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Floral Architecture and Potential Floral Visitors of Dragon Fruit (*Hylocereus* spp. : Fam. Cactaceae)

Nagabhushana Reddy, G. Eswarappa, K. T. Vijayakumar and K. S. Jagadish
Department of Apiculture, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : nagabhushanareddy.b1997@gmail.com

Authors Contribution

Nagabhushana Reddy : Experimentation, data processing and manuscript preparation;

G. Eswarappa & K. S. Jagadish : Conceptualization, design, editing and supervision;

K. T. Vijayakumar : Editing manuscript

Corresponding Author :
Nagabhushana Reddy

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Abstract

The floral biology of *Hylocereus undatus* Haw. and *Hylocereus polyrhizus* Haw. in relation to floral visitors for enhancing cross pollination was studied at farmer's field, Suradenupura, Yelahanka, Bengaluru during 2021-22. Totally, 61 parameters with respect to morphology and floral biology were recorded. The flowering period initiated during 3rd week of April and required 17.75 ± 0.96 and 19 ± 2.58 days from bud initiation to flower opening in *H. undatus* and *H. polyrhizus*, respectively. Anthesis started at 19:00 hrs, reached maximum between 01:30 to 03:40 hrs and closed completely on next day between 11:30 to 12:00 hrs, while, anther dehiscence (14:00 hrs) started 5 hrs before anthesis. Pollen grains were viable (17:00 hrs) after 3 hrs of anther dehiscence, but stigma receptivity (23:00 hrs) started 9 hrs after anther dehiscence, after 6 hrs of pollen viability and 4 hrs after anthesis. Longevity of flower was 16 hrs and 30 minutes. Cessation of flowering is on 2nd week of September in *H. undatus* and 3rd week of October in *H. polyrhizus*. Sepals of un-opened flower buds secreted nectar and pollen is major floral reward for floral visitors. Heterostyly and protandry nature of flowers needs external agents for pollination. 14 floral visitors were recorded on the flowers of two dragon fruit types of which *A. mellifera* L. abundance was maximum.

Keywords : Floral architecture, Floral biology, Floral visitors

Dragon fruit, *Hylocereus undatus* (Haw.) Britton and Rose is a climbing cactus species which has received worldwide recognition as an ornamental and fruit crop. These fruits are most beautiful in the family Cactaceae, with a bright red peel studded with green scales and white or red flesh with tiny black seeds. The flesh of the fruit is juicy and very delicious in taste, so it is considered as 'King of Fruits' in Southeast Asia. Flowers are beautiful and nicknamed as 'Noble Woman' or 'Queen of the Night'. The consumption of fruits is known to bring down cholesterol levels, stabilizes the blood sugar levels, fends off colon cancer, shore up urinary function, cranks up the brain workings and improves the sharpness of the eyes. Dragon fruit is contemplated as the fruit crop for the future (Gunasena *et al*., 2006).

Dragon fruit, *Hylocerus* spp. is an exotic fruit crop belonging to the family Cactaceae, native to Central and South American rainforests. It has been well established as a new crop in various tropical countries due to its precocious yielding ability and its acceptability in the market. Dragon fruit has been introduced to India during late 1990's. In India, it is cultivated in Karnataka, Kerala, Tamil Nadu, Maharashtra, Gujarat, Orissa, West Bengal, Andhra pradesh and Andaman and Nicobar Islands in a small area of less than 400 ha (Karunakaran *et al.,* 2019). At the onset of flowering, 3-5 spherical buttons emerge from the stem margins and 2-3 of these may develop into flower buds in about 13 days. The light green cylindrical flower buds reach about 28 cm after 17 days when anthesis occurs. The flowers are large,

hermaphrodite and extremely showy. They are whitish pink in some types, very fragrant, nocturnal and bell shaped. The flower opens rapidly, starting between 6.30 - 7.00 pm and opening of the flower is completed at about 10.00 pm. Around 2.00 pm the flower closes after pollination and thereafter the flower begins to wilt. The petals close completely by daybreak (Gunasena *et al*., 2006).

It is reported that light intensity and temperature may affect the anthesis. On warm cloudy days, the flower may open at about 4.00 pm, whereas, in cool temperatures the wilting of flowers may be delayed till about 1.00 am. However, flowers remain open until the next morning if flowers are not pollinated during the night by nocturnal pollinators. The development of a floral bud to a fully opened flower takes 25-35 days (Pushpakumara *et al*., 2005 and Zee *et al*., 2004).

Flower production in Sri Lanka is usually from April to November, sometimes extending till December and it occurs in four to six flushes. Flowering is induced by long days; hence it is a photoperiod responsive species. However, the effect of photoperiod is dependent on temperature and that the time from photoperiodic induction to flower appearance increases when the temperature rises beyond the optimal point (Pushpakumara *et al*., 2005). The flowers of *Hylocereus polyrhizus* (Haw.) Britton and Rose are large, white in colour with nocturnal anthesis, accompanied by strong floral emission. The extension of floral anthesis also indicated mixed pollination syndromes of nocturnal and diurnal pollinators. Self-incompatibility of the plant is evidenced by spatial segregation of the sexual organs with approach herkogamy and dry-type stigma and numerous stigma lobes positioned above the anthers creating a large area that enhances a large amount of pollen deposition (Cho *et al*., 2021).

Pollination is essential in fruit production of the dragon fruit. As the flowers open in the night, bats and hawk moths in the natural range pollinate the flowers. In many countries where the crop is grown as a new crop, pollination is poor due to the lack of natural pollinators. Hence, hand pollination has been suggested to increase fruit set. Under Srilankan conditions, honey bee *Apis cerana* F., little honey bee *Apis florea* F. and rock bee *Apis dorsata* F. effectively pollinate the dragon fruit during the early morning hours (Pushpakumara *et al*., 2005).

Material and Methods

Two types of dragon fruit *viz*., Vietnam royal white, *Hylocereus undatus* (Haw.) Britton and Rose and Vietnam royal pink, *Hylocereus polyrhizus* (Haw.) Britton and Rose were selected to study the floral biology, floral visitors and their impact on fruit yield and quality parameters during 2021-22 in a farmer's field at Suradenupura (13° 12'08''N and 77° 33'50''E), Yelahanka (Tq.), Bengaluru Urban.

Floral Biology of Dragon Fruit

Detailed observations on the number of days taken for full bud development, time of anthesis, time of anther dehiscence, pollen viability, stigma receptivity, pollen output and longevity of flowers were recorded in both *Hylocereus undatus* and *Hylocereus polyrhizus* at the experimental site.

Duration from Flower Bud Initiation to Flower Opening

Newly initiated buds (n=10) on the stem were randomly selected and were tagged. The date on which the floral buds was initiated and their sequence of opening was recorded. From this data, the total number of days taken for flower opening was computed.

Time of Anthesis

The time of flower opening (anthesis) was recorded by tagging ten randomly selected flower buds (n=10). The tagged buds were observed from 0600 hrs at different time periods of the day upto opening of flower and the time of anthesis was recorded.

Longevity of Flower

A set of ten fully matured floral buds (n=10) were serially numbered by using tags and were observed daily to record the time and day of anthesis. The opened flowers were further monitored till they closed

completely. The time gap between opening of the flower and till it closed completely was considered as longevity of flower.

Time of Anther Dehiscence

Randomly selected floral buds (n=10) along with some portion of stem, were plucked from the plant and were observed for anther dehiscence in the laboratory. The sepals and petals were removed before opening of the flower and anthers were observed by using a hand lens (10 X). The dehiscence of anther was characterized by its change of colour.

Pollen Viability

Pollen grains were collected immediately from the time of dehiscence and upto complete closing of the flower. The collected pollen grains were dusted on a glass slide and one to two drops of acetocarmine solution (2%) was placed on these grains, covered with the cover slip and were left for 4-5 minutes for proper staining. Slides were examined under microscope. Deeply stained and normal looking pollen grains were considered to be viable, whereas, shrivelled, lightly stained or colourless pollen grains were counted as non-viable (Derin and Eti, 2001).

Stigma Receptivity

Randomly selected matured floral buds (n=10) from the plant were brought to laboratory before anthesis and anther dehiscence. The petals, sepals and stamens were removed before anthesis in order to expose the stigma for testing its receptivity.

A drop of hydrogen peroxide (6%) was placed on to the surface of the stigma and formation of bubbles were observed through hand lens (10 X). The bubbling from stigma was considered as mark of receptivity of stigma. The observations were recorded at hourly intervals from previous day of flower opening, till it closed completely.

Pollen Output Per Flower

The sepals and petals of fully matured five floral buds of both the varieties were removed before anther dehiscence (1400 hrs). The floral buds were covered with plastic covers. At the time of complete closing of the flower (1200 hrs), flowers were shaken for the collection of the pollen in the plastic covers. The study was conducted both in the field as well as in the laboratory. The weight difference between the cover with pollen and the empty cover was treated as pollen yield per flower. It was expressed as grams of pollen grains per flower.

Floral Architecture of Dragon Fruit

Flowers (n=10) were randomly selected from the plant and were brought to the laboratory. The floral architecture parameters such as flower length, flower width, number of sepals per flower, number of petals per flower, number of stamens per flower, length of stamens and length of carpel were recorded by dissecting individual floral parts and also by taking the cross section of the ovary. Emphasis was laid on those structures that were useful in attracting floral visitors to enhance cross pollination (Cruden, 1977; Pias & Guitian, 2001 and Griffin & Barrett, 2002).

***Apis* and Non-*Apis* Floral Visitors of Dragon Fruit**

The observations on different species of floral visitors, their abundance, composition and diversity were recorded to recognize the most efficient pollinator species during the flowering period. All the *Apis* and non-*Apis* floral visitors including crepuscular and nocturnal visitors of dragon fruit at different phases of its flowering were collected through methods suggested by Belavadi and Ganeshaiah (2013), through visual scanning and sweep net sampling technique.

Visual Counting of Floral Visitors

Ad-libitum sampling of floral visitors for a sampling time of five minutes at hourly intervals was followed. All the floral visitors including nocturnal visitors of dragon fruit flower per sampling time were counted and recorded. The observations on species of floral visitors and number of each species per sample were recorded starting from 0600 to 1800 hrs, at hourly intervals for a period of 5 min in each hour. This was done to record variations in species composition and their abundance if any, at different time intervals of

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the day. The crepuscular and nocturnal visitors of dragon fruit were recorded through time-lapse camera and by visual observations. The observations were repeated at different phases of flowering. Among the insect floral visitors, the most frequently visiting species and type of floral resource (nectar/pollen) they collected was recognized during these observations for drawing further interpretations on their foraging behaviour (Belavadi and Ganeshaiah, 2013).

Results and Discussion

Floral Biology of Dragon Fruit Types

A total of 61 parameters with respect to floral morphology and floral biology were recorded in dragon fruit types, *Hylocereus undatus* (white flesh) and *Hylocereus polyrhizus* (pink flesh). The observations on floral biology parameters such as time taken from bud initiation to anthesis, time of anthesis, longevity of flower, time of anther dehiscence, pollen viability and stigma receptivity were recorded at different flowering phases of dragon fruit types during 2021-22 (Table 1).

Time taken from Floral Bud Initiation to Anthesis

The initiation of spherical button type floral buds from marginal spines of the stem was recorded during 3rd week of April in both the dragon fruit types, *Hylocereus undatus* (white flesh) and *Hylocereus polyrhizus* (pink flesh). Similarly, earlier study by Pushpakumara *et al.*, (2005) revealed that the flower production of dragon fruit in Sri Lanka usually starts from April to November, it may extend upto December.

Around 17.75 ± 0.96 and 19 ± 2.58 days were required for the floral bud to open completely in *Hylocereus undatus* and *H. polyrhizus* (Table 1), respectively. Contrary to the present findings, Pushpakumara *et al*., (2005) stated that, the three-five spherical buttons emerge from the stem margins at the onset of flowering and only two-three developed into flower buds in about 13 days at Sri Lanka.

Initiation of Anthesis and Longevity of Flowers

The flowers of *Hylocereus undatus* and *H. polyrhizus* which are nocturnal in anthesis, started opening in

Table 1

Floral biology and floral architecture of *Hylocereus undatus* (white flesh) and *H. polyrhizus* (pink flesh) dragon fruit types during 2021-22

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Floral bud initiation	3rd week of April	3rd week of April
Days taken from floral bud initiation to flower opening	17.75±0.96	19±2.58
Initiation of anthesis	19:00 to19:30 hrs.	19:00 to19:30 hrs.
Time at which flower opens fully	01:30 hrs.	01:30 hrs.
The time in which flowers remains open fully	01:30 hrs. to 03:40 hrs.	01:30 hrs. to 03:40 hrs.
Time at which closing of flower started	03:40 hrs.	03:40 hrs.
Time at which flower closes completely	11:30 to 12:00 hrs.	11:30 to 12:00 hrs.
Longevity of flower	16 hours and 30 minutes	16 hours and 30 minutes
Time of anther dehiscence	14:00hrs. (Before anthesis)	14:00hrs. (Before anthesis)
Time at which pollens become viable	17:00hrs. (Before anthesis)	17:00hrs. (Before anthesis)
Time at which stigma become receptive viability and 4hrs after flower	23:00 hrs. (after 6hrs of pollen viability and 4hrs after flower opening)	23:00 hrs. (after 6hrs of pollen opening)
Type and symmetry of flower Zygomorphic	Hermaphrodite and Zygomorphic	Hermaphrodite and

Continued....

TABLE 1 Continued....

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Length of fully opened flower (cm)	29.50 ± 1.83	29.55 ± 0.76
Number of basal sepals	30±2.16	30±2.94
Colour of basal sepals	Dark greenish with pink colour	Dark greenish and edges lined
Length of basal sepals (cm)	3.45±0.26	3.55±0.31
Width of basal sepals(cm)	0.88±0.26	1.16±0.36
Number of middle sepals	13±0.82	13±1.41
Colour of middle sepals	Light greenish to light yellowish pink colour	Light green and edges lined with
Length of middle sepals (cm)	9.3±1.62	9.68±1.58
Width of middle sepals(cm)	1.12±0.36	1.24±0.2
Number of transitional sepals	19.25±1.71	19.25±0.96
Colour of transitional sepals	Light yellowish to whitish	Light yellowish to whitish
Length of transitional sepals (cm)	14.75±0.92	15.18±0.96
Width of transitional sepals (cm)	1.3±0.34	1.21±0.17
Number of petals	21.75±3.30	21.75±2.63
Colour of petals	White	White
Length of petals (cm)	12.13±0.99	13.87±2.0
Width of petals (cm)	3.3±0.6	2.95±0.57
Number of stamens	1269.±96.43	1337.±184.52
Colour of stamens	Dull white	Dull white
Length of basal stamen (cm)	8.93±0.43	9.42±0.05
Length of middle stamen (cm)	8.50±0.39	9.15±0.16
Length of apical stamen (cm)	6.78±0.15	7.33±0.51
Length of pistil (cm)	24.25±2.54	25.55±0.85
Length of style (cm)	19.7±2.17	21.0±0.80
Perimeter of style (cm)	2.83±0.15	2.45±0.06
Diameter of style (cm)	0.75±0.06	0.55±0.06
Shape of the ovary	Oval	Round
Position of ovary	Epigynous(Inferior ovary)	Epigynous(Inferior ovary)
Diameter of basal part of ovary (cm)	0.93±0.1	0.91±0.09
Diameter of middle part of ovary (cm)	1.50±0.08	1.21±0.15
Diameter of apical part of ovary (cm)	0.98±0.15	0.90±0.08
Number of ovules per ovary	Numerous	Numerous
Number of stigma lobes	25.0±0.82	25.5±1.29
Length of stigma lobes (cm)	1.98±0.48	2.68±0.1
Nectar secretion	Sepals of un-opened flower bud	Sepals of un-opened flower bud
Pollen yield per flower(g)	1.95±0.26	1.98±0.17
Colour of pollen	White	White
Shape of pollen	Round	Round

Continued....

Table 1 Continued....

Parameters/Observations	*Hylocereus undatus* (Mean ± SD)	*Hylocereus polyrhizus* (Mean ± SD)
Nature of pollen	Sticky	Sticky
Scope for cross pollination	Heterostyly and Protandry	Heterostyly and Protandry
Length of pistil over stamens before opening of flower (cm)	3.37±1.25	2.4±0.48
Length of pistil over stamens after opening of flower (cm)	2.25±0.28	1.75±0.28
Structure of flower that attracts insect visitors for enhancing cross pollination	Cone shaped stigma lobes and petals	Cone shaped stigma lobes and petals
No. of phases of flowering per year	7 phases	8 phases
Duration of flowering within each phase	4.85±0.37 days	4.62±0.51 days
No. of days between the flowering phases	16.33±7.20 days	19.70±9.90 days
No. of days taken from bud initiation to fruit harvest	50-55 days	50-55 days
No. of days taken from flower opening to fruit harvest	30-35 days	30-35 days
Cessation of flowering	2nd week of September	3rd week of October

between 19:00 to 19:30 hrs, opened fully at 01:30 hrs and remain fully opened upto 03:40 hrs. The closing of the flower commenced at 3:40 hrs and it closed completely in between 11:30 to 12:00 hrs. Longevity of the flower in both dragon fruit types was 16 hrs and 30 minutes (Table 1). These findings are similar to that of Pushpakumara *et al*. (2005) who stated that, the flower opens rapidly in between 6.30 - 7.00 pm and its opening is completed at 10.00 pm. The flowers started closing around 2.00 am, after pollination and thereafter, the flower begins to wilt. On warm cloudy days, the flower may open at about 4.00 pm, while in cool temperatures, the wilting may be delayed till about 1.00 pm. The petals completely closed by day break.

Time of Anther Dehiscence

The extent of dehisced anthers were observed in ten flowers each of *Hylocereus undatus* and *H. polyrhizus* with the help of hand lens (10 X) at hourly intervals before opening of flower starting from 12:00 hrs both in the farmer's field and as well as Post graduate laboratory at the Department of Apiculture, UAS, GKVK, Bengaluru. All the observed flowers revealed that anthers were completely dehisced before opening of flowers by 14:00 hrs of the day (Patil *et al.,* 2024 and Gaddi *et al.,* 2024).

Floral Architecture of Dragon Fruit

The observations on floral architecture parameters *viz.,* symmetry of flower, length of fully opened flower, number of sepals per flower, length of the sepals, number of petals per flower, length of the petals, number of stamens per flower, length of stamens, number of stigma lobes, length of style, length of stigma lobes, extension of heterostyly, diameter of the ovary, position of the ovary, pollen and nectar yield and other morphometric measurements of the flowers were recorded by dissecting individual floral parts and also by taking the cross section of ovary in both dragon fruit types (Table 1).

Type, Symmetry and Length of Fully Opened Flower

The flowers are hermaphrodite, zygomorphic in symmetry and the length of fully opened flower in *Hylocereus polyrhizus* (29.55 ± 0.76 cm) was slightly greater than the length of fully opened flower of *H. undatus* (29.50 ± 1.83 cm). The variation in the length of the flower is attributed to the genetic make-up of the two types of dragon fruit.

Description of Sepals and Petals

There was no variation in the number of petals present in the flowers of *Hylocereus undatus* (21.75 ± 3.30)

and *H. polyrhizus* (21.75 ± 2.63) and they were white in colour. The length of petals was more in *H. polyrhizus* (13.87 ± 2.0 cm) compared to the length of petals of *H. undatus* (12.13 ± 0.99 cm). However, width of petals was more in *Hylocereus undatus* (3.3 ± 0.6 cm) as compared to 2.95 ± 0.57 cm width in *H. polyrhizus*.

The flowers of *Hylocereus undatus* and *H. polyrhizus* consist of three types of sepals *viz.,* basal sepals (30.00 ± 2.16 and 30.00 ± 2.94), middle sepals (13.00 ± 0.82 and 13.00 ± 1.41) and transitional sepals (19.25 ± 1.71 and 19.25 ± 0.96), respectively, (Table 1). The colour of basal sepals in *Hylocereus undatus* was dark greenish and these sepals were dark green and their edges were lined with pink colour in case of *Hylocereus polyrhizus.* However, middle sepals in *Hylocereus undatus* were light greenish to light yellowish and these sepals were light green and edges lined with pink colour in case of *Hylocereus polyrhizus*. However, transitional sepals in both the types of dragon fruit were light yellowish to whitish in colour. The length of basal (3.55 ± 0.31 and 3.45 ± 0.26 cm), middle (9.68 ± 1.58 and 9.31 ± 1.62 cm) and transitional sepals (15.18 ± 0.96 and 14.74 ± 0.92 cm) were more in *Hylocereus polyrhizus* compared to *H. undatus*. The width of basal (1.16 ± 0.36 and 0.88 ± 0.26 cm) as well as middle sepal (1.24 ± 0.2 and 1.12 ± 0.36 cm) was more in *Hylocereus polyrhizus* as compared to that of *H. undatus,* with the exception of width (1.30 ± 0.34 and 1.21 ± 0.17 cm) of transition sepals.

Description of Stamens and Style

The flowers of *Hylocereus polyrhizus* (1337 ± 184.52) had more number of stamens as compared to *H. undatus* (1269 ± 96.43) and they were dull white in colour. Flower consisted of three types of stamens *viz.,* basal, middle and apical stamens in both types of dragon fruit. The length of basal (9.42 ± 0.05 and 8.93 ± 0.43 cm), middle (9.15 ± 0.16 and 8.50 ± 0.39cm) and apical (7.33 ± 0.51 and 6.78 ± 0.15 cm) stamens was more in *H. polyrhizus* than *H. undatus*.

There was variation in length, perimeter and diameter of pistil and style in the flowers of *Hylocereus undatus* and *H. polyrhizus*. The length of pistil and style in flowers of *H. polyrhizus* (25.55 ± 0.85 and 21 ± 0.80 cm) was more than that of *H. undatus* (24.25 ± 2.54 and 19.7 ± 2.17 cm) flowers. However, perimeter and diameter of style were more in the flowers of *H. undatus* (2.83 ± 0.15 and 0.75 ± 0.06 cm) as compared to that of *H. polyrhizus* (2.45 ± 0.06 and 0.55 ± 0.06 cm) flowers.

Description of Ovary and Stigma Lobes

The ovary in the flowers of *Hylocereus undatus* was oval in shape and epigynous in position, whereas in *H. polyrhizus,* ovary was round in shape and epigynous in position. The diameter of basal, middle and apical part of ovary was more in *H. undatus* (0.93 ± 0.1, 1.50 ± 0.08 and 0.98 ± 0.15 cm) as compared to that of *H. polyrhizus* (0.91 ± 0.09 cm, 1.21 ± 0.15 cm and 0.90 ± 0.08 cm) with numerous ovules per ovary. The number and length of stigma lobes in the flowers of *H. polyrhizus* (25.5 ± 1.29 and 25 ± 0.82 cm) was relatively maximum compared to that of *H. undatus* (2.68 ± 0.1 and 1.98 ± 0.48 cm) flowers.

Floral Rewards

The unopened floral bud and opened flowers offered important rewards for floral visitors. The sepals of unopened flower buds secreted the unquantifiable nectar, which attracted the floral visitors before opening of the flowers in both the types of dragon fruit (Plate 9 and 10). The laboratory studies on estimation of pollen yield revealed that the flower of *H. polyrhizus* (1.98 ± 0.17g) offered maximum yield of pollen to floral visitors as compared to 1.95 ± 0.26 g pollen in the flower of *H. undatus*. The pollen of both types of dragon fruit were characterised by white colour, round shape and sticky nature.

Scope for Cross Pollination of Flowers

The heterostyly before and after opening of flowers in *Hylocereus undatus* (3.37 ± 1.25 and 2.25 ± 0.28 cm) and in *H. polyrhizus* (2.4 ± 0.48 and 1.75 ± 0.28 cm) necessitated the biotic or abiotic agents to transfer the pollen grains from anthers to the stigma lobes for effective cross pollination of flowers. The flower structures especially cone shaped stigma lobes and petals attracted the insect floral visitors and provided

enough space for the floral visitors to load the pollen on to their hind legs, during this process also effective cross pollination of the flowers was achieved.

Fruit Harvest and Cessation of Flowering

Around 50-55 days were required from bud initiation upto fruit harvest and 30-35 days were required from flower opening upto fruit harvest in both *Hylocereus undatus* and *H. polyrhizus*.The plants of *H. undatus* stopped the flower production during 2nd week of September, whereas the plants of *H. polyrhizus* stopped the flower production during 3rd week of October.

Pollen Viability and Stigma Receptivity

The observations recorded at hourly interval before anthesis (12:00-18:00 hrs) and after anthesis (19:00-12:00 hrs) on pollen viability and stigma receptivity of *Hylocereus undatus* and *H. polyrhizus* under laboratory conditions are as presented in the Table 2 and Table 3. The staining of pollen grains with acetocarmine solution (2%) and examination under the microscope revealed that pollen grains are non-viable from 14:00-16:00 hrs before opening of the flower. The pollen grains became viable

Table 2

Pollen viability and stigma receptivity of dragon fruit type, *Hylocereus undatus*

Time (hrs)	*Hylocereus undatus* (white flesh)	
	Pollen viability	Stigma receptivity
Before anthesis		
12:00	NV	NR
13:00	NV	NR
14:00	NV	NR
15:00	NV	NR
16:00	NV	NR
17:00	V	NR
18:00	V	NR
After anthesis		
19:00	V	NR
20:00	V	NR
21:00	V	NR
22:00	V	NR
23:00	V	R
24:00	V	R
01:00	V	R
02:00	V	R
03:00	V	R
04:00	V	R
05:00	V	R
06:00	V	R
07:00	V	R
08:00	V	R
09:00	V	R
10:00	V	R
11:00	V	R
12:00	V	R

Continued....

Table 2 Continued....

Note : NV= Non-viable; V= Viable; NR=Not-receptive; R=Receptive

Table 3

Pollen viability and stigma receptivity of dragon fruit type *H. polyrhizus*

Time (hrs)	*Hylocereus undatus* (pink flesh)	
	Pollen viability	Stigma receptivity
Before anthesis		
12:00	NV	NR
12:00	NV	NR
13:00	NV	NR
14:00	NV	NR
15:00	NV	NR
16:00	NV	NR
17:00	V	NR
18:00	V	NR
After anthesis		
19:00	V	NR
20:00	V	NR
21:00	V	NR
22:00	V	NR
23:00	V	R
24:00	V	R
01:00	V	R
02:00	V	R

Continued....

Table 3 Continued....

Time (hrs)	*Hylocereus undatus* (pink flesh)	
	Pollen viability	Stigma receptivity
03:00	V	R
04:00	V	R
05:00	V	R
06:00	V	R
07:00	V	R
08:00	V	R
09:00	V	R
10:00	V	R
11:00	V	R
12:00	V	R

Note : NV= Non-viable; V= Viable; NR=Not-receptive; R=Receptive

(17:00 hrs) after anther dehiscence (14:00 hrs) and before anthesis (19:00 hrs) upto complete closing of the flower (12:00 hrs) in both types of dragon fruit. The reaction of hydrogen peroxide (6%) on stigmatic surface in the form of bubbles observed through hand lens (10x) revealed that the stigma was not receptive starting from before anthesis of flower (13:00 hrs) and upto after anthesis (22:00 hrs) in both the types of dragon fruit. The stigma became receptive after anthesis, starting from 23:00 hrs upto closing of the flowers (12:00 hrs). It is clear that the stigma became receptive four hours after flower opening and six hours after pollen attained viability (Table 2 and 3).

Phases of Flowering

There are seven phases of flowering per year (Table 4) in *Hylocereus undatus,* first phase of flowering started in the 1st week of May and ended in 2nd week of May (06-05-2022 to 10-05-2022), second phase of flowering started and ended in 4th week May (27-05-2022 to 31-05-2022), third phase of flowering started and ended in 2nd week of June (09-06-2022 to 12-06-2022), fourth phase of flowering started in started in 4th week of June and ended in 1st week of July (27-06-2021 to 01-07-2021), fifth phase of flowering started and ended in 3rd week of July (19-07-2021 to 23-07-2021), sixth phase of flowering started and ended in 1st week of August (02-08-2021 to 06-08-2021) and seventh phase of flowering started in 1st week of September and ended in 2nd week of September (04-09-2021 to 08-09-2021). The number of days of flowering in all the phases ranged from 4-5 days with a mean of 4.85 ± 0.37 days and there was 9 to 29 days gap in between the phases of flowering, with a mean of 16.33 ± 7.20 days. The number of phases of flowering and respective flowering period of *Hylocereus undatus* indicated 5 months of reproductive period from May to September and 7 months of vegetative period from October to April.

Table 4

Flowering phases of *Hylocereus undatus* at Suradenupura, Bengaluru urban during 2021-22

Flowering Phases	Hylocereus undatus		
	Flowering period	No. of days of flowering	Gap between flowering phases (Days)
1	06-05-2022 to 10-05-2022	5	
2	27-05-2022 to 31-05-2022	5	17
3	09-06-2022 to 12-06-2022	4	9
4	27-06-2021 to 01-07-2021	5	15
5	19-07-2021 to 23-07-2021	5	18
6	02-08-2021 to 06-08-2021	5	10
7	04-09-2021 to 08-09-2021	5	29
Mean ± SD	-	4.85 ± 0.37	16.33 ± 7.20

Table 5

Flowering phases of *Hylocereus polyrhizus* at Suradenupura, Bengaluru urban during 2021-22

Flowering Phases	Hylocereus undatus		
	Flowering period	No. of days of flowering	Gap between flowering phases (Days)
1	05-05-2022 to 08-05-2022	4	
2	26-05-2022 to 30-05-2022	5	18
3	09-06-2022 to 12-06-2022	4	10
4	27-06-2021 to 30-06-2021	4	15
5	19-07-2021 to 23-07-2021	5	19
6	02-08-2021 to 06-08-2021	5	10
7	04-09-2021 to 08-09-2021	5	29
8	15-10-2021 to 19-10-2021	5	37
Mean ± SD	-	4.62 ± 0.51	19.70 ± 9.90

There were eight phases of flowering per year (Table 5) in *Hylocereus polyrhizus,* first phase of flowering started in the 1st week of May and ended in 2nd week of May (05-05-2022 to 08-05-2022), second phase of flowering started and ended in 4th week May (26-05-2022 to 30-05-2022), third phase of flowering started and ended in 2nd week of June (09-06-2022 to 12-06-2022), fourth phase of flowering started and ended in 4th week of June (27-06-2021 to 30-06-2021), fifth phase of flowering started and ended in 3rd week of July (19-07-2021 to 23-07-2021), sixth phase of flowering started and ended in 1st week of August (02-08-2021 to 06-08-2021), seventh phase of flowering started in 1st week of September and ended in 2nd week of September (04-09-2021 to 08-09-2021) and eighth phase of flowering started and ended in 3rd week of October (15-10-2021 to 19-10-2021). The number of days of flowering in all the phases ranged from 4-5 days with a mean of 4.62 ± 0.51 days and there were 10 to 37 days gap in between the phases of flowering, with a mean of 19.70 ± 9.90 days. The number of phases of flowering and respective flowering period of *H. polyrhizus* indicated 6 months of reproductive period from May to October and 6 months of vegetative period from November to April. The gap of 9-29 days between phases of flowering in *H. undatus* and gap of 10-37 days between phases of *H. polyrhizus* flowering was recorded. The variation might be due to prevailing temperature of the experimental site and crop nutrient management between phases, either for late or early induction of the floral buds. Since it is a long day plant, it requires more sunlight and hence very few farmers in Karnataka installed artificial lighting system with 9 watts bulb in between the four poles from 1900-0400 hrs which helps to induce the floral buds in the areas where the prevailing temperature is too low.

Apis and Non-*Apis* Floral Visitors of Dragon Fruit

The diurnal and nocturnal floral visitors of *Hylocereus undatus* and *Hylocereus polyrhizus* in the farmer's field at Suradenupura, Bengaluru urban district, were recorded during different flowering phases. The diurnal floral visitors were recorded from 0600 upto1200 hrs, whereas, nocturnal floral visitors were observed from 1800 upto 0600 hrs at hourly intervals in each flowering phase (Table 6). Totally fourteen species of floral visitors which included *Apis* and non-*Apis* species were recorded at different flowering phases of *Hylocereus undatus* and *Hylocereus polyrhizus* during 2021-22, out of which seven species from Hymenoptera *viz., Apis dorsata* F., *Apis cerana* F., *Apis mellifera* L. and *Apis florea* F. belonging to Apidae were regular diurnal flower visitors. These findings are supported by the reports of Pushpakumara

Table 6

Floral visitors of dragon fruit types, *Hylocereus undatus* and *Hylocereus polyrhizus* during flowering period of 2021-22

Order	Family	Sl. No.	Scientific name	Visiting status	Forage collected	Foraging period (hrs)
Hymenoptera	Apidae	1	*Apis dorsata* Fab.	Regular	P+N	05:40-11:00
		2	*Apis cerana* Fab.(yellow & black strain)	Regular	P+N	06:00- 11:30
		3	*Apis florea* Fab.	Regular	P+N	08:00- 12:00
		4	*Apis mellifera* L.	Regular	P+N	06:00-11:30
	Vespidae	5	*Ropalidia marginata* P.	Occasional	N	08:00-18:00
	Formicidae	6	*Camponotus compressus* F.	Regular	N	06:00-18:00
		7	*Tapinoma melanocephalum* F.	Regular	N	06:00-18:00
Lepidoptera	Nymphalidae	8	*Tirumala* sp.	Occasional	N	07:00-08:00
Coleoptera	Chrysomelidae	9	*Colasposoma* sp.	Occasional	P	7:30-09:00
	Coccinellidae	10	*Coccinella transversalis* F.	Occasional	P	08:00-10:00
	Meloidae	11	*Mylabris pustulata* Thun.	Occasional	P	07:00-09:00
	Scarabidae	12	*Popillia schizonycha* A.	Occasional	P	07:00-09:00
	Curculionidae	13	*Myllocerus viridanus* F.	Occasional	p	07:30-10:00
	Nitidulidae	14	*Carpophilus* sp.	Regular	P	02:00-12:00

Note : P : pollen; N : nectar

et al., (2005) who stated that *Apis cerana* F., *Apis florea* F. and *Apis dorsata* F. were the most likely pollinators of *H. undatus* and *H. polyrhizus* in Bulathsinhala, Sri Lanka. Similarly, Muniz *et al.,* (2019) recorded the visitation of *A. mellifera* on *H. undatus* and *H. polyrhizus* at Northeastern Brazil. The wasp *Ropalidia marginata* P. under Fam. Vespidae was a diurnal occasional visitor, whereas *Camponotus compressus* F. and *Tapinoma melanocephalum* F. belonging to Formicidae were regular diurnal flower visitors. Muniz *et al.,* (2019) witnessed the visitation of ants and wasps on *Hylocereus undatus* and *Hylocereus polyrhizus*at Northeastern Brazil. The *Tirumala* sp. from Lepidoptera which belonged to Family Nymphalidae is an occasional and diurnal flower visitor. Six species from Coleoptera, one each belonging to Chrysomelidae (*Colasposoma* sp.), Coccinellidae (*Coccinella transversalis* F.), Meloidae (*Mylabris pustulata* Thun.), Scarabidae (*Popillia schizonycha* A.), Curculionidae (*Myllocerus viridanus* F.) were found as occasional visitors, whereas *Carpophilus* sp. from Nitidulidae was a regular nocturnal visitor (Table 6). On the contrary to the present findings on the nocturnal visitors, many earlier studies (Muniz *et al.,* 2019; Locatelli *et al.,* 1997 and Rocha *et al.,* 2019) conducted in the place of origin of this crop showed that *Pilosocereus* species was pollinated by bats and moths, but no such non-insect pollinators could be observed in the present study.

The honey bees, *Apis dorsata*, *Apis cerana*, *Apis mellifera* and *Apis florea* collected nectar from sepals of unopened flower bud (Plate 19) and pollen from fully opened flowers. Among honey bees, *Apis dorsata* (05:40-11:00 hrs) was the first visitor of the flower followed by *A. cerana* (06:00- 11:30 hrs), *A. mellifera* (06:00- 12:00 hrs) and *A. florea* (06:00-11:30 hrs), whereas, from non-*Apis* species, *Camponotus compressus* (0600-1800 hrs) and *Tapinoma melanocephalum* (0600-1800 hrs) were the first visitors which collected nectar from the sepals of unopened floral bud, followed by *Tirumala* sp. (07:00-08:00 hrs), which collected the nectar from sepals of just opened flower. However, *Mylabris*

pustulata (07:00-09:00 hrs), *Popillia schizonycha* (07:00-09:00 hrs), *Colasposoma* sp. (7:30-09:00 hrs), *Myllocerus viridanus* (07:30-10:00 hrs) and *Coccinella transversalis* (08:00-10:00 hrs) collected the pollen from opened flower. The *Ropalidia marginata* (0800-1800 hrs) foraged on the nectar from the sepals of unopened floral bud. The *Carpophilus* sp. was the only nocturnal visitor which foraged on the pollen from 02:00-12:00 hrs (Table 6).

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