**Changes in physicochemical properties during maturation of Dragon Fruit (*Hylocereus polyrhizus*) based on three harvest stages**

**ABSTRACT**

Dragon fruit (*Hylocereus polyrhizus*) is an exotic fruit with its cultivation increasing rapidly in several regions. Being a non-climacteric fruit and of perishable nature, understanding harvest maturity stage is important for ensuring quality fruit to consumers. The present study was conducted for two consecutive years during 2020-21 and 2021-22 under foothills of Nagaland at Seithekema-C village, Chümoukedima district, Nagaland, India, laid out in Completely Randomized Design replicated five times, consisting of three harvesting stages *viz.,* H1- 25 Days after anthesis (DAA), H2- 30 DAA and H3- 35 DAA. Fruits were tagged in the morning following anthesis and harvested according to the treatment requirement. Physical and quality aspects were analyzed where it was evident that changes in biochemical factors occur during maturation. Among the three maturity stages, physiochemical factors such as fruit size, fruit firmness, TSS, titratable acidity, TSS: acid ratio, sugar content were recorded to be optimum at 30 DAA (H2), while storability in terms of lower post-harvest spoilage was recorded in 25 DAA (H1). At initial stage (25 DAA), higher total phenol content (6.87 GAE mg/g) was recorded followed by H2 (30 DAA) with 4.98 GAE mg/g and the minimum content (3.11 GAE mg/g) was recorded in H3 (35 DAA). This finding indicated a decline in total phenolic content as the fruit underwent development and ripening whereas an increasing trend in the betacyanin content was found with the advancement in fruit maturity. For optimum quality with longer shelf life, harvesting of dragon fruit at 30 DAA is rendered to be congenial for Chümoukedima region of Nagaland, India.

***Keywords:*** *dragon fruit, Hylocereus polyrhizus, maturity indices, total phenolic content, betacyanin*

1. **INTRODUCTION**

Dragon fruit (*Hylocereus polyrhizus*) has become one of the most sought after fruits due to its notable health benefits and rich nutritional profile. Its big showy flowers that blooms at night time and the vibrant and peculiar shaped fruits, which are low in calories, with high fibre and rich antioxidant properties are few of the reasons that this fruit has gained many sobriquets such as- Queen of the Night, Wondrous fruit of the 21st century, Belle of the night, Noble woman, Cinderella plant and health fruit. Dragon fruit is a tropical fruit belonging to the Cactaceae family. Native to Central America but now widely cultivated in Southeast Asia and other tropical and sub-tropical regions.

Dragon fruit is highly adaptable to diverse agroclimatic conditions and also very easy to propagate. It has high drought tolerance and easy adaptability to harsh climatic conditions owing to its modified stem structure for water storage, reduced or absence of leaves, waxy surfaces and night-time opening of tissues for absorption of carbon dioxide (CAM pathway) (Luders and McMahon, 2006). It is a long day plant and day length tremendously affects flowering and fruit setting, along with other environmental factors such as temperature, humidity, rainfall etc. The flowers open at night and are hermaphroditic in nature which are mostly pollinated by nocturnal pollinators like bats and moths, while some flowers remain open till morning, bees act as pollinators in such cases. Manual pollination is also carried out by collecting the pollen from one flower and using a small brush to pollinate many flowers.

Dragon fruit is a non- climacteric fruit. Data shows that it has a low respiration rate during the maturation period and should be harvested when ripe for good quality (Van To *et. al*., 2000). An understanding of measurement of maturity is pivotal to postharvest handling. Different growing environment may influence the product physical development and nutritional quality differently by affecting the stimulation of the biosynthesis of secondary metabolites and health promoting phytochemicals (Singh *et. al*., 2022), thus the correct harvesting time varies depending on the agroclimatic conditions where the crop is cultivated. Association of picking time with a certain ripeness stage is important for long-term fruit storage (Ozgen *et. al*., 2002). Understanding these physicochemical changes is critical for determining the optimal harvest time, ensuring prolonged shelf life, and maintaining fruit quality for both local markets and export. Thus, this study was taken up in Chümoukedima region of Nagaland, India to shed light on the developmental changes in dragon fruit during maturation and identify the optimum harvest stage.

1. **MATERIALS AND METHODS**

The experiments were carried out for two consecutive years during 2020-2022 under foothills of Nagaland at Seithekema-C village, Chümoukedima district, Nagaland, and brought the fruits for post-harvest quality analysis at laboratory of Department of Horticulture, School of Agricultural Sciences, Nagaland University situated at 25.78º N latitude and 93.79º E longitudes at an elevation of 171 m above mean sea level. The area of the farm experiences humid subtropical conditions with an average annual rainfall ranging from 2000-2500 mm starting from April until end of September, with predominantly high humidity of 70-90%.

The experiment was laid out in Completely Randomized Design replicated five times, consisting of three harvesting stages *viz.,* 25 DAA (Days after anthesis), 30 DAA and 35 DAA. The flowers were tagged the next morning following the night of anthesis and harvested accordingly. The Erma Hand Refractometer was used to measure the Total soluble solids content in fruit juice, with the reading indicated as °brix. The concentration of ascorbic acid in fruit samples was determined using a 2,6 dichlorophenol-indophenol titration method. The fruits total sugar content, as well as their reducing and non-reducing sugar content were analysed (AOAC., 1994). The estimation of total phenolics in the fresh fruit sample was conducted using the Folin-Ciocalteau process as described by Singleton (1999) and expressed as mg gallic acid equivalents (GAE) per gram of sample in fresh weight (mg/g). Calibration curve with equation y = 0.0007x + 0.0225 (R2 = 0.994) was obtained using Gallic acid as standard and total phenolic content was calculated using the formula:

$$C=c x\frac{V}{m}$$

 Where,

C= Total phenolic content in mg GAE/g fresh weight), c= Concentration of gallic acid obtained from calibration curve in mg/ml, V= Volume of extract in ml and m= Mass of extract in gram. Betacyanin content was estimated by measuring the absorbance of the aqueous extract by following the method laid out by Razak *et. al.* (2017). The observance readings obtained was used to calculate the total betacyanin concentration (mg/100 g of fresh weight) using the equation:

$$\frac{A \left(MW\right) x V x \left(DF\right) x 1000}{ELW} 100$$

Where, A= absorbance at 538 nm (λ max), L (path length) = 1.0 cm, DF= dilution factor, V= volume extract (mL), W= fresh weight of extracting material (g). For betanin, E (mean molar absorptivity) = 6.5 x 104 L/mol cm and MW (molecular weight) = 550 g/mol. Firmness of fruit was determined with the help of a penetrometer fitted with 11 mm probe. The data obtained from the design were subjected to statistical analysis and for the significant component of ANOVA.

1. **RESULTS AND DISCUSSION**

**Textural changes of fruit skin/ firmness (kg/cm2)**

 Among the three harvesting stages, initial harvest at 25 DAA recorded highest pooled value (11.07 kg/cm2) for firmness, while the lowest was recorded in 35 DAA with 7.62 kg/cm2 as illustrated in Figure 1. Similar trend has been reported by Singh *et. al.* (2022) where firmness was maximum at harvest stage of 25 DAA and firmness reduced as the maturity stage progressed. In dragon fruit, with advancement in maturity, peel thickness decreases along with reduction in fruit firmness. Change in cell wall texture is an important criterion of fruit ripening which leads to reduction in firmness. This reduction may be due to degradation of cell wall components (pectin, cellulose, hemicellulose) and metabolism of cell contents (Wang *et. al*., 2024) caused by the action of hydrolytic enzymes (Singh *et. al.,* 2022) as a part of fruit maturation and ripening.

**Post-harvest spoilage (%)**

 Data pertaining to effect of harvesting stages on post- harvest spoilage as shown in Figure 2 showed minimum spoilage recorded in immature stage (25 DAA) with 16.76% and the maximum spoilage in 35 DAA (43.53%) on storage for 10 days. Fruit quality deteriorate after harvest leading to incidence of spoilage due to microorganisms as well as rapid physiological processes like weight loss, respiration and accelerated ripening in dragon fruit (Ali *et. al.,* 2014).

**Figure 2**: Post-harvest spoilage in different stages of dragon fruit

**Figure 1**: Changes in firmness during maturation of dragon fruit

**Fruit weight (g)**

 Data depicted an increasing trend in fruit weight with the advancement in maturity stages of dragon fruit. On the day of harvest, highest fruit weight was observed in H3 (35 DAA) with average weight of 240.42 g and the least fruit weight was recorded in H1 (25 DAA) with an average weight of 183.49 g. Jamaludin *et. al*. (2010) and Malgalhaes *et. al.* (2019) have reported similar findings of an increasing trend in fruit size, up to 35 DAA followed by a meager decline as the fruit continue to develop, whereby Chang and Yen (1997) reported that dragon fruits harvested at 50 DAF are 50% heavier in comparison to initial stages (30 DAA). Also, Prasad *et. al.* (2000) and Babu *et. al*. (2017) have reported a linear increase in fruit weight of pomegranate from fruit set to harvest. This increase in weight is mainly due to the physiochemical changes during fruit development and maturation, where there is accumulation of water, sugars, other solutes and seed maturation (Jamaludin *et. al*., 2010; Chitarra and Chitarra, 2005).

**Pulp weight (g)**

 Pooled data indicated highest pulp weight in H3 (30 DAA) with 174.38 g followed by 158.89 g in H2 (30 DAA) and lowest in H1 (25 DAA) with 103 g, which indicates that pulp weight increased with advancement in maturity stages as illustrated in Figure 3. Ortiz and Takahashi (2015) also reported that as dragon fruit matures, pulp mass increased linearly. Additionally, Singh *et. al*. (2022) corroborated with these findings that dry matter content of dragon fruit pulp increased up to 35 DAA, as a result of rapid cell differentiation, after which there was a decrease, up to 45 DAA of the evaluation.

**Peel weight (g)**

 Maximum peel weight was recorded in fruits harvested at H1 (25 DAA) with 80.49 g followed by H2 (30 DAA) at harvest with 66.05 g. The lowest value was recorded in H3 (35 DAA) with 55.70 g. This finding is in conformity with Franco *et. al.* (2022), Singh *et. al.* (2022) and Paliyath and Murr (2008) who reported peel content and thickness decreased with fruit maturity and development which the latter explains degradation and decomposition of cell wall components, mainly cellulose, hemicellulose and pectin are responsible for the decreased size and weight of fruit skin.

**Figure 3**: Changes in fruit weight, peel weight and pulp weight during maturation of dragon fruit

**Total Soluble Solids (ºB)**

 The experimental results pertaining to TSS content is presented in Figure 4 which outline that highest TSS content was recorded in H3 (35 DAA) with 13.48 ºB and minimum in the initial stage of harvest H1 (25 DAA) with 8.44 ºB. Singh *et. al.* (2022) elucidated that TSS increased steadily with progression of maturity until 40 DAA in dragon fruit.

**Titratable acidity (%)**

A perusal of data presented in Figure 5 depicts maximum acidity (0.47) in H1 (25 DAA) which followed a decreasing trend with maturity, and at 35 DAA (H3) minimum acidity content was recorded with 0.24%. There was continuous and progressive decrease in acidity as maturity stage and fruit development progressed in dragon fruit which was also reported by Singh *et. al.* (2022) and Magalhaes *et. al.* (2019). This reduction may be due to the usage of organic acids as substrate in physiochemical processes such as respiration or their conversion into sugars (Chitarra and Chitarra, 2005).

**TSS-Acid ratio**

The results obtained from TSS- Acid ratio presented in Figure 6 showed minimum value recorded at 25 DAA (H1) with 17.64 which may be due to increased acidity in immature fruits and the maximum TSS-acid ratio was recorded in H3 (35 DAA) with 55.74 followed by H2 (30 DAA) with 37.30. Similar trend of increase in TSS-acid ratio with progression in maturity stage was reported by Ortiz and Takahashi (2015) in dragon fruit and Babu *et. al.* (2017) in pomegranate. It was reported by To *et. al.* (2002) that the optimum TSS- acid ratio for dragon fruit is approximately 40 and fruits achieved this value at 31 DAA.

**Figure 4**: Changes in TSS during maturation of dragon fruit

**Figure 6**: Changes in TSS: acid ratio during maturation of dragon fruit

**Figure 5**: Changes in Titratable acidity during maturation of dragon fruit

**Total sugar (%)**

 The findings on total sugar content as shown in Figure 7 recorded highest total sugar content (8.43%) in H3 (35 DAA) and minimum value (4.90%) in H1 (25 DAA), which projects an increase in the amount of total sugar content with the advancement in fruit maturation. Dragon fruit being a non- climacteric fruit (Mizrahi and Nerd, 1999), generally achieve the peak sweetness before harvest and lack accumulation of carbohydrates within the fruits, thus, typically do not undergo significant conversion of starch to sugar after harvest, also there is lack of additional source of assimilates for sugar unlike fruits still attached to tree (Punitha *et. al.,* 2010).

**Reducing sugar (%)**

With regard to effect of maturity stages on reducing sugar content in dragon fruit, maximum value (5.35%) was recorded in H3 (35 DAA) and minimum reducing sugar content (3.48) in H1 (25 DAA) as shown in Figure 7. Fairly similar finding has been reported by Trong *et. al.* (2022) where reducing sugar content increased rapidly as the fruit progressed towards ripening and a maximum was reached at 32 DAA, after which there was a decrease, which he remarked that the fruit undergo ripening stage and a large amount of organic acids and starch are converted into sugar. The primary sugar in dragon fruit are glucose and fructose, while sucrose is present in lesser amount (Wang *et. al.,* 2024; Wu *et. al.,* 1997).

**Non-reducing sugar (%)**

The data on non- reducing sugar content of dragon fruit as influenced by maturity stage is presented in Figure 7 which depicts a significant variation among the treatments. At 0 DAH, highest non- reducing sugar content was recorded in H2 (30 DAA) with 3.05% and minimum in the initial stage of harvest H1 (25 DAA) with 1.35%.

**Figure 7:** Changes in Total sugar, reducing sugar and non-reducing sugar during maturation of dragon fruit

**Ascorbic acid (mg/100g pulp)**

The data pertaining to effect of maturity stages on ascorbic acid content in dragon fruit is presented in Figure 8 which depicts ascorbic acid was recorded to be more in immature fruits with maximum content (9.82 mg/100ml) in H1 (25 DAA) and the minimum content (5.04 mg/100ml) in H3 (35 DAA) on the day of harvest. This finding indicated that ascorbic acid decreased with advancement in fruit maturity so ascorbic acid was higher in fruits harvested at initial maturity, which has also been reported by Franco *et. al.* (2022), Martineli *et. al.* (2020), Enciso *et. al.* (2011) in dragon fruit, Blissett *et. al.* (2019), Baloch and Bibi (2012) in mango, Deepthi *et. al.* (2016) in guava, Kamol *et. al.* (2014), Gomez *et. al.* (2023) in pineapple, Rahman *et. al.* (2014) in strawberry and Rekha *et. al.* (2012) in citrus.

**Total phenolic content (mg GAE/100g fresh wt.)**

It was noted that harvesting at initial stage (H1- 25 DAA) had higher total phenol content (6.87 GAE mg/g) followed by H2 (30 DAA) with 4.98 GAE mg/g and the minimum content (3.11 GAE mg/g) was recorded in H3 (35 DAA). This finding indicated a decline in total phenolic content as the fruit underwent development and ripening. Similar trend was reported by Singh *et. al.* (2022), Zitha *et. al.* (2022) in Dragon fruit, Aldhanhani *et. al.* (2022) in Ber, Ahmed *et. al.* (2021) in Date palm, Wojdylo and Oszmianski (2020) in Apple, Vithana *et. al.* (2019) in Mango, where total phenolic content was highest at initial stage of fruit development, thereafter declined with advancement in fruit ripening. The rapid increase in total phenol content during the green stage was due to increase in its biosynthesis or metabolism of phenolic compounds (Aldhanhani *et. al.* 2012) whereby, the continual decrease may be due to increase in the activity of polyphenol oxidase that converts soluble phenolics into insoluble phenolics (Singh *et. al.* 2022) leading to reduction in phenolic synthesis, also phenols are continuously transformed into other substances during development (Zhang *et. al.* 2022).

**Betacyanin content in pulp (mg/100g of fresh wt.)**

Betacyanin is the water-soluble pigment that renders the red-violet color of the pericarp of dragon fruit. The highest content was recorded in H3 (35 DAA) with 38.66 mg/100g while lowest was found in H1 (25 DAA) with 21.74 mg/100g as illustrated in Figure 9. Consequently, this depicts an increasing trend in the betacyanin content with the advancement in fruit maturity. This finding is in conformity with Phebe *et. al.* (2009), Jamaludin *et. al.* (2010), Ortiz and Takahashi (2015), Mustafa *et. al.* (2018) and Singh *et. al.* (2022). It was observed that by 25 DAA, the red-violet coloration had already manifested in the pulp which indicated the degradation of chlorophyll and the synthesis of betacyanin. Jamaludin *et. al.* (2010) reported that this red-violet color appears only after seeds have matured. In agreement with Phebe *et. al.* (2009) who reported that synthesis of betacyanin pigment in flesh was earlier than that in peel, it was found that the colour of pulp had turned completely red-violet at the initial harvest stage of 25 DAA while the peel was still green with signs of colour development. Among other factors, the availability of sugar and light activates the synthesis of this pigment, so along with the increase in sugar content, there is increase in betacyanin content as the fruit matures (Castellar *et. al.,* 2003).

**Betacyanin content in peel (mg/100g of fresh wt.)**

Among the harvesting stages, the maximum content (36.53 mg/100g) was recorded in H3 (35 DAA), followed by H2 (30 DAA) with 28.70 mg/100g and the minimum value (20.37 mg/100g) was recorded in H1 (25 DAA). As it was found in pulp, the betacyanin content gradually increased as the fruit undergo maturation and development. The loss in green colouration of peel is due to diminishing chlorophyll content, which is followed by synthesis of betacyanin pigment (Phebe *et. al.*, 2009) giving the red coloration as the fruit advances in maturity. Also, high concentration of pectin in fruit hamper extraction of betacyanin (Chia and Chong, 2015) thus, lower amount is found in immature fruits.

**Table 1:** Physicochemical properties of Dragon Fruit

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Ascorbic acid (mg/100ml)** | **Total phenolic content (mg GAE/100g FW)** | **Betacyanin in pulp (mg/100g FW)** | **Betacyanin in peel (mg/100g FW)** |
| **2021** | **2022** | **pooled** | **2021** | **2022** | **pooled** | **2021** | **2022** | **pooled** | **2021** | **2022** | **pooled** |
| H1  | 9.53 | 10.11 | 9.82 | 6.47 | 7.28 | 6.87 | 20.72 | 22.75 | 21.74 | 19.56 | 21.18 | 20.37 |
| H2  | 6.40 | 7.66 | 7.03 | 4.86 | 5.11 | 4.98 | 33.11 | 33.98 | 33.55 | 28.03 | 29.37 | 28.70 |
| H3  | 4.57 | 5.50 | 5.04 | 3.10 | 3.12 | 3.11 | 37.96 | 39.35 | 38.66 | 37.63 | 35.43 | 36.53 |
| *SEm±* | **0.08** | **0.10** | **0.06** | **0.14** | **0.22** | **0.13** | **0.41** | **0.49** | **0.32** | **0.60** | **0.87** | **0.53** |
| *CD (P=0.05)* | **0.23** | **0.28** | **0.18** | **0.41** | **0.62** | **0.37** | **1.17** | **1.41** | **0.90** | **1.73** | **2.51** | **1.49** |

**CONCLUSION**

From the present study, it is evident that harvest maturity is crucial in order to obtain the best quality of dragon fruit. The findings indicated a decline in firmness, peel weight, titratable acidity and total phenolic content as the fruit underwent development and ripening whereas an increasing trend in the TSS, sugar profile and betacyanin content were observed with the advancement in fruit maturity. Among the three maturity stages, physiochemical factors such as fruit size, fruit firmness, TSS, titratable acidity, TSS: acid ratio etc. were recorded to be optimum at 30 DAA (H2), while storability in terms of lower post-harvest spoilage was recorded in 25 DAA (H1).

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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