Introduction

Dragon fruit (*Selenicereus* spp.) has emerged as an important high-value fruit crop owing to its attractive appearance, nutritional benefits, and increasing market demand. In India, the crop was introduced during the 1990s by growers themselves, without proper varietal evaluation or scientific assessment of flowering and pollination behaviour. Following its rapid commercial expansion after the 2000s, farmers increasingly experienced problems such as poor fruit set, smaller fruits, and inconsistent fruit quality. Pollination efficiency is a major determinant of fruit development in dragon fruit, a multiple-seeded berry, as its flowering period coincides with the monsoon season (May–October). Several cultivated types exhibit delayed-deficit pollination, resulting in inadequate fertilization, poor seed formation, and reduced fruit size and quality. Since seed development is closely associated with fruit growth and development, insufficient pollination directly contributes to lower productivity and marketable yield. Therefore, understanding the floral traits and reproductive biology governing pollination efficiency is crucial for identifying the causes of delayed-inadequate pollination. Therefore, identification of key floral traits associated with effective fertilization can help in developing suitable agronomic interventions, including improved pollination practices, as well as genetic interventions aimed at developing varieties with superior reproductive traits. Such approaches would ultimately help in bridging the yield gap arising from cultivation of genotypes with poor pollination efficiency.

Dragon fruit flowers are nocturnal and remain open during night and early morning hours; therefore, floral architecture and flower movement play a crucial role in determining pollination efficiency. Although prolonged flower opening is generally assumed to favour insect-mediated pollination, our observations suggest that effective pollination depends more on the spatial relationship and movement of floral organs than merely the duration of flower opening. During full bloom, a considerable gap often exists between the stigma and anthers, allowing insects to move freely without ensuring effective pollen transfer. In contrast, gradual flower-closing movements may bring the stigma and anthers into closer proximity, thereby enhancing pollen deposition and fertilization.

Importance of Flower Opening and Closing Dynamics in Dragon Fruit Pollination

Since dragon fruit is cultivated across diverse agro-climatic regions of India, ranging from extremely dry to high-rainfall areas, environmental stresses such as high temperature and heavy rainfall further aggravate deficit pollination by reducing pollen viability or causing pollen washout. Under such conditions, floral movements may function as adaptive mechanisms promoting efficient pollination. In white-fleshed (*S. undatus*) varieties, flower bending occurring as a part of floral senescence around 18 hours after anthesis (in mid-day), appears to be a major passive driver facilitating pollen contact and successful fertilization. Flower bending is also observed in red-fleshed types; however, flower-closing behaviour, which generally occurs early morning (around 12 hours after anthesis), is predominantly observed in red-fleshed varieties. Since pollen viability remains comparatively higher during this stage, flower closing may be more effective in promoting pollen deposition and fertilization than the bending. Thus, flower closing in red-fleshed types (*S. polyrhizus/ costaricensis*) may represent important floral mechanisms influencing pollination efficiency in dragon fruit. Earlier, a standard methodology was developed to measure and quantify flower bending dynamics in dragon fruit (Boraiah *et al*., 2025), which established its association with pollination efficiency. However, a standardized methodology to quantify flower opening and closing dynamics is still lacking, despite its probable role in influencing pollination and fertilization.

Since dragon fruit is a multiple-seeded berry, fruit size largely depends on the number of ovules get fertilized. Therefore, early pollination with viable pollen is essential for achieving better fruit set, seed development, and fruit size. Understanding and quantifying flower opening and closing dynamics can thus provide valuable insights into the mechanism governing pollination efficiency and can help in improving both agronomic management and varietal selection in dragon fruit. To understand the differential pattern of flower opening and closing, the present methodology used two different species (i.e red- and white-fleshed type/varieties) exhibiting contrasting pattern of antheisis particularly flower closing.

Methodology:

Pre-requisites to quantify the flower opening and closing dynamics

Materials: Digital camera, timer, 30 cm long scale.

Information: Flowering stages and varieties or species.

Calculating the duration between flower opening and closing (anthesis period)

Ten flowers from each species were observed for sequences of their opening stages from just opening to complete blooming and finally closing to track and record different anthesis stages, time and period. Timing of each stage of anthesis was recorded and photographed. The duration of flower opening was calculated by recording the time taken between the start of anthesis (flower opening) and end of anthesis (closing of flower). This will be useful for tracking or measuring the diameter of flower.

Table 1. Anthesis period in dragon fruit

Species	Flower opening initiation	Flower closing (next day of anthesis)
*S. undatus**	7.00-7.30 pm	09.00-10.00 am
S. polyrhizus/ costaricensis	6.30-7.00 pm	08.30-09.30 am

*only partial closing observed

Method 1: Image-based Measurement of Flower Diameter

The digital cameras on tripod were fixed horizontally to the flowers such that the position of the petals could be seen clearly, and flower images with an overhead view were taken automatically at 30-min intervals during 20 hours from 6.00 PM on the day of anthesis to 2 PM on next day of anthesis. Flash option was used to take images during the night. Diameters (D, Fig. 1) of flowers during the opening and closing process were measured using an open-source image analysis software (ImageJ). All the images should be captured from the same distance/angle in front view to measure accurate and relative diameter.

Method 2: Manual measurement of flower diameter

Ten flowers (minimum of six) were labelled and tracked for change in the diameter across the different phases of anthesis period. Measurement (in centimeter) of the diameter of the flowers (between tips of innermost petals) was made using scale at every 30 minute interval across the anthesis period and calculation of the relative flowering diameter (Y) was made as described below.

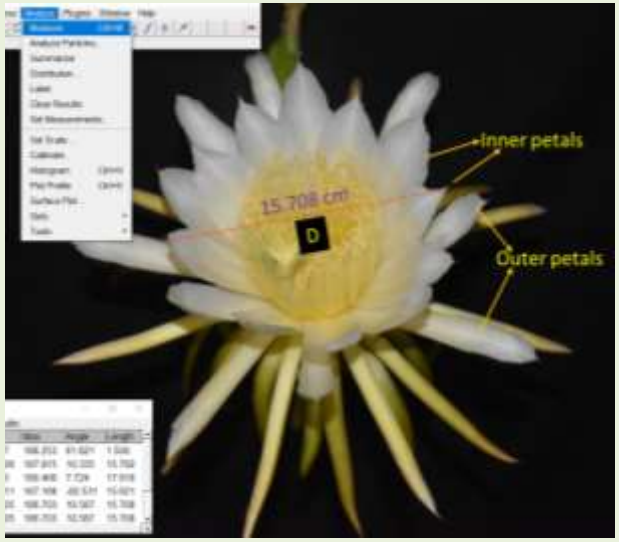


Figure 1. Relative measurement of diameter of flower using image analysis.

Calculation of relative flowering diameter (Y)

Normalized relative flowering diameter (Y) was calculated as, Y = Dt/Dmax, where, Dt represents D at time t, and Dmax is the maximum of D during the anthesis period (different anthesis phase) for each flower. Minimum of six flowers from each variety (red and white-fleshed types) should be considered for the purpose of measuring diameter across the time using above approach. After the calculation of Y values for each flower, the average Y value from six independent flowers was calculated for each time point.

Stepwise procedure to measure the flower diameter

Select & label the flowers of each variety/species before initiation of anthesis.

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Record anthesis period; measure the flower diameter using a 30 cm scale at 30-minute intervals throughout the anthesis period.

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Measure the diameter (cm) of the flowers by recording the distance between tips of inner most opposite opened petals

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Calculate relative diameter either via manual or image-based data as shown in the fig. 1.

Table 1. The proposed score for quantifying flower opening/closing patterns

Score	Relative flower diameter (Y)	Classification of flower opening
0	0.00 – 0.009	Completely closed
1	0.01 – 0.09	Initiation of opening / nearly closing
2	0.10 – 0.30	Partially opened/ closed
3	0.30 – 0.69	Moderately opened
4	0.70 – 0.89	Fully opened
5	0.90 – 1.00	Completely opened

Note: The dual terminologies of flower opening and closing depends on the time of anthesis progression

Uniqueness of measuring the trait

Quntifying the flower diameter dynamics during anthesis period provides a simple, rapid, and non-destructive method to study flower opening and closing behaviour in dragon fruit. The trait is useful for understanding pollination efficiency, reproductive behaviour, species or taxonomic classification, and genetic diversity. Early flower closing may promote self-pollination (autogamy), thereby improving fruit set, fruit size, yield, and productivity. Hence, flower closing behaviour can serve as an important indirect trait for evaluating yield potential and grouping genotypes or species.

References:

Boraiah KM, Priyanka Jadhav, Harisha CB, Basavaraj PS, VD Kakade, Hanamanth M Halli, KK Pal, and K Sammi Reddy (2025). Identification and measurement of flower bending in dragon fruit, Technical folder No.77. ICAR-NIASM, Baramati (Pune), Maharashtra, India.

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METHODOLOGY

Quantifying the Flower Opening and Closing Dynamics in Dragon Fruit



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