Introduction

Dragon fruit is one of the world's most popular exotic fruit crops. It is cultivated as a commercial crop outside its origin (Mexico). It is grown throughout the tropical and subtropical regions of the world. The widespread cultivation of the crop is attributed to its nutritive value, vibrant, attractive colours and unique taste. Highly water-use efficient CAM photosynthesis and other morphological features make it adapt and grow across diverse agro-climatic zones of several countries including India. In general, the productivity in the newly introduced regions is very low and inconsistent due to lack of knowledge on floral traits which determines the pollination efficiency vis-à-vis productivity.

1. Importance of flower bending in dragon fruit

Since the crop is grown in almost all the states of India including extreme dry and wet regions. It may face challenges of heat stress and heavy rains. Both conditions may lead to deficit pollination, with the former affecting the pollen viability, whereas the latter causes rain-induced pollen washout. Floral nastic movements may also affect pollination as a mechanism to favour the mode and efficiency of pollination. It was observed that the flower-bending event plays a vital role in pollination of white-fleshed varieties. In dragon fruit heterostyly and sturdiness of flower delays pollination. As pollination delays after anthesis, pollens lose viability and leads to low fruit sets or smaller fruits associated with less seed due to deficit pollination and fertilization of only part of millions of ovules in the ovary. Being a multiple seeded berry, the size of the fruit will depend on the number of ovules that get fertilized. Hence, to get good fruit size, early pollination with adequate viable pollens is crucial to maximize the fertilization of ovules. The flower closing and bending may promote early pollination in the crop. Considering its significance, tracking and measuring the flower bending in dragon fruit is essential.

2. Identification of flower bending

The floral and pollination biology was studied with a series of experiments from 2020 to 2024. As a part of the study, we have attempted to identify the mechanisms promoting pollination in dragon fruit. We predicted that several floral morphologies and behaviours, including flower bending, may play an important role in the pollination of dragon fruit. The continuous tracking of flower from anthesis to the withering stage revealed that flower bending is a more extended event spanning about 10-12 hours between late morning hours (10.00 AM) and late evening hours (8.00 PM) on the next day of anthesis. It can be identified easily by observing the inclination of the bulged and loosely arranged corolla part towards the anterior side of the mother axis (Fig 2.)

3. Measurement of flower bending

The bending of flower was determined on the next day of anthesis (i.e anthesis occurs around 7.00–8.00 PM) at particular time intervals between 8.00 AM (12 h after anthesis) and 8.00 PM (24 h after anthesis). Twenty flowers were marked and tracked to study the bending pattern. The bending of the flower measured at different phases of anthesis based on relative (Method 1) or actual (Method 2) angle of inclination.

Pre-requisites to measure flower bending:

Materials: Camera, timer to record timing of the day, Ribbon for hanging, physical or online protractor.

Information: Flowering stages and varieties or species.

Methodologies to measure flower bending:

Method 1: To determine the relative bending angle based on visual observation, the red-coloured ribbon was hanged from the base of the flower. The relative bending patterns of flowers of different phases can be compared by visually observing the relative inclination of freely hanged corolla/calyx towards the mother axis (here ribbon as a reference axis for the mother axis).

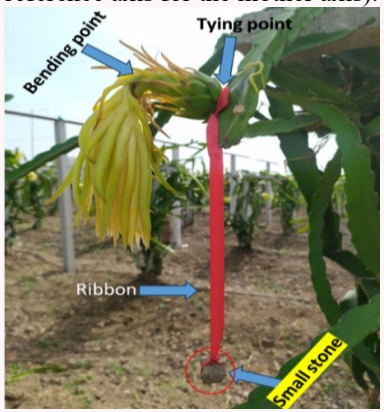

Fig. 1. Relative measurement of angle using ribbon method.

Method 2: To measure the actual and accurate angle of inclination, an image was uploaded in the background of the transparent protractor and then the protractor was dragged or added pushpins to figure out the degrees of angles between the floral/rigid perianth tube axis (red arrow) and bending axis of loose and freely hanged corolla/calyx (blue arrow). The bending style encompassed by the corolla can be considered as reference line for drawing the bending axis (blue arrow). In Fig. 2, the inclination angle is approximately 100° and the bending direction is towards the anterior end (At).

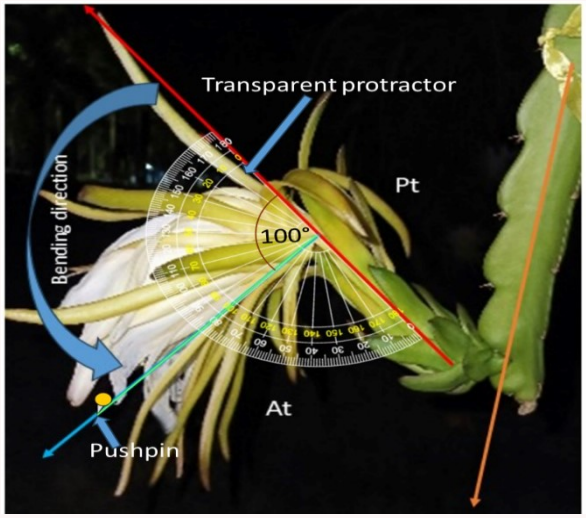

Fig. 2. Inclination angle measurement using protractor. Orange arrow indicates mother axis, red arrow indicates floral axis and blue arrow represents inclination line of bending flower. At: anterior end; Pt: posterior end.

Stepwise procedure to measure the flower bending:

Tagging of about 100 flowers of desired plant or variety and divide into five sets of 20 each

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Each set of flowers were visually observed for bending at particular time after anthesis.

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Capture good quality images of each set of flowers at different time intervals.

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Measure the inclination angle either using physical protractor or online protractor as shown in the fig. 2.

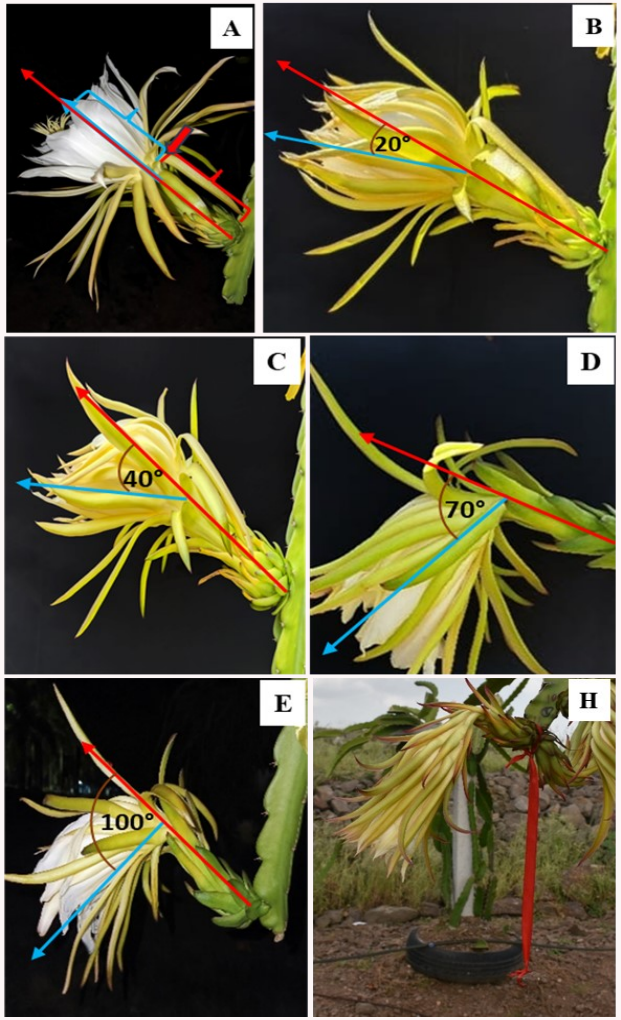

Fig. 3. Measuring the inclination angle of the flower at different phases of anthesis. Flower morphological descriptors used for measuring the angle (A). Measure the angle of inclination between (the point of inclination indicated with a thick red arrow) the perianth tube (red brace) axis (red arrow) attached to the cladode and axis (blue arrow) of loose freely arranged corolla/calyx (blue brace). The measured angle can be image-based, actual (B-E) or relative (H) in field conditions.

Proposed bending Score

The bending of flowers is classified based on the 0-4 scoring method (Table 1). For instance, flowers with a bending angle between 31°- 60° given a score of 2. Finally, based on the average score, the intensity of flower bending is determined as described in Table 1.

Table 1. The proposed score (0-4) for estimating flower bending intensity in dragon fruit.

Score	Angle	Bending intensity
0	0°-5°	No bending (Fig. 3A)
1	6°-30°	Slight bending (Fig. 3B)
2	31°-60°	Partial bending (Fig. 3C)
3	61°-90°	Highly bending (Fig. 3D)
4	>90°	Complete bedning (Fig. 3E)

Note: The inclination or bending mainly depends on the genotype and weather conditions, including temperature, RH, and wind speed.

Conclusion:

The information on the importance of bending of flowers and its measurement will help unravel the association between the trait and the pollination efficiency vis-à-vis fruit size in dragon fruit. Further, by adopting the methodology, researchers may be able to explore the mechanisms of flower bending. Breeders can consider flower bending as an important trait in their breeding programme to develop varieties with efficient pollination and better fruit size, as well as a trait for identifying germplasm with variation for bending pattern.

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Identification and measurement of flower bending in dragon fruit

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