which again may be due to the peculiar climatic factors prevailing here.

Alan Carle, Pedro Ortiz and Distans varieties took the longest number of days (27) for stabilisation of growth of the inflorescence followed by variety De Rooij with 26 days as per Fig.2. The phenotypic correlation studies revealed that there was significant correlation between number of flowers per bract and number of days for full opening of bracts and the variety Alan Carle recorded the highest number of flowers per bract the size of the inflorescence was also highest in these two varieties substantiating the requirement of longer days for attaining full growth.

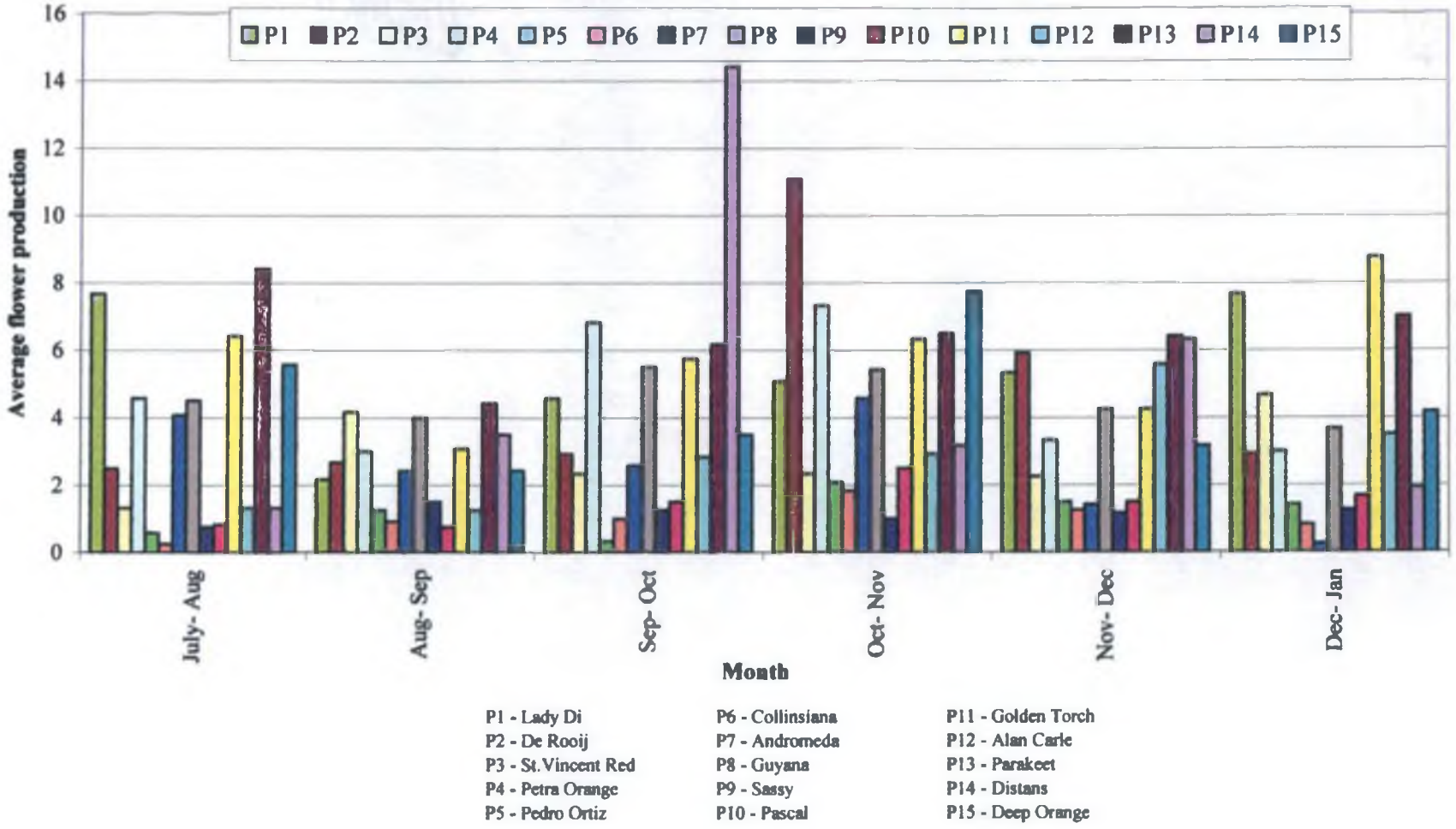


Fig. 1. Phenology of flowering in Heliconia

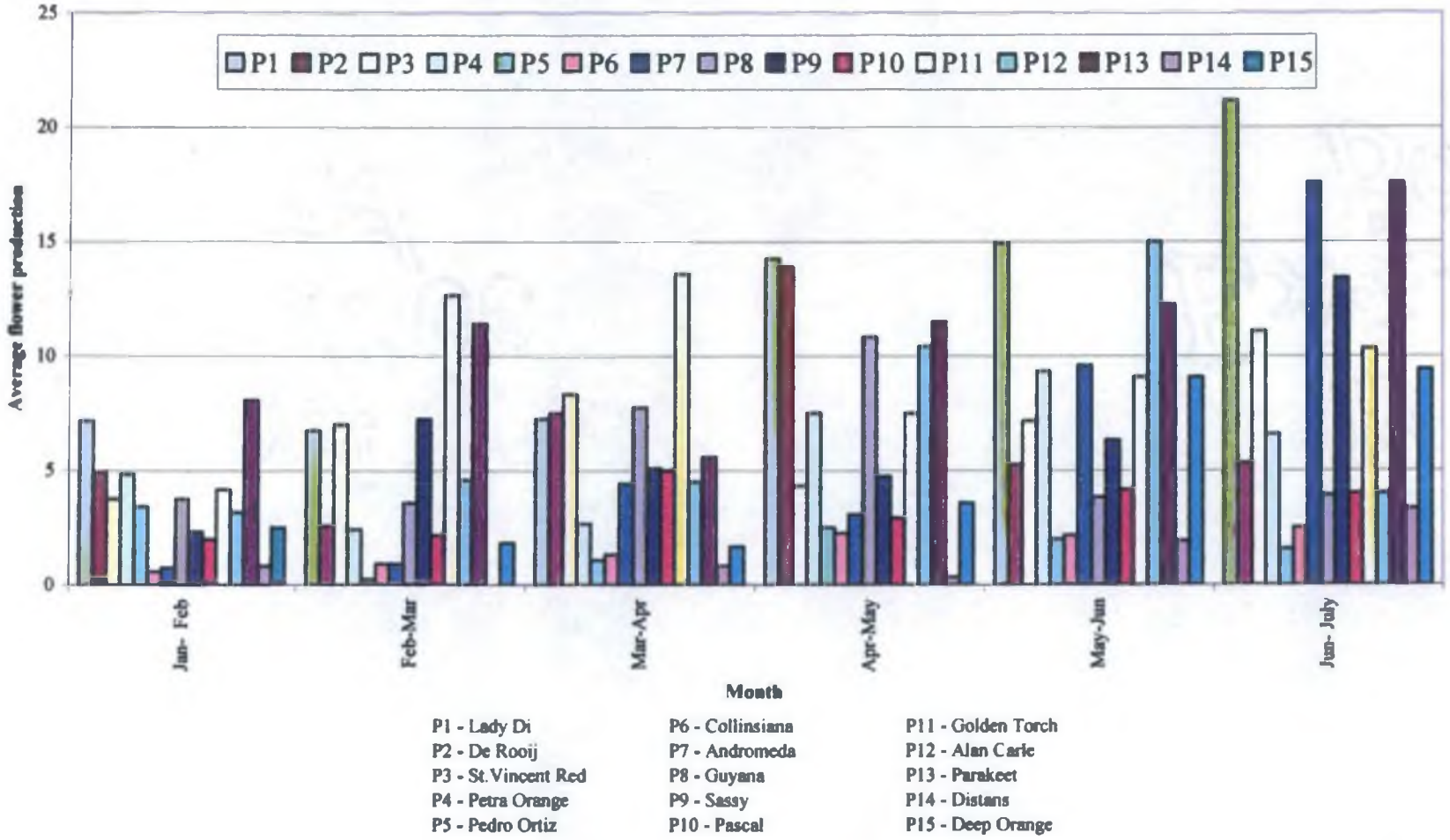


Fig. 1. Phenology of flowering in Heliconia (Continued)

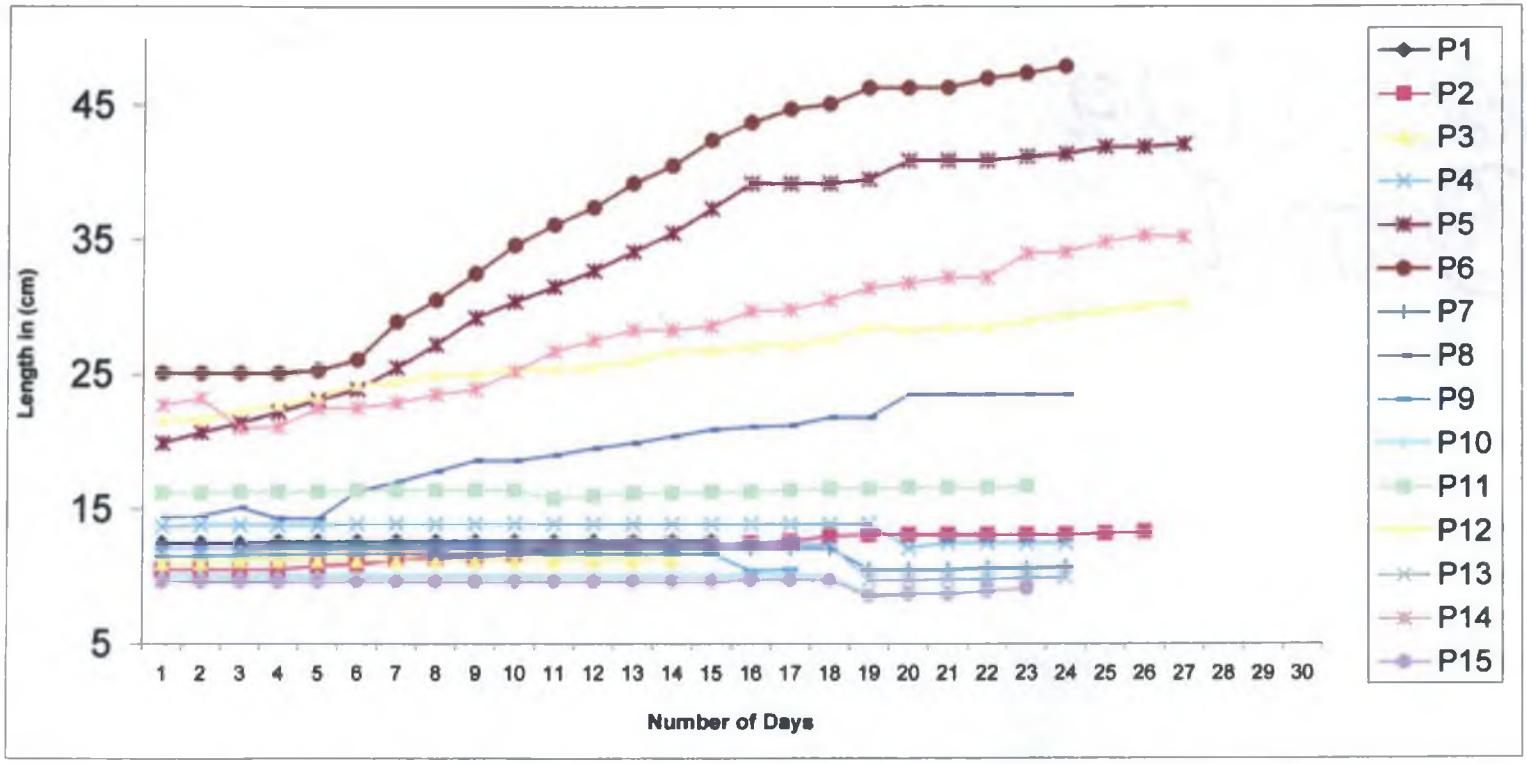


Fig. 2 Pattern of growth (Spike) of Heliconia

P1-Lady Di
P2-De Rooij
P3-St. Vincent Red
P4-Petra Orange
P5-Pedro Ortiz
P6-Collinsiana
P7-Andromeda
P8-Guyana
P9-Sassy
P10-Pascal
P11-Golden Torch
P12-Alan Carle
P13-Parakeet
P14-Distans
P15-Deep Orange

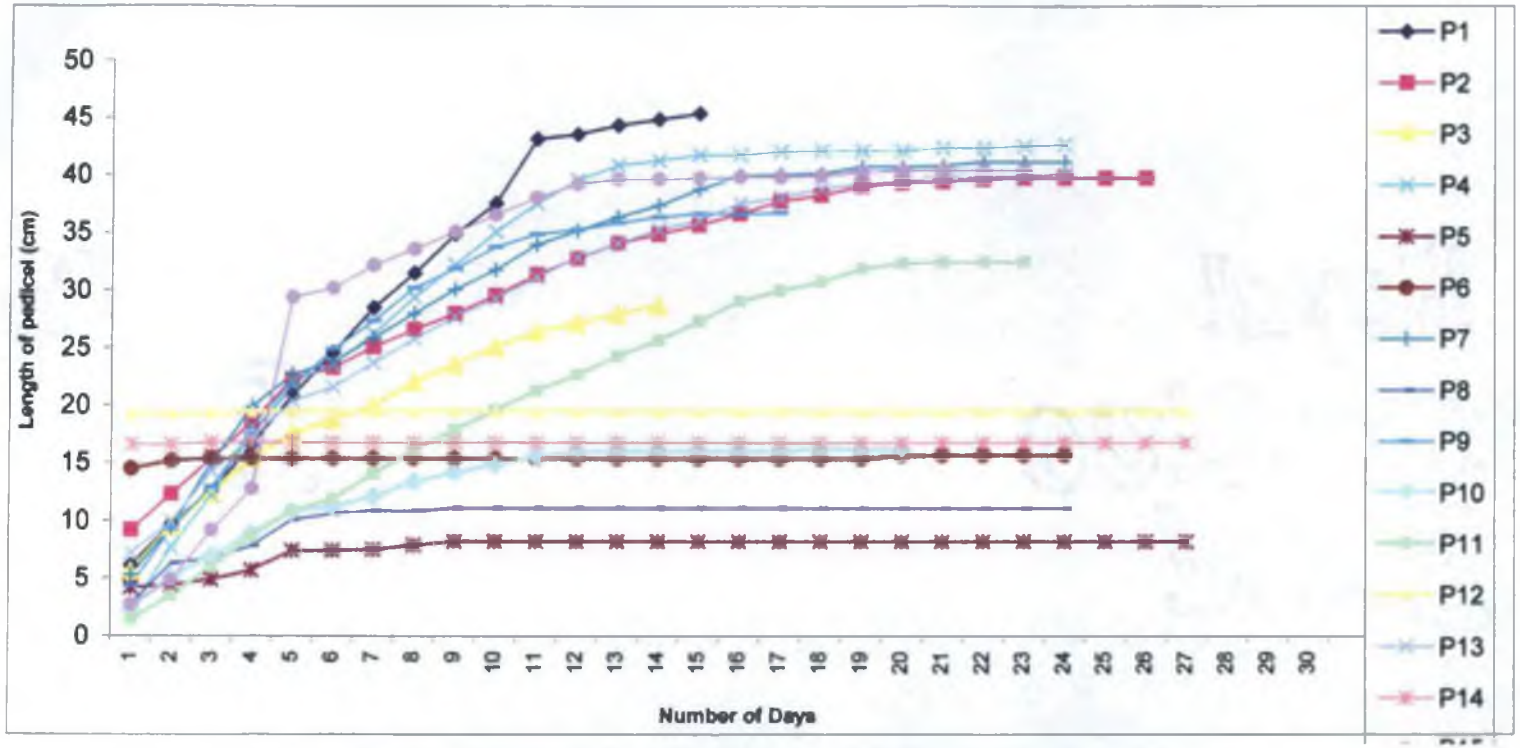


Fig. 2. Pattern of Growth (Pedicel) of Heliconia (Continued)

P1-Lady Di
P2-De Rooij
P3-St.Vincent Red
P4-Petra Orange
P5-Pedro Ortiz
P6-Collinsiana
P7-Andromeda
P8-Guyana
P9-Sassy
P10-Pascal
P11-Golden Torch
P12-Alan Carle
P13-Parakeet
P14-Distans
P15-Deep Orange

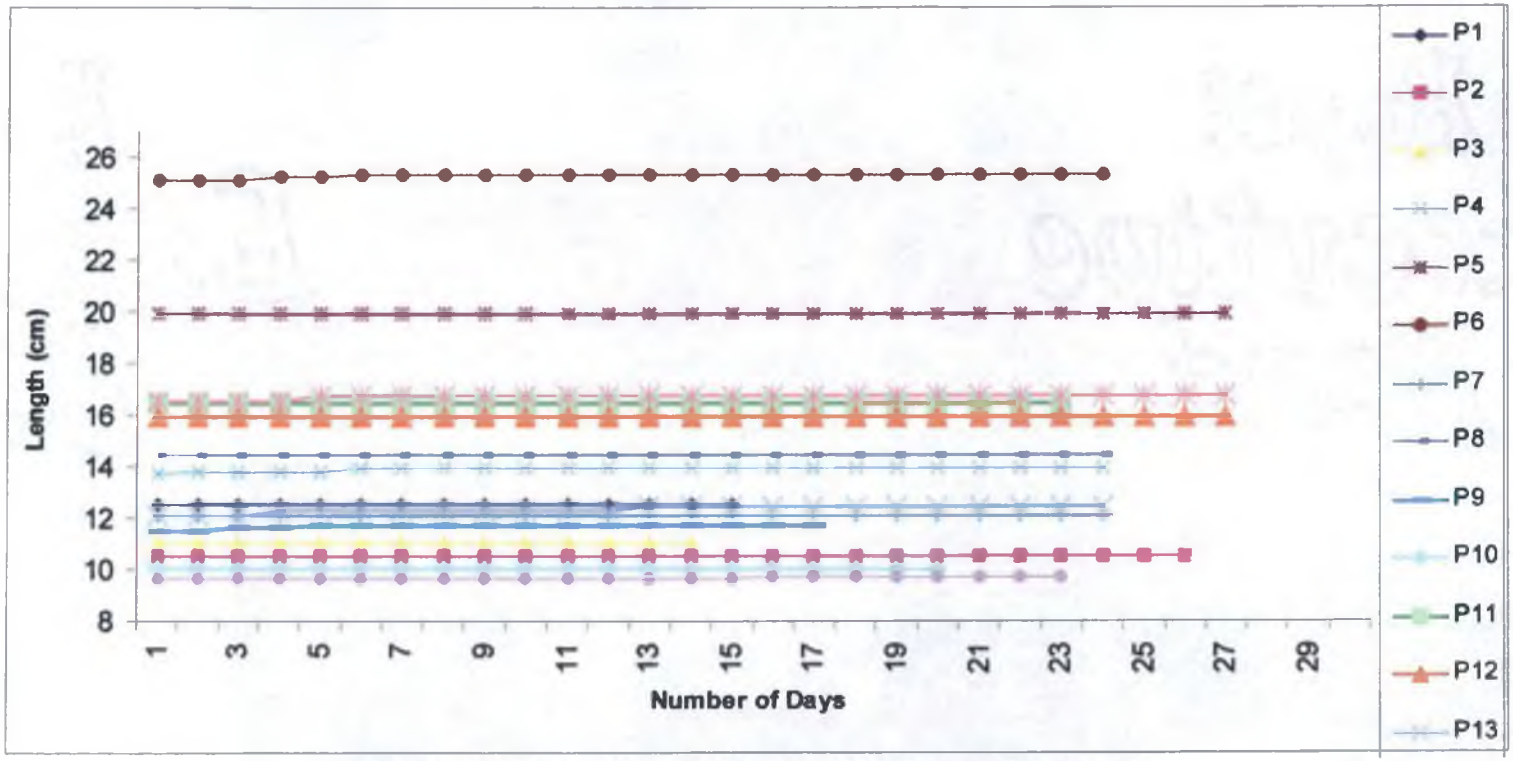


Fig. 2. Pattern of Growth (Bract) of Heliconia (Continued)

P1-Lady Di
P2-De Rooij
P3-St.Vincent Red
P4-Petra Orange
P5-Pedro Ortiz
P6Collinsiana
P7-Andromeda
P8-Guyana
P9-Sassy
P10-Pascal
P11-Golden Torch
P12-Alan Carle
P13-Parakeet
P14-Distans
P15-Deep Orange

Length of inflorescence is an important character in any cut flower. In heliconia also it was suggested by Atehortua (1997) and also by Mc Donald (1991) in Orchid breeding programme. However in heliconia it has been observed that inflorescence of larger dimensions are not always desirable, some of the varieties having large inflorescence have stout flower stalks contributing high total weight to the inflorescence. This is disadvantageous when the flowers are to be air lifted increasing the freight charges considerably. Further, very large inflorescences are not suitable for tabletop arrangements limiting their cut flower use. In the present investigation the *H. psittacorum* varieties produced compact inflorescence with lower weight, which was an acceptable character, Pascal recorded the lowest value of 26.95 cm, followed by Guyana with 29.87 cm. The highest inflorescence length was recorded for Collinsiana (57.6 cm), but this was a pendant type of heliconia, the pendant types are usually cut along with the entire flower stalk from the base and used as such for decorations of larger dimensions. So for this particular variety of pendant type the high inflorescence length was not an undesirable character.

Rani (2002) has reported that days to first flower opening from inflorescence emergence was primarily decided by the length of the inflorescence and its rate of growth in orchids. But this report was in contrary with the present study, as in heliconia the length of inflorescence showed negative correlation with characters like days from first to last flower opening (-0.0270), days from emergence to male phase (-0.0014) and days from emergence to female phase (-0.2283).

Number of days taken from emergence to full opening of bracts was lowest for the variety Andromeda which was on par with variety Petra Orange, the highest number of days taken was observed for the variety Alan Carle. In heliconia the inflorescence was harvested nearly after all the bracts are opened,

hence the time taken from opening of first bract to the last bract was not critical in this crop for determining the vase life.

Number and size of bract per inflorescence were important characters in deciding the beauty of the inflorescence in heliconia. As per Broschat *et al.* (1984), cultivars Andromeda and Golden Torch inflorescence have three or four bracts, from the present study, variety Andromeda produced 4.25 and Golden Torch produced 4.42 bracts per inflorescence. Varieties Pedro Ortiz and Collinsiana read highest number of bracts and size of bracts making these varieties eye catching but rather unwieldy in size. Pedro Ortiz had broader bracts arranged in compact manner than in Collinsiana, but in Collinsiana the bracts were arranged at wider spacing in the inflorescence and the shape of the bract was also long and narrow. In the *H. psittacorum* varieties the bract size ranged from 14.61m^2 in St Vincent Red to 77.43 m^2 in Alan Carle and number of bracts ranged from2.83 to 5.92 in Deep Orange and Alan Carle, respectively.

Peak anthesis time was between 5 and 6 am. For variety Collinsiana flower opening was found distributed. Anthesis time was delayed in summer season by one or two hours in varieties Parakeet, Distans and Deep Orange. This can be signified as reported by Croat (1980) that process related to anthesis varied with species and environment. Also the early flower opening in rainy season could be due to the rain splash on the perianth parts of the flower.

According to Synge (1947), anthesis refers to the flower opening, which brings about exposure of anthers and stigma to pollen vectors.

The varieties Petra Orange, Pedro Ortiz, Guyana, Golden Torch, and Alan Carle did not show any flower opening thus, varieties that did not show flower opening came under different species of which varieties Alan Carle, Golden Torch, Guyana and Pedro Ortiz are hybrids, signifying that it was not a species specific character. Shankar *et al.* (1981) has described the sexual polymorphism in cardamom and have reported about a plant, which has non-opening flowers.

Acetocarmine staining method was used to find pollen fertility of the selected genotypes. Pollen fertility was highest for Lady Di (89.39%), which was on par with Parakeet (85.14%). The lowest was recorded for Guyana (23.23 %), Alan Carle (24.92 %) and Pedro Ortiz (26.55 %). The fertile cultivars like Lady Di and Parakeet produced 1.48 percent and 4.56 percent seeds respectively upon selfing. The low fertile varieties like Guyana, Alan Carle and Pedro Ortiz did not set any seeds upon selfing. The high fertility was in accordance with the report of David (1985), that heliconia flower contains high fertile stamens that produce viable pollen and contrary report was made by Lee *et al.* (1994) that the varieties Sassy and Petra were completely sterile and Lady Di and Andromeda were only partially fertile, but in the present study, Sassy gave very good pollen fertility of 82.09 percent by the Acetocarmine staining method and Lady Di gave 89.39 percent fertility which was the highest in the study which may be attributed to the effect of favourable environmental conditions.

Venugopal and Parameswar (1974) reported that in cardamom, pollen grain of erect type were the largest and that of semi-erect the smallest. The pollen size of fertile pollen ranged from 365.25 μm in Petra Orange to 240.75 μm in variety Distans. It was observed that the size of pollen and its fertility are not related to the inflorescence size.

Anthocyanin content was recorded highest for genotype Lady Di with 58.38 mg/100 gm followed by Pedro Ortiz (38.78 mg/100 gm) and St. Vincent Red (35.76 mg/100 gm) all with dark red bracts.

The magnitude of variability present in a crop is of great importance as it provides basis of effective selection. Since, the observed variability in a population was the sum of variation arising due to the genotypic and environmental effects, knowledge of genetic variation contributing to gain under selection was essential (Allard, 1960).

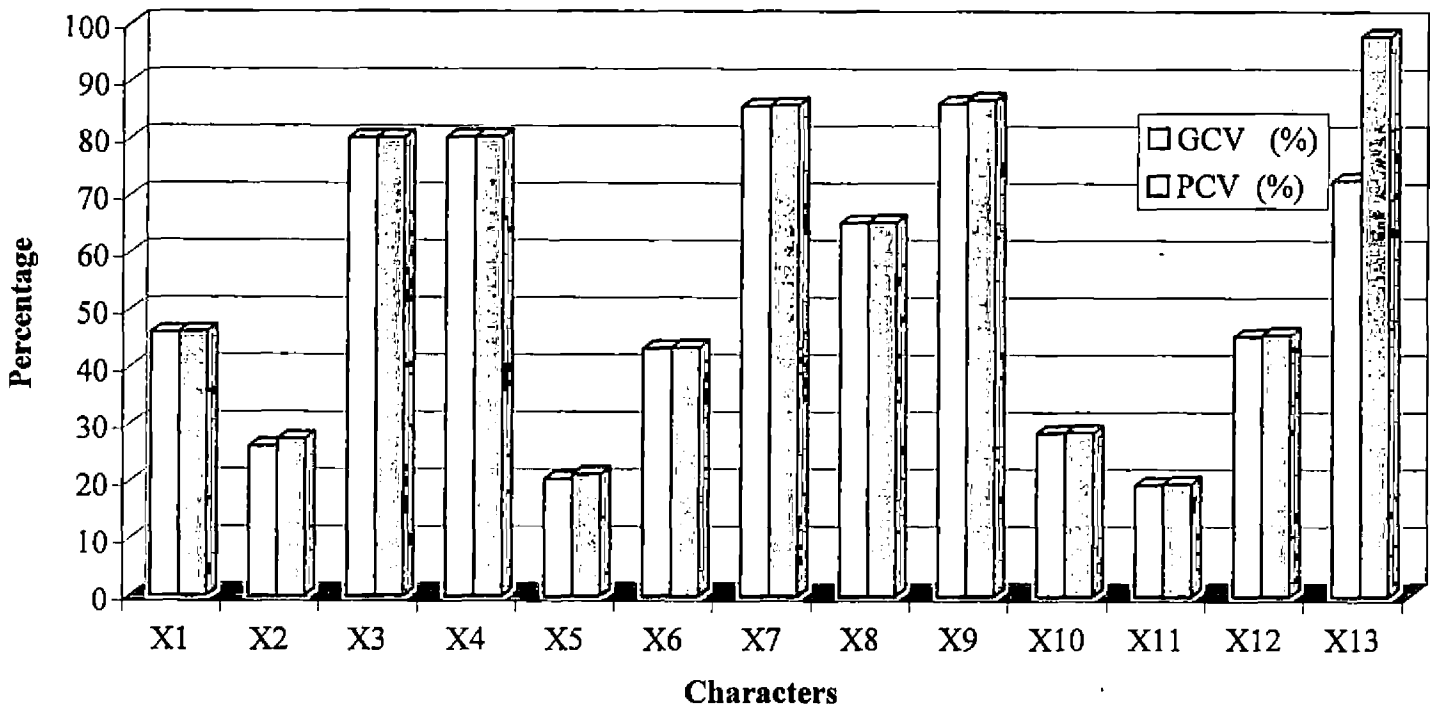
Phenotypic and genotypic coefficients of variation were estimated based on the coefficient of variation and these parameters were used to compare the variability among the fifteen genotypes. The GCV provides a valid

basis for comparing and assessing the range of genetic diversity for quantitative characters and PCV measures the extent of total variance. GCV and PCV are better indices for comparison of characters with different units of measurements, than estimates of quantitative variation like range and variation around mean.

A perusal of Table 8 and Fig.3 shows that highest PCV was obtained for pollen fertility (97.97%) and with GCV of 72.75 percent followed by Anthocyanin content with combined high PCV and GCV of 86.76 percent. The variability at genotypic (86.16%) was maximum for anthocyanin content followed by number of flowers per bract (86.66%). This reveals the great extend of variability for these characters, thereby suggesting good scope for improvement of these important characters. Lower values of GCV and PCV were estimated for the character size of bract as 19.45 percent for GCV and 19.67 percent for PCV indicating low magnitude of variability. So, improvement of this character has only a limited scope. It was seen that the size of bract was characteristic of particular species with little variation among different varieties of the same species at the same time extend of variability was very high between species.

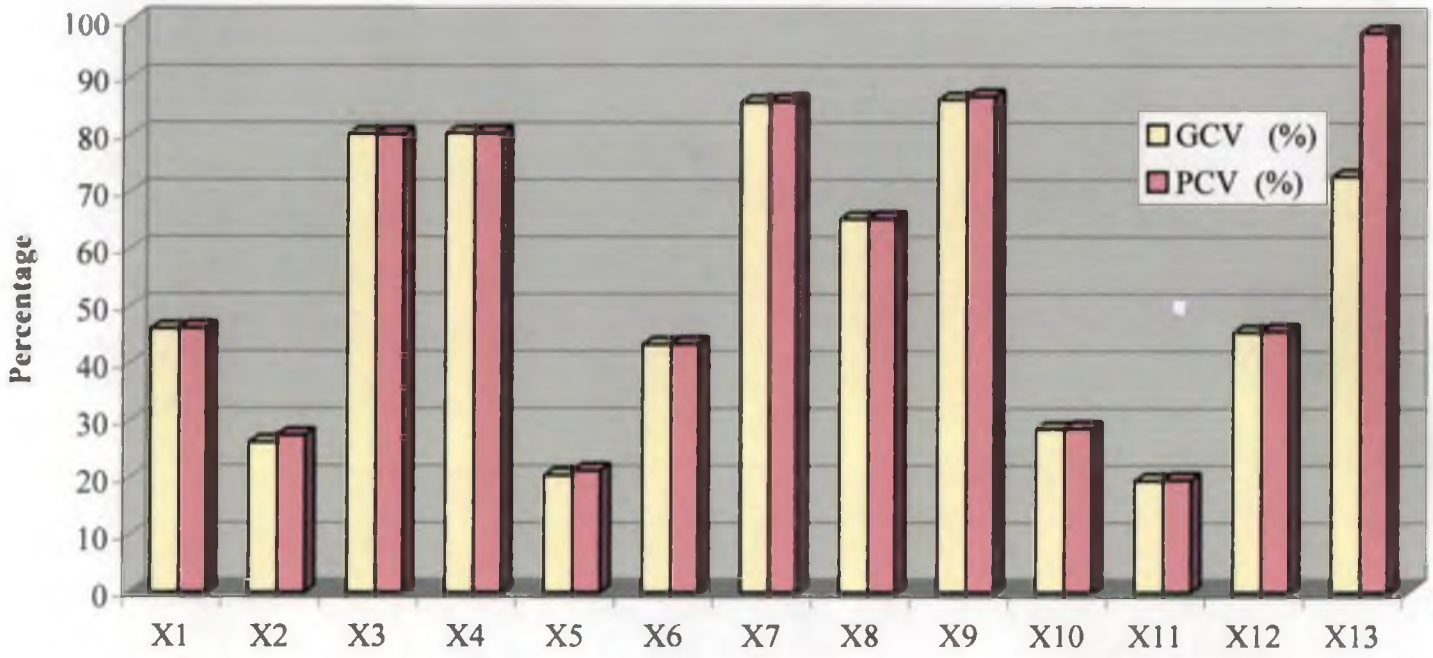
Heritability estimates the transmissibility of character from one generation to other and it provides a measure of the value of selection for different attributes. But heritability does not necessarily mean a high genetic advance for a particular character (Allard, 1960).

Heritability along with genetic advance was more useful than heritability alone in predicting the resultant effect of selecting the best individuals (Johnson *et al.*, 1955). Fig. 4 shows the distribution of characters in terms of heritability (H^2) and genetic advance (GA). The characters days from first to last flower opening, number of flowers per inflorescence, days from emergence to male phase, number of flowers per bract and anthocyanin content recorded high heritability and genetic advance was high for number of flowers per bract and anthocyanin content. Hence these characters can be considered for further crop improvement programmes.



X_1 Days from flower bud emergence to full opening of bracts
X_2 Days for Full unfurling of all the bracts
X_3 Days from first to last flower opening
X_4 Days from emergence to male phase
X_5 Days from emergence to female phase
X_6 Number of bracts
X_7 Number of flower/ bract
X_8 .Number of flower/ inflorescence
X_9 Anthocyanin content (mg/100gm)
X_{10} Length of inflorescence (cm)
X_{11} Size of bract (cm2)
X_{12} Pollen size (μ)
X_{13} Pollen fertility (%)

Fig. 3. GCV and PCV for thirteen traits in fifteen parental varieties of Heliconia



X_1 Days from flower bud emergence to full opening of bracts
X_2 Days for Full unfurling of all the bracts
X_3 Days from first to last flower opening
X_4 Days from emergence to male phase
X_5 Days from emergence to female phase
X_6 Number of bracts
X_7 Number of flower/ bract
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X_{11} Size of bract (cm2)
X_{12} Pollen size (μ)
X_{13} Pollen fertility (%)

Fig. 3. GCV and PCV for thirteen traits in fifteen parental varieties of Heliconia

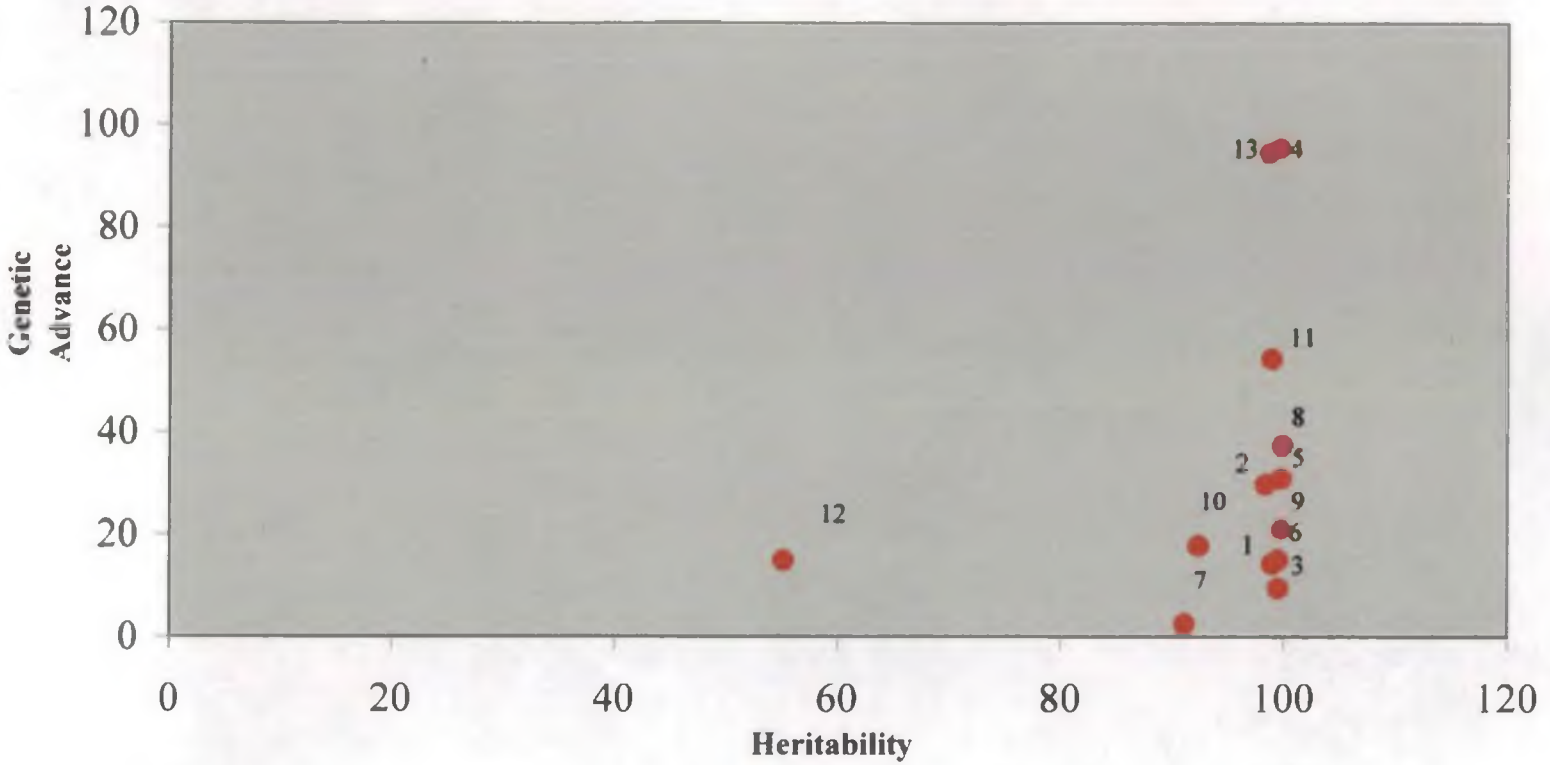
All the characters under the present study showed high heritability as per the classification of Robinson(1965). So selection of phenotypically superior plants with respect to these characters will result in significant improvement in the next generation. But as per the classification of Allard (1960) all the characters except the character pollen fertility showed high heritability.

If 5 percent selection was to be practiced, high genetic advance can be expected for number of flowers per bract and lowest for number of days for full opening of bracts. High heritability and genetic advance indicates that the character was controlled by additive gene action, suggesting the possibility of genetic improvement of those characters through selection (Panse and Sukhatma, 1967). In the present study the characters anthocyanin content and number of flowers per bract recorded high heritability coupled with high genetic advance, which shows that genetic improvement of these characters are possible through selection.

Genetically related characters tend to move in the same direction under selection favouring any one of such related traits. Such correlated response to selection was the basic property of quantitative traits under the control of polygenic system. The quantitative traits governed by one or a few genes do not exhibit correlated changes on selection (Sharma, 1994). The genotypic correlation (inherent) between the characters helps to differentiate the vital association useful in breeding from non-vital ones (Falconer, 1989).

The significance of pair wise correlation was estimated (Fig.5, 6 and 7). The genotypic, phenotypic and environmental correlations between all the possible pairs of characters are discussed. In the present study, days from first to last flower opening showed significant positive phenotypic correlation with days from emergence to male phase and pollen size revealing that these characters are important in breeding programmes.

If a positive correlation was observed for a pair of characters, certainly improvement in one character will improve the other character also, thus



1	Length of inflorescence (cm)	6	Days from flower bud emergence to full opening of bracts		
2	Size of bract(cm^2)	7	Days for unfurling of all the bracts	11	Pollen size (µ)
3	Number of bracts	8	Days from first to last flower opening	12	Pollen fertility (percent)
4	Number of flower/ bract	9	Days from emergence to male phase	13	Anthocyanin content (mg/100gm)
5	Number of flower/ inflorescence	10	Days from emergence to female phase		

Fig. 4. Heritability and genetic advance for thirteen traits in fifteen parental varieties of Heliconia

helping a breeder to select characters on the correlated response to selection. If the improvement in one character results in a decrease in the other character, this will also help the breeder in the selection of character if necessary. Similar results have been reported by Asish (2002) and Premna (2003) in Anthurium.

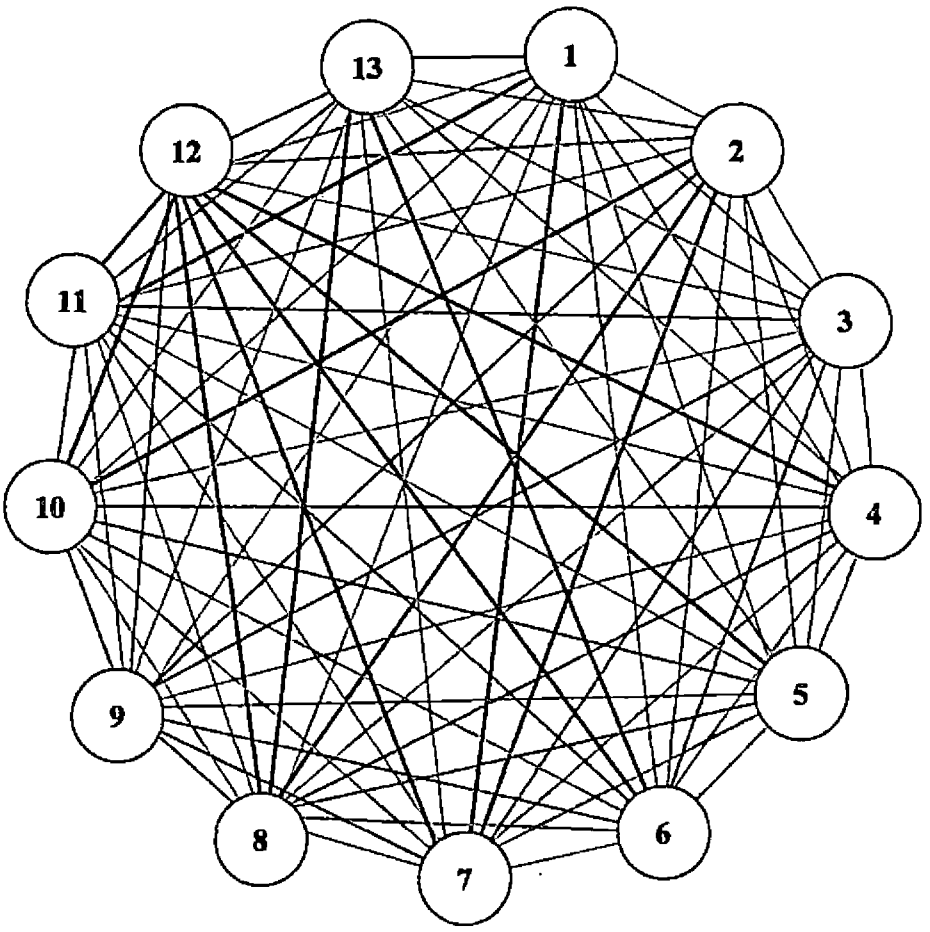
Environmental correlation was found for characters such as number of bract, which showed significant positive correlation with days from emergence to female phase, size of bract showed significant positive correlation with days to full opening of bracts and vice versa. Pollen size and days from emergence to male phase showed significant negative correlation. Anthocyanin content showed significant negative correlation with number of bracts. Hence the role of environment in the expression of these characters limits the chances of inheriting these characters through breeding.

Days from emergence to male phase showed positive genotypic correlation with first to last flower opening and negative correlation with days from emergence to female phase. Length of inflorescence was negatively correlated to days from emergence to male and female phase. Hence, a selection for increased length will result in decrease in number of days taken from emergence of bud to male or female phase. A clear understanding of these phenomena is critical in breeding programmes.

Size of bract was negatively correlated to pollen size and positively correlated to pollen fertility. It was also positively correlated to number of days from emergence to female phase and anthocyanin content.

Pollen size was positively correlated to pollen fertility and negatively correlated to number of bracts and number of flowers per bract.

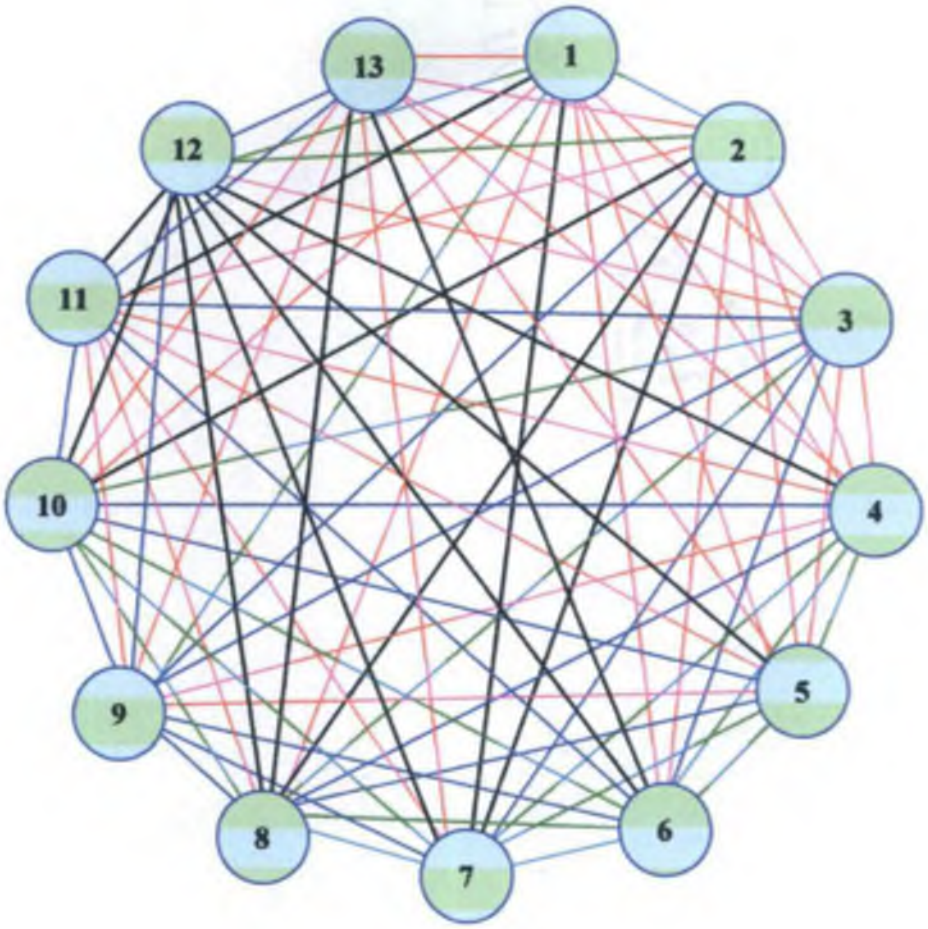
Berry and Kress (1991) has reported that in heliconia, pollination was mainly ornithophilous. Nectar feeding Bats (*Melanycteris woodfordi*) are pollinator of green heliconia and 'The Bronzy Hermit'- Common Humming Bird (*Glaucis aenea*) and 'Crowned Woodnymph Humming Bird'(*Thularania colombica*)



1 - Days from first to last flower opening
2 - Days from emergence to male phase
3 - Days from emergence to female phase
4 - Length of inflorescence (cm)
5 - Days from bud emergence to full opening of bracts
6 - Days for unfurling of all the bracts
7 - Number of bracts
8 - Number of flower/ bract
9 - Number of flower/ inflorescence
10 - Anthocyanin content (mg/100gm)
11 - Size of bract (cm2)
12 - Pollen size (μ)
13 - Pollen fertility (%)

Positive
Positive significant
Negative
Negative significant

Fig. 5. Phenotypic correlation coefficient among the characters in Heliconia



1 - Days from first to last flower opening
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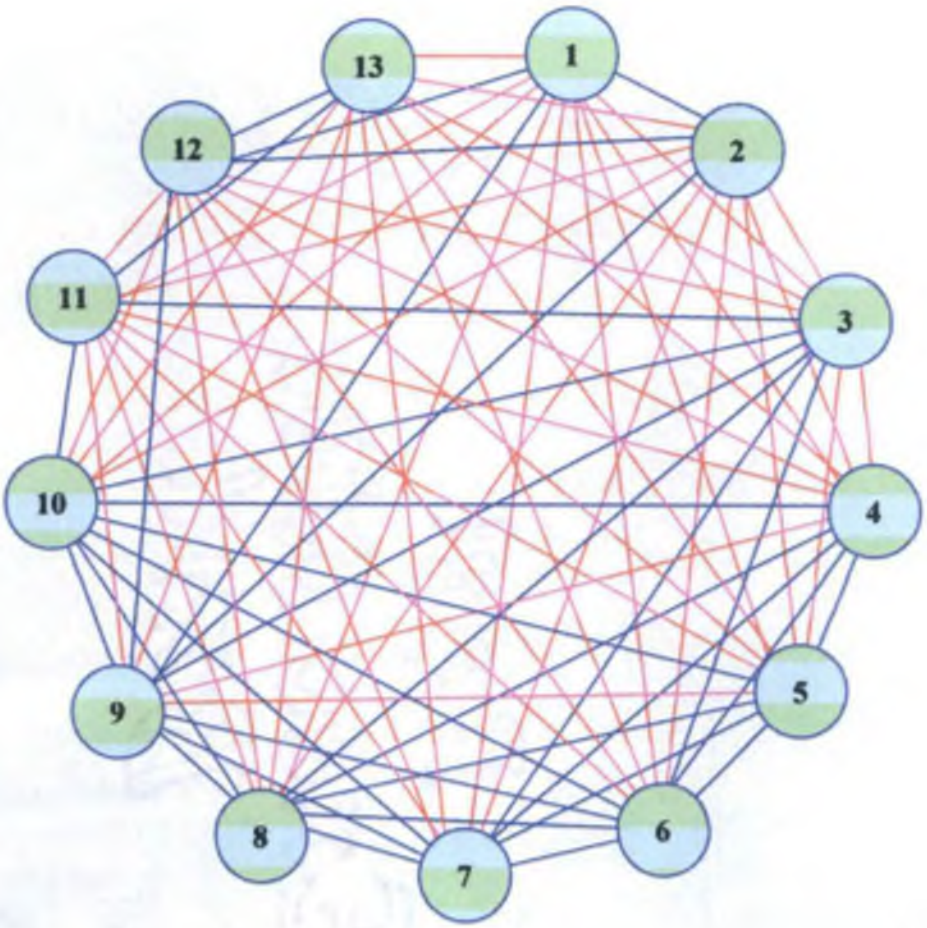
7 - Number of bracts
8 - Number of flower/ bract
9 - Number of flower/ inflorescence
10 - Anthocyanin content (mg/100gm)
11 - Size of bract (cm2)
12 - Pollen size (μ)
13 - Pollen fertility (%)

Positive
Positive significant
Negative
Negative significant

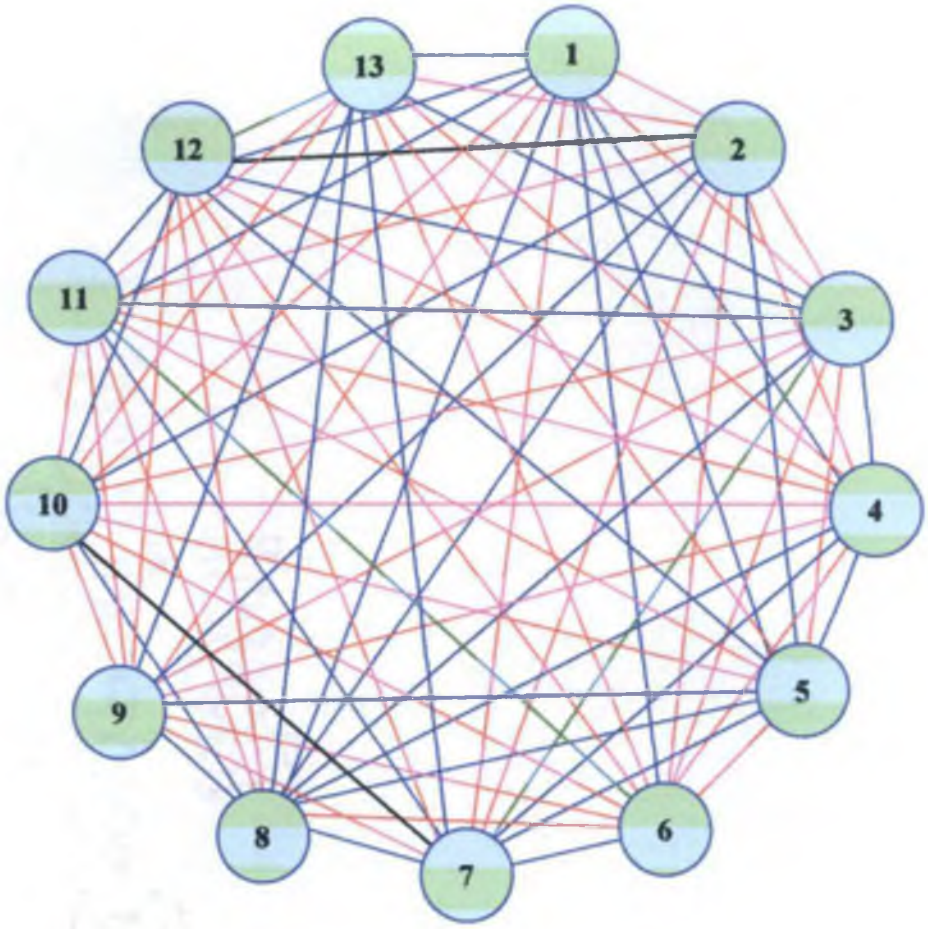
Fig. 5. Phenotypic correlation coefficient among the characters in Heliconia



1 - Days from first to last flower opening
2 - Days from emergence to male phase
3 - Days from emergence to female phase
4 - Length of inflorescence (cm)
5 - Days from bud emergence to full opening of bracts
6 - Days for unfurling of all the bracts
7 - Number of bracts
8 - Number of flower/ bract
9 - Number of flower/ inflorescence
10 - Anthocyanin content (mg/100gm)
11 - Size of bract (cm2)
12 - Pollen size (μ)
13 - Pollen fertility (%)

Positive
Negative

Fig. 6. Genotypic correlation coefficient among the characters in Heliconia



1 - Days from first to last flower opening
2 - Days from emergence to male phase
3 - Days from emergence to female phase
4 - Length of inflorescence (cm)
5 - Days from bud emergence to full opening of bracts
6 - Days for unfurling of all the bracts
7 - Number of bracts
8 - Number of flower/ bract
9 - Number of flower/ inflorescence
10 - Anthocyanin content (mg/100gm)
11 - Size of bract (cm2)
12 - Pollen size (μ)
13 - Pollen fertility (%)

Positive
Positive significant
Negative
Negative significant

Fig. 7. Environmental correlation coefficient among the characters in Heliconia

are exclusive pollinators of heliconia. However, Humming birds are alien to this place (Kerala-India). The observations of the present study also shows that birds have got role in pollination as 'Lotens Sun Bird' (*Nectarina lotenia*) was a common visitor of the heliconia flowers especially on varieties with bright coloured bracts like Lady Di, Distans, St.Vincent Red, Parakeet etc.

Grewal (1993) and Neelakandan (1996) have described 'Lotens Sun Bird' of family Nectariniidae to be feeding on flower nectar, insects, spiders etc. which may be possible pollinator in many plants.

Stingless Bees (*Melipona iridipennis* syn. *Trigona iridipennis)* was found frequently visiting the heliconia flowers during the day of anthesis.

Ants of various species were found intensively visiting the heliconia inflorescence during the period of unfurling of inflorescence and also during flower opening.

Ariophanta (Land Snail) was found visiting the heliconia flowers; especially in varieties like Collinsiana, Distans, Pedro Ortiz etc., which could also prove to be a possible pollinator of heliconia.

A thorough understanding of the compatibility relationships of the genera under considerations is essential for further breeding programmes. According to Atehortua (1997) future objectives in heliconia breeding will include plants adapted to a wider range of environment, smaller size and weight to facilitate transport, different flowering times to allow a year-round market and longer vase and transportation life. The factors mentioned are very much relevant in this context also.

In the present study, very high degree of incompatibility (84.76%) leading to flower and ovary abscission was observed without any visible post pollination floral changes. 11.42 percent ovary dried up within two months after pollination and 0.04 percent crossed berries dried up before maturity after two months of growth. In the case where abscission was observed without any

visible post pollination floral changes and even the initial swelling of ovary following pollination was not detected had incompatibility to the highest degree. Incompatibility to a lesser strength than the first level was observed where ovary dried up with in two months after pollination exhibiting initial blue colour and swelling. Least strength of incompatibility was seen in cases where berry dried up before maturity after two months of growth.

According to Watson and Dallwitz (1991) cross-fertilization between species were generally unsuccessful because pollen of one species was usually inhibited by other species. This report is in accordance with the result obtained in the study. The highest degree of incompatibility reaction exhibited in all the crosses attempted were in line with the report of Kress (1983) which states that crossability barriers between the majority of species were strong and foreign pollen tubes were inhibited at the stigmatic surface, within the stylar tissue or within the ovary. The site of inhibition was consistent for each pair of species, and depended on the parentage and the direction of the cross. Although additional isolating mechanisms, such as pollinator specificity and phenological separation were present, pre-fertilization crossability barriers acted as the ultimate mechanism to prevent hybridization. The type of barrier (stigmatic, stylar or ovarian) that existed between two species was not dependent upon the geographical distribution of the parental species or the specific types of pollinators that visit them, but in some cases might indicate taxonomic relationships.

Johansen (1990) has reported high incompatibility in interspecific pollination in Dendrobium. Incompatibility response was initiated by auxin content in pollinia.

In *Solanum*, Singh and Roy (1986) reported that the crossing was not successful in either direction of cross between cultivars Round Black and *Solanum surattense*. However the hybrid had good pollen fertility of 76.7 percent.

Another possible reason for the incompatibility as reported by Leon Hardt (1977) when large flowers are pollinated using pollen from small

flowers was purely physical rather than genetic. The pollen tube may not have had the physical capacity to grow down the length of the column to reach the unfertilised ovules. In the present investigation, different species of heliconia showed high amount of variation in structure of stigma (Plate 3).

Self-compatibility assessment was made for the female parent in the breeding programme and also for all the other fourteen varieties. High percentage of selfed seeds was obtained from the varieties Parakeet and De Rooij. Least percentage of fruit set was for St.Vincent Red. Lady Di (female parent in crossing) gave 1.48 percent seed set. The varieties Petra Orange, Pedro Ortiz, Collinsiana, Guyana and Alan Carle produced no berries at all. Lee *et al.* (1994) has reported that *H. latisptha* cv. Distans and Lady Di had only very low rate of fruit set (2.8-4.7%). The above report was in line with the present study as Andromeda yielding 2.9 per cent seed under open pollination and 2.26 percent seed under selfing. There was slight variation for Lady Di variety with 1.92 percent seed set on open pollination and 1.48 percent on self-pollination.

Lee *et al.* (1994) also has reported that poor fruit set of the varieties Andromeda and Lady Di was attributed to poor pollen germination on stigmas rather than poor pollination or self-incompatibility. The variety Sassy yielded 1.48 percent berries under open pollination and 1.19 percent seeds under selfing (Plate 5). This was contradictory to the studies of Lee *et al.* (1994), which reports that the variety Sassy was completely sterile.

Taking into account, the extend of self and cross compatibility, from the present investigation there appears to be many barriers in hybridisation programme in heliconia. Heliconia is a crop with wide variability and there is immense scope for exploitation of this variability provided, means are devised to overcome these barriers. Such means include attempting *in vitro* pollination and fertilisation; alternative methods of breeding like mutation breeding, using chemical or physical mutagens can also be attempted.

Summary

6. SUMMARY

The present investigation 'Floral biology and compatibility studies in Heliconia' was carried out in the Department of Pomology and Floriculture, College of Agriculture, Vellayani during 2004-2005 with the objective of studying the floral biology of Heliconia and compatibility of selected varieties. The results of the analysis are summarised below :

- Fifteen selected genotypes of heliconia analysed for the variation among the sixteen floral characters viz. days from flower bud emergence to full opening of bracts, days from first to last flower opening, days from emergence to male phase, duration of male phase, days from emergence to female phase, duration of female phase, number of inflorescence per plant per year, number of bracts, number of flowers per bract, number of flowers per inflorescence, anthocyanin content, length of inflorescence, size of bract, pollen size and pollen fertility.

- Anthesis time was estimated for the varieties. The peak anthesis time was estimated to be between 3 and 6 am. For variety Collinsiana, anthesis was found distributed from 8 pm to 7 am. There was no flower opening for varieties Petra Orange, Pedro Ortiz, Guyana, Golden Torch and Alan Carle.

- Pollen fertility estimated using acetocarmine staining method revealed that, Lady Di had the highest pollen fertility of 89.39 percent which is on par with Parakeet. The lowest pollen fertility was recorded for Guyana (23.23%).

- Qualitative characters such as colour and blending of colours of bracts and flowers were identified. Total anthocyanin content was estimated and highest value was recorded for Lady Di (58.38 mg/100 g).

- Variability studies revealed that highest variability for phenotypic component was observed for the character pollen fertility (97.97%) followed by anthocyanin content (87.76%). Genotypic component of variability was highest with 86.16 percent for anthocyanin content. The characters anthocyanin content and number of flowers per bract recorded high heritability coupled with high genetic advance, which shows that genetic improvement of these characters are possible through selection.

- Correlation studies revealed that days from first to last flower opening showed significant positive phenotypic correlation with days from emergence to male phase and pollen size. Days from emergence to male phase showed positive genotypic correlation with days from first to last flower opening and negative correlation with days from emergence to female phase. Length of inflorescence was negatively correlated to days from emergence to male and female phase. The environmental correlation was found for characters such as number of bracts, which had positive correlation with days from emergence to female phase, size of bract had positive correlation with days to full opening of bract and vice versa.

- Selfing of the selected fifteen varieties of heliconia yielded highest percent seed set for Parakeet (4.56%).

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- Cross compatibility estimation using Lady Di as female parent and other fourteen varieties as pollen parents yielded no seed set. Percentage of incompatibility estimates revealed 84.76 percent crossed flowers with very high degree of incompatibility, where ovary dried up without any visible post - pollination changes.

- Variety Sassy had 1.48 per cent fruit set under open pollination and 1.19 per cent by selfing, though it was reported by Lee *et al.* (1994) to be completely sterile.

- Lotens Sun Bird (*Nectarina lotenia*), Stingless Bees (*Melipona iridipennis* syn. *Trigona iridipennis)* and Ants were identified to be the possible pollinators of Heliconia.

- Land Snail (Ariophanta) was found as a frequent visitor of Heliconia during night hours especially in varieties like Collinsiana, Distans and Pedro Ortiz and there is possibility of it being a pollinator in these varieties, even though its exact role is not known.

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*Original not seen

Appendix

APPENDIX – I

Analysis of variance of floral characters in Heliconia

Sl. No.	Characters		Mean square	
		(Degrees of freedom)	Genotype (14)	Error (28)
1	Number of inflorescence/ plant/Year		248.36**	8.51**
2	Length of inflorescence (cm)		248.88**	6.7**
3	Size of bract (cm^2)		6438.88**	30.03**
4	Number of bracts		5.09**	0.16
5	Number of flower/ bract		64.05**	0.11
6	Number of flower/ inflorescence		6488.02**	8.99**
7	Days from bud emergence to full opening of bracts		146.45**	0.54
8	Days for full unfurling of all the bracts		5.09**	0.16
9	Days from first to last flower opening		989.24**	0.42
10	Days from emergence to male phase		316.03**	0.29
11	Duration of male phase		962.76**	0.35
12	Days from emergence to female phase		316.03**	0.29
13	Duration of female phase		962.76**	0.35
14	Pollen size (μ)		2263.37**	8.97**
15	Pollen fertility (%)		2117.2**	7.84**
16	Anthocyanin content (mg/100g)		677.56**	0.59

** Significant at 1 per cent level

Abstract

FLORAL BIOLOGY AND COMPATIBILITY STUDIES IN HELICONIA

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ABSTRACT

The present study, " Floral biology and compatibility studies in Heliconia" was undertaken to understand the Floral biology and to analyse the compatibility reaction of the selected genotypes of heliconia which would prove to be help in further breeding and crop improvement programmes.

Floral biology of fifteen heliconia genotypes and their compatibility was assessed by taking one promising variety of heliconia (Lady Di) with seed set as female parent and crossing with other fourteen selected pollen parents.

Variability studies indicated high phenotypic coefficient of variation for pollen fertility (97.97 %) .The variability of genotypic coefficient was highest for anthocyanin content (86.76 %) followed by number of flowers per bract. This reveals a great extend of variability for these characters. The character anthocyanin content and number of flowers per bract recorded high heritability coupled with high genetic advance.

Number of days from first to last flower opening showed significant positive phenotypic correlation with number of days from emergence to male phase and pollen size. The number of days from emergence to male phase showed positive genotypic correlation with first to last flower opening and negative correlation with days from emergence to female phase. Length of inflorescence was negatively correlated to number of days from emergence to male and female phase.

Peak anthesis time was found to be between 3 and 6 a.m for all the varieties except for variety Collinsiana where anthesis was found distributed between 8 p.m and 7 a.m. No flower opening was observed for varieties Petra Orange, Pedro Ortiz, Guyana, Golden Torch and Alan Carle.

Pollen fertility (89.39 %) was found to be highest for Lady Di, which was on par with Parakeet. The lowest pollen fertility was for variety Guyana (23.23%).

Anthocyanin content was the highest for Lady Di (58.38 mg/ 100 g).

Selfing yielded the highest percent seed set (4.56 %) for Parakeet.

Seed set was obtained for variety Sassy under open pollination and selfing.

Compatibility analysis where Lady Di was used as female parent and other fourteen selected varieties of Heliconia as pollen parents yielded no seed set. Very high degree of incompatibility (84.76 %) where ovary dried without any visible post pollination changes was observed in the compatibility analysis.

Lotens Sun Bird (*Nectarina lotenia*), Stingless Bees (*Melipona iridipennis* syn. *Trigona iridipennis)* and Ants were identified to be the possible pollinators of Heliconia.

The present study reveals many cross compatibility barriers in hybridisation of heliconia which should be overcome with precise physical, mechanical or chemical means as there exists a wide variability and potentiality for this crop which can be exploited for further crop improvement programmes and evolution of newer attractive varieties with highly desirable characters.