Plant Archives Vol. 26, No. 2, 2026 pp. 2469-2477 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.338

GENOTYPIC VARIABILITY IN PHYSICO-CHEMICAL AND BIOCHEMICAL PROPERTIES OF DRAGON FRUIT (*Hylocereus* SPP.) UNDER HUMID TROPICAL CONDITIONS

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(Date of Receiving-12-08-2026; Date of Revision-14-10-2026; Date of Acceptance-17-10-2026)

ABSTRACT

Dragon fruit (*Hylocereus* spp.) has gained prominence for its striking fruit morphology, vibrant pulp colouration, palatable flesh and rich profile of health-promoting bioactive compounds. The present study evaluated the fruit-character and biochemical traits for twenty dragon-fruit collections. Significant effects were observed for all twelve fruit characters. Fruit length ranged from 6.66 to 12.07 cm among the observed means, fruit diameter from 5.56 to 10.99 cm, fruit weight from 142.50 to 750.00 g, and yield from 0.54 to 4.40 kg per pole. Biochemical attributes also showed substantial variation, with TSS ranging from 10.15 to 16.65 °Brix, total sugars from 6.65 % to 26.94%, anthocyanin from 0.02 mg/g to 0.29 mg/g, and ascorbic acid from 7.93 mg/100 g to 20.62 mg/100 g. Collection C11 was notable for fruit (750.00 g) and pulp weight (623.06 g), C15 for fruit length (12.07 cm) and seed per 50 g pulp (2008), C19 for bract number (41.50) and pulp-to-fruit ratio (0.85) and C1 for yield per pole (4.40 kg/pole). Among biochemical traits, C4 recorded the highest TSS (16.65 °Brix), reducing sugars (12.04%) and ascorbic acid (20.62 mg/100 g); C8 had the highest TSS-to-acidity ratio (126.67); C17 had markedly higher total sugars (26.94%) and C7 recorded the highest anthocyanin value (0.29 mg/g). The results demonstrate considerable phenotypic and biochemical diversity among collections and indicate opportunities for selecting material according to marketable fruit size, pulp recovery, yield and nutritional quality.

Key words : Dragon fruit, *Hylocereus* spp., Fruit characters, Fruit quality, Biochemical properties, TSS, Sugars, Anthocyanin, Ascorbic acid.

Introduction

Dragon fruit, commonly known as pitaya or pitahaya, is a tropical and subtropical fruit crop of the cactus family that has attracted increasing interest because of its unusual fruit appearance, adaptability and nutritional value. Species traditionally associated with the crop differ markedly in peel and pulp colour, fruit size and quality characteristics. White-fleshed, red-fleshed and other colour types occur within the cultivated dragon-fruit complex, and this diversity is reflected in both consumer appeal and biochemical composition. Different studies have demonstrated substantial variation in fruit weight, pulp weight, bract morphology, fruit yield and quality traits among dragon-fruit germplasm (Dantas *et al*., 2025; Santos-Pelaez *et al*., 2024; Sethunath and Bhaskar, 2024).

Fruit characters are particularly useful because they combine descriptors of botanical identity with traits of direct commercial importance. Fruit length and diameter influence visual grade and packing, while fruit weight, pulp weight and pulp-to-fruit ratio provide practical

information about edible yield. Bract number, apex-bract length, bract spacing and basal width also contribute to fruit appearance and can help distinguish genotypes. Earlier Indian characterisation work recorded wide variation in fruit and pulp weight and identified fruit traits as useful descriptors for differentiating *Hylocereus* types (Abirami *et al*., 2021; Sethunath and Bhaskar, 2024).

Biochemical quality adds another dimension to fruit evaluation. TSS is commonly used as a practical indicator of soluble solids and perceived sweetness, while acidity contributes to flavour balance. Sugars provide an important component of eating quality, whereas pigments and antioxidant-related compounds add nutritional and functional value. Arivalagan *et al*. (2021) reported differences between white- and red-pulp dragon fruits in TSS, sugar, phenolic and antioxidant characteristics, with red-pulp types generally showing stronger phenolic and antioxidant potential. Recent reviews have likewise highlighted the contribution of phenolics, flavonoids, betalains, vitamins and other phytochemicals to the nutritional importance of pitaya (Bishoyi *et al*., 2024; Kumari *et al*., 2025).

Dragon fruit (*Hylocereus* spp.; also classified within Selenicereus) is an emerging high-value fruit crop in Kerala. Its cultivation has received support through state horticultural programmes promoting exotic and high-value fruit crops, reflecting growing interest in diversifying fruit production and meeting market demand. However, the performance and quality of individual planting materials can vary, making reliable characterisation important for selecting suitable material for cultivation. Sethunath and Bhaskar (2024) documented diversity among dragon-fruit genotypes cultivated in Kerala after evaluating genotypes from orchards in four districts and reported variation in yield and quality attributes. Nevertheless, characterisation remains relevant at the level of individual collections and datasets, particularly when fruit morphology, edible recovery, yield and biochemical properties are considered together. The twenty collections evaluated in the present study provide an opportunity to compare these traits side by side and to identify contrasting material with desirable combinations of fruit and quality characteristics. Such comparisons can support preliminary selection, although the identity of the collections and their performance across seasons and locations should be confirmed before making cultivar-level recommendations.

Fruit characters are important both as descriptors for distinguishing genotypes and as indicators of commercial value. Since no single trait necessarily reflects overall performance, simultaneous assessment of fruit and biochemical attributes is useful for identifying material suited to different market and production objectives. Accordingly, this study aimed to characterise the variation among twenty dragon-fruit collections using the supplied fruit and biochemical datasets. The specific objectives were: (i) to quantify variability in fruit morphological, weight, edible-recovery and yield traits; (ii) to assess variation in biochemical quality, including TSS, titratable acidity, TSS-to-acidity ratio, sugars, anthocyanin and ascorbic acid; and (iii) to identify collections with superior or otherwise desirable trait values that may be prioritised for further evaluation. It was hypothesised that the collections would differ in fruit and biochemical attributes, and that the treatment with the best value for one trait would not necessarily be superior across all traits.

Materials and Methods

The study was carried out in the Department of Fruit Science laboratory, College of Agriculture, Vellanikkara, during 2024–2025. Fruits from twenty different collections of fruit orchard belonging to species *Hylocereus costaricensis*, *Hylocereus undatus*, *Hylocereus polyrhizus* and *Hylocereus megalanthus* designated as Collection 1 to Collection 20 (C1–C20) were selected for the study. Fruit characteristics were observed for these twenty collections aged 5 years including ten plants of medium pink to pink-skinned, dark pink-pulped *Hylocereus costaricensis*; six plants of pink-skinned, white-pulped *Hylocereus undatus*; four plants of red-skinned, red-pulped *Hylocereus polyrhizus*; and one plant of yellow-skinned, white-pulped *Hylocereus megalanthus* (Table 1).

For each collection, twenty representative fruits were randomly selected and evaluated in two replications (ten fruits in each replication). Recorded traits included fruit length, fruit diameter, number of bracts, length of apex bracts, distance between bracts, width of the base of the bract, total fruit weight, peel weight, pulp weight, number of seeds per 50 g fruit, pulp-weight-to-fruit-weight ratio, and yield per pole. The length of the ripened fruit from each collection was measured using a Vernier calliper and noted in centimetres (cm). The fruit diameter was measured with a Vernier calliper and recorded in

Table 1 : Collection details of different species.

Species	***Hylocereus costaricensis***	***Hylocereus undatus***	***Hylocereus polyrhizus***	***Hylocereus megalanthus***
Collections	C1, C2, C4, C11, C15, C16, C17, C18, C19	C5, C6, C9, C10, C13, C14	C3, C7, C12, C20	C8

centimetres (cm). The total number of bracts on the fruit was counted and expressed as a number. The measurement of the bract length at the apex part of the fruit was conducted using a Vernier calliper and recorded in millimetres (mm). The distance between bracts in the central region of the fruit was measured using a Vernier calliper in millimetres (mm). The width of the basal bract was measured using a Vernier calliper and noted in millimetres (mm). Fruits were randomly selected from each genotype and weighed using an electronic balance. Fruit weight was expressed in grams (g). Peel weight was recorded using an electronic balance after pulp removal and noted in grams (g). Pulp weight was recorded using an electronic balance after peel removal and expressed in grams (g). Seeds were manually counted per 50 g of pulp from the selected fruits, and the count was recorded as a numerical value. The ratio was calculated by dividing pulp weight by total fruit weight (pulp weight ÷ fruit weight). Yield was recorded in plants aged 5 years for season 2024-2025 on a four plants per-pole basis of two poles per replication and expressed in kilograms (kg).

The biochemical analysis also contained twenty collections with two replications. The characters were TSS, titratable acidity, TSS-to-acidity ratio, total sugars, reducing sugars, anthocyanin content and ascorbic acid. The total soluble solids (TSS) content of dragon fruit pulp was determined using a hand refractometer and expressed in degrees Brix (°Brix). Titratable acidity of dragon fruit pulp was determined by titrating a known quantity of sample against standardized 0.1 N NaOH, with phenolphthalein as the indicator (Ranganna, 1986). The results were expressed as percentage (%) citric acid. The TSS/acidity ratio was calculated by dividing the total soluble solids (°Brix) by the titratable acidity (% citric acid). Ascorbic acid content of dragon fruit was estimated by the 2,6-dichlorophenol indophenol (DCPIP) visual titration method, in which ascorbic acid reduces the dye to a colourless leucobase in an oxalic acid medium, with the appearance of a persistent pink colour marking the end point, and the results were expressed as mg/100 g of fruit (Ranganna, 1986). Reducing sugar content of dragon fruit was estimated by the Lane and Eynon (1923) method, in which the ground sample was made up to 250 ml with distilled water, clarified with neutral lead acetate and potassium oxalate, filtered and the filtrate titrated against a mixture of Fehling's solutions A and B (5 ml each) using methylene blue as the indicator, with the results expressed as percentage (%) using the formula: Reducing sugar (%) = (Fehling's factor (0.05) × Dilution × 100) ÷ (Titre value × Weight of sample). Total sugars of the fruit pulp were estimated, in which 50 ml of the clarified filtrate from the reducing sugar extraction was gently boiled with citric acid and water to invert the sucrose, neutralized with NaOH, made up to 250 ml and titrated against a mixture of Fehling's solutions A and B, with the results calculated as: Total sugar (%) = (Fehling's factor × Dilution × 250) ÷ (Titre value × Weight of sample) (Ranganna, 1986). Anthocyanin content of fruit pulp was estimated spectrophotometrically by extracting 2 g of ground pulp in 25 ml of 1% methanolic HCl overnight at refrigerated temperature, filtering through Whatman No. 1 paper, re-extracting the residue with 10 ml of the same solvent for one hour, making the combined extract up to 50 ml, and reading the absorbance at 540 nm, with total anthocyanin (mg/g) calculated as $25 \times A \div 98.2$, where A is the absorbance. The data were collected from two replications and analyzed using analysis of variance (ANOVA) under a completely randomized design (CRD), following Fisher's method. One-way ANOVA was followed by Duncan's multiple range test at the 0.05 level. Treatment effects were tested at the 5% level of significance and differences between treatment means were compared using the critical difference (CD) at $P < 0.05$. The statistical analysis of the supplied datasets was performed using RAISINS (R and AI Solutions for INferential Statistics), with R as the underlying statistical environment (Hisham *et al*., 2025 and R core team, 2024).

Results and Discussion

The fruit dataset showed pronounced differences among the twenty collections. According to the analysis, all twelve fruit characters were significant at the $P < 0.05$ level of testing. This broad significance indicates that treatment identity was associated with measurable changes not only in fruit dimensions but also in bract architecture, fruit partitioning, seed number and yield. The data are given in Fig. 1, Tables 2 and 3.

Fruit length was greatest in C15 (12.07 cm), whereas C8 recorded the lowest value (6.66 cm). C15 was reported to differ significantly from all other collections, while C8 remained statistically comparable with C7, C9 and C13. Fruit diameter followed a related but not identical pattern: C16 recorded the highest value (10.99 cm), while C8 had the smallest diameter (5.56 cm). C16 was statistically on par with C1, C2, C4, C11, C15, C18 and C19.

Bract traits also varied strongly. T_{19} produced the greatest number of bracts (41.50), whereas C8 had only 11.50. The length of the apex bract was highest in C19 (45.63 mm) and lowest in C3 (6.05 mm). C4 had the greatest distance between bracts (32.20 mm), while C8

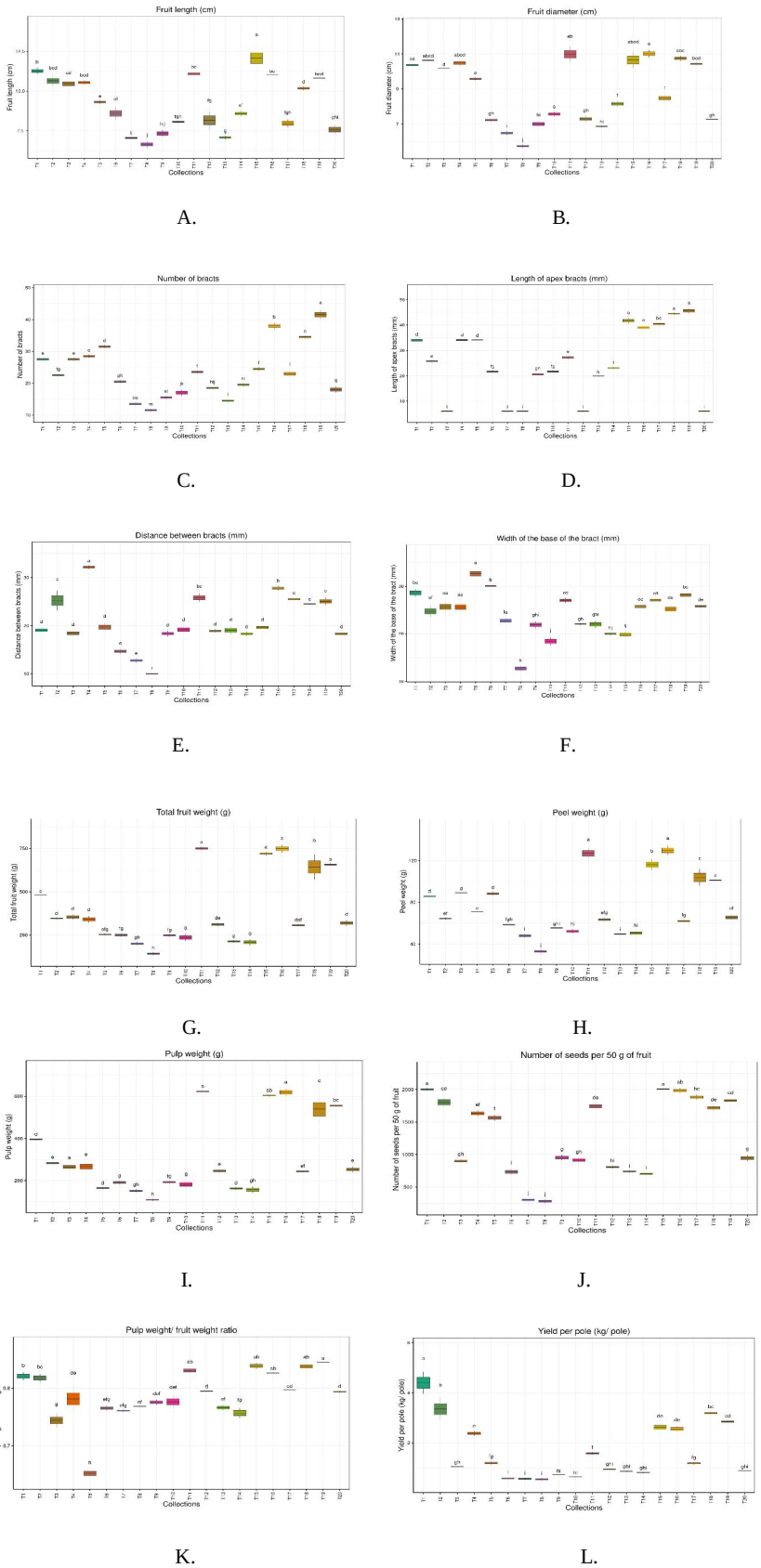


Fig. 1 : Box plot depicting the data on fruit morphological and yield parameters of dragon fruit A. Fruit length (cm), B. Fruit diameter (cm), C. Number of bracts, D. Apex bract length (mm) E. Distance between bracts (mm), F. Basal bract width (mm), G. Total fruit weight (g), H. Peel weight (g), I. Pulp weight (g), J. Seeds per 50 g fruit, K. Pulp/fruit weight ratio, L. Yield per pole (kg pole^{-1}) distributed across collections.

Table 2 : Fruit size and bract characters of twenty dragon fruit collections.

Collections	Fruit length (cm)	Fruit diameter (cm)	Bracts (no.)	Apex bract length (mm)	Distance between bracts (mm)	Basal bract width (mm)
C1	11.27	10.31	27.50	34.02	19.09	28.63
C2	10.64	10.59	22.50	25.77	25.25	24.75
C3	10.46	10.09	27.50	6.05	18.46	25.70
C4	10.54	10.43	28.50	34.12	32.20	25.68
C5	9.30	9.57	31.50	34.14	19.72	32.66
C6	8.60	6.85	20.50	21.70	14.68	30.08
C7	7.05	6.17	13.50	6.05	12.79	22.79
C8	6.66	5.56	11.50	6.05	10.00	12.73
C9	7.33	6.84	15.50	20.65	18.38	21.89
C10	8.06	7.41	17.00	21.68	19.20	18.44
C11	11.09	10.89	23.50	27.24	25.87	27.02
C12	8.17	7.28	18.50	6.05	18.95	22.10
C13	7.07	6.76	14.50	19.89	19.05	21.98
C14	8.59	8.07	19.50	23.09	18.31	20.01
C15	12.07	10.57	24.50	41.72	19.63	19.88
C16	11.05	10.99	38.00	39.05	27.83	25.75
C17	7.98	8.48	23.00	40.39	25.56	27.13
C18	10.17	10.72	34.50	44.53	24.52	25.24
C19	10.81	10.42	41.50	45.63	25.08	28.16
C20	7.58	7.27	18.00	6.05	18.33	25.84
CD (5%)	0.80	0.75	2.09	1.64	2.12	2.16
SE(d)	0.38	0.36	1.00	0.79	1.02	1.04
SE(m) ±	0.27	0.25	0.71	0.56	0.72	0.73
CV (%)	4.1	4.1	4.2	3.1	4.9	4.3

had the smallest (10.00 mm). Similarly, the widest basal portion of the bract occurred in C5 (32.66 mm), compared with 12.73 mm in C8. The da analysis showed C19 as significantly distinct for bract number, C4 and C8 as distinct for bract spacing, and C5 and C8 as distinct for basal bract width.

Fruit mass and edible recovery showed particularly large contrasts. C11 recorded the highest total fruit weight (750.00 g), while C8 had the lowest (142.50 g). C11 was statistically comparable with C15 and C16. Peel weight was highest in C16 (129.83 g), followed by C11, whereas C8 recorded the lowest peel weight (32.96 g) and was significantly different from the other collections. Pulp weight reached 623.06 g in C11 and only 109.54 g in C8; C11 was on par with C15 and C16.

The number of seeds per 50 g fruit was highest in C15 (2008.00) and lowest in C8 (281.50). C15 was statistically comparable with C1 and C16. The pulp-weight-to-fruit-weight ratio ranged from 0.65 in C5 to 0.85 in C19, with C19 on par with C11, C15, C16 and C18. Yield per pole was highest in C1 (4.40 kg pole^{-1}), whereas C8 produced the lowest value (0.54 kg pole^{-1}). C1 was significantly different from all other collections, while C8 was statistically comparable with C6, C7, C9, C10, C12, C13, C14 and C20.

The magnitude and direction of these differences are biologically meaningful (Table 4). C11 combined very high fruit weight and pulp weight, suggesting strong potential for fresh-fruit markets where large fruits and edible recovery are preferred. C15 combined the longest fruit with a high seed count, whereas C19 excelled in bract number and pulp recovery. C1, in contrast, produced the highest yield per pole even though it was not the treatment with the highest individual fruit weight. This distinction is important because productivity at plant or pole level cannot be inferred from fruit size alone. Similar separation among fruit weight, pulp weight and yield traits has been observed in dragon-fruit germplasm studies, where substantial diversity was recorded for fruit and pulp weight and fruit yield (Santos-Pelaez *et al*., 2024). Abirami *et al*. (2021) reported fruit weight between 26.5–419.3 g whereas the result shows 750 g fruit in C11 due to the first flowering and less number of flowers during initial time.

Table 3 : Fruit weight components, seed number and yield of twenty dragon fruit collections.

Collections	Fruit wt. (g)	Peel wt. (g)	Pulp wt. (g)	Seeds/50 g pulp	Pulp/fruit ratio	Yield/pole (kg)
C1	481.50	85.71	395.28	2005.00	0.82	4.40
C2	345.50	64.39	282.60	1801.50	0.82	3.35
C3	355.00	89.13	264.34	897.50	0.74	1.05
C4	340.50	71.17	266.51	1634.00	0.78	2.38
C5	253.50	88.38	165.32	1566.50	0.65	1.19
C6	250.00	58.55	191.45	735.00	0.77	0.58
C7	201.00	48.01	152.99	303.00	0.76	0.56
C8	142.50	32.96	109.54	281.50	0.77	0.54
C9	247.50	55.45	192.05	954.00	0.78	0.72
C10	235.00	52.32	182.68	917.00	0.78	0.65
C11	750.00	126.94	623.06	1742.50	0.83	1.58
C12	310.50	63.60	246.90	811.50	0.80	0.95
C13	212.50	49.64	162.86	739.50	0.77	0.87
C14	207.50	50.29	157.21	701.50	0.76	0.82
C15	720.00	116.12	603.88	2008.00	0.84	2.62
C16	748.50	129.83	618.67	1985.50	0.83	2.55
C17	306.50	62.16	244.34	1884.00	0.80	1.18
C18	642.50	103.81	538.69	1716.50	0.84	3.19
C19	656.50	101.32	555.18	1832.50	0.85	2.84
C20	319.00	65.70	253.30	946.00	0.79	0.89
CD (5%)	59.10	8.85	52.64	117.22	0.02	0.45
SE(d)	28.33	4.24	25.24	56.20	0.01	0.22
SE(m) ±	20.03	3.00	17.85	39.74	0.01	0.15
CV (%)	7.3	5.6	8.1	4.4	1.3	13.2

Table 4 : Variation in fruit and yield attributes among twenty collections.

Character	Highest treatment	Lowest treatment
Fruit length (cm)	C15 (12.07)	C8 (6.66)
Fruit diameter (cm)	C16 (10.99)	C8 (5.56)
Number of bracts	C19 (41.50)	C8 (11.50)
Apex bract length (mm)	C19 (45.63)	C3 (6.05)
Distance between bracts (mm)	C4 (32.20)	C8 (10.00)
Basal bract width (mm)	C5 (32.66)	C8 (12.73)
Total fruit weight (g)	C11 (750.00)	C8 (142.50)
Peel weight (g)	C16 (129.83)	C8 (32.96)
Pulp weight (g)	C11 (623.06)	C8 (109.54)
Seeds per 50 g fruit	C15 (2008.00)	C8 (281.50)
Pulp/fruit weight ratio	C19 (0.85)	C5 (0.65)
Yield per pole (kg pole^{-1})	C1 (4.40)	C8 (0.54)

A notable feature of the dataset is the repeated appearance of C8 at the lower end of several traits. It had the smallest fruit length and diameter, fewest bracts, shortest bract spacing, narrowest bract base, lowest fruit and pulp weight, fewest seeds per 50 g fruit and lowest yield. This consistency suggests that C8 represents a distinctly smaller-fruited phenotype within the evaluated material. C8 belongs to *Hylocereus megalanthus* and similar reports were given in a study of Abirami et al. 2021. Such a treatment may nevertheless have value if associated with a desirable biochemical profile or other agronomic attributes; therefore, fruit size alone should not be used as the sole criterion for selection.

The biochemical dataset also showed substantial variation among different collections. The reported one-way ANOVA indicated significant difference for TSS, TSS-to-acidity ratio, total sugars, reducing sugars, anthocyanin and ascorbic acid, while titratable acidity was reported as non-significant (Table 5).

TSS varied from 10.15 to 16.65 °Brix. C4 recorded the highest TSS (16.65 °Brix), followed by C8 (15.20), C16 (15.10) and C1 (14.85), whereas C6 had the lowest value (10.15 °Brix. The overall treatment mean calculated from the reported values was approximately 12.50 °Brix. The variation is within the broad range reported for dragon fruit and although the exact value depends on genotype, maturity and environment. Arivalagan *et al*. (2021) reported TSS in a range of 8–12% and the observed

Table 5 : Biochemical quality values of the twenty collections.

Collections	TSS (°Brix)	Acidity (%)	TSS/acidity ratio	Total sugars (%)	Reducing sugars (%)	Anthocyanin (mg/g)	Ascorbic acid (mg/100 g)
C1	14.85	0.15	99.41	11.93	7.04	0.13	14.27
C2	14.20	0.14	101.43	13.52	7.30	0.12	17.44
C3	12.05	0.13	96.83	8.54	5.30	0.15	14.27
C4	16.65	0.15	107.65	10.63	12.04	0.15	20.62
C5	11.45	0.14	81.79	12.63	7.35	0.06	11.09
C6	10.15	0.15	70.12	7.72	4.36	0.07	9.51
C7	10.25	0.15	66.17	8.90	5.68	0.29	12.68
C8	15.20	0.12	126.67	6.65	4.24	0.08	11.10
C9	10.70	0.11	102.23	8.12	5.30	0.03	9.52
C10	10.40	0.14	74.29	8.62	5.35	0.04	11.10
C11	12.45	0.12	94.11	11.93	6.89	0.11	12.69
C12	11.20	0.14	86.73	7.86	4.58	0.03	11.05
C13	10.95	0.12	91.25	9.82	6.06	0.04	9.51
C14	11.10	0.13	82.45	8.83	5.30	0.04	12.64
C15	13.90	0.15	91.34	10.27	6.73	0.04	11.10
C16	15.10	0.16	94.38	7.40	4.15	0.08	20.62
C17	14.10	0.15	94.00	26.94	11.29	0.08	17.45
C18	10.30	0.14	75.42	7.86	6.06	0.10	14.27
C19	14.30	0.14	104.58	11.45	6.66	0.10	20.62
C20	10.65	0.14	77.50	7.78	4.73	0.02	7.93
CD	0.94	NS	20.72	1.34	0.71	0.02	4.43
SE(d)	0.45	0.02	9.94	0.64	0.34	0.01	2.12
SE(m)±	0.32	0.01	7.03	0.46	0.24	0.01	1.50
CV (%)	3.6	10.8	10.9	6.2	5.4	12.7	15.8

value is high as 16.65 °Brix suggests the effect of maturity stage and collection type.

Titratable acidity showed comparatively narrow variation, with the reported treatment means ranging only from 0.11 to 0.16 per cent. This limited variation is consistent with the non-significant ANOVA result. In practical terms, the comparatively stable acidity means that much of the observed difference in the TSS-to-acidity ratio was associated with variation in soluble solids rather than large changes in acidity.

The TSS-to-acidity ratio ranged from 66.17 in C7 to 126.67 in C8. C8 therefore combined a high TSS value with low reported acidity, producing the highest ratio. C4 had a ratio of 107.65, while T_{19} recorded 104.58. A higher ratio generally indicates a sweeter flavour balance when acidity remains low, although sensory quality cannot be fully predicted from the ratio alone.

Total sugars showed the widest and most striking treatment contrast. C17 recorded 26.94 %, substantially exceeding the other reported means, while C8 had 6.65%. C2 had 13.52% and C5 12.63%. Reducing sugars ranged from 4.15% in C16 to 12.04% in C4. The strong treatment effect for sugars suggests considerable biochemical differentiation among the evaluated material. This is important for selection because consumers generally associate soluble solids and sugars with eating quality, while breeders and processors may also value specific sugar profiles. Arivalagan *et al*. (2021) reported total sugars in a range of 5.13–7.06% and mentioned that white-pulped fruits were superior for sugars.

Anthocyanin content ranged from 0.02 mg/g to 0.29 mg/g. C7 had the highest value (0.29 mg/g), while several collections recorded 0.03 mg/g to 0.08 mg/g. The coefficient of variation for anthocyanin was 13 per cent, and the ANOVA indicated a significant treatment effect. Dragon-fruit colour chemistry is complex and is commonly associated with betalain pigments as well as other phenolic compounds; therefore, the anthocyanin variable in the present dataset should be interpreted strictly as the measured parameter reported by the analysis rather than assumed to represent total red-violet pigment

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concentration. Abirami *et al*. (2021) have shown marked differences in antioxidant-related compounds among dragon-fruit species and fruit tissues.

Ascorbic acid varied from 7.93 mg/100 g in C20 to 20.62 mg/100 g in C4, C16 and C19. C4 therefore combined high TSS, high reducing sugar and high ascorbic acid, giving it a particularly interesting quality profile. Published nutritional characterisation of Nur *et al*. (2023) reported 9–10 mg/100 g in pulp has confirmed the presence of vitamin C in dragon fruit, although reported concentrations vary considerably with genotype and analytical conditions.

The coefficient of variation values provide additional context. TSS (4%), total sugars (6%) and reducing sugars (5%) showed relatively low experimental variation, indicating good precision for these measurements. Ascorbic acid had the largest CV (16%), followed by anthocyanin (13%) and acidity and the TSS-to-acidity ratio (11%). The variation in biochemical traits reflects the collection related differences.

An important outcome of the combined dataset is that the treatment performing best for one quality dimension was not necessarily superior for all other dimensions. C11 was outstanding for fruit and pulp weight, whereas C1 had the highest yield per pole. C15 had the longest fruit and highest seed number, and C19 had the highest bract number and pulp-to-fruit ratio. On the biochemical side, C4 combined the highest TSS with the highest reducing sugars and a high ascorbic-acid value; C17 was exceptional for total sugars; C8 showed the highest TSS-to-acidity ratio despite having low fruit size and yield; and C7 recorded the highest anthocyanin value.

This lack of a single universally superior treatment is typical of multi-trait fruit evaluation. Selection for commercial cultivation therefore needs to reflect the intended end use. Fresh-fruit production may place greater emphasis on fruit weight, attractive bract architecture, pulp recovery and yield. Premium fresh markets may additionally favour high TSS and balanced sweetness. Processing or functional-food applications may prioritise sugar concentration, pigments and antioxidant-related compounds. Published dragon-fruit studies similarly show that morphological and biochemical traits can vary independently enough to justify multi-trait characterisation rather than selection on one descriptor alone.

The present findings also fit within the wider literature on dragon-fruit diversity. Tao *et al*. (2014) demonstrated considerable variation among dragon-fruit accessions using morphological traits and ISSR markers, supporting the view that the crop contains substantial exploitable diversity. Abirami *et al*. (2021) likewise documented variation in fruit weight, pulp weight, bract traits and yield among four genotypes of three *Hylocereus* species in the Andaman & Nicobar Islands in India. Biochemical studies have further shown that species and tissues differ in sugars, phenolics, flavonoids and antioxidant potential, emphasising the importance of evaluating both agronomic and nutritional attributes (Arivalagan *et al*., 2021).

Conclusion

The combined fruit and biochemical datasets demonstrate substantial diversity among the twenty dragon-fruit collections. All twelve fruit characters showed significant differences in the data analysis, with particularly large contrasts in fruit weight, pulp weight, bract characters and yield. C11 was prominent for fruit and pulp weight, C15 for fruit length, C19 for bract number and pulp-to-fruit ratio, and C1 for yield per pole. Biochemical quality was similarly variable. C4 was notable for TSS, reducing sugars and ascorbic acid, C17 for total sugars, C8 for TSS-to-acidity ratio and C7 for anthocyanin.

The twenty dragon-fruit collections showed useful preliminary diversity in fruit morphology, edible recovery, yield and biochemical quality. C1 is recommended for further yield-focused evaluation because it recorded the highest yield per pole (4.40 kg pole^{-1}); its yield advantage should be confirmed across seasons given the 13.2% yield CV. C11 merits evaluation for large-fruit fresh-market use because it recorded the highest fruit weight and pulp weight. C19 is a candidate for fresh-fruit selection where high pulp-to-fruit ratio and prominent bract characteristics are desirable. For quality-oriented selection, C4 merits further testing for high TSS, reducing sugars and ascorbic acid, while C17 is a candidate for sugar-rich fruit or processing applications because it recorded the highest total-sugar value. C8 had the highest TSS-to-acidity ratio and could be retained as a quality-specific candidate, although its low fruit weight and yield make it less attractive for yield-led production. C7 recorded the highest reported pigment value, but any pigment-related recommendation must remain provisional until the analytical method and pigment identity are confirmed. These collections should be considered for further evaluation, not as validated superior cultivars. Their performance should be confirmed under uniform growing conditions, with more replications and over multiple seasons before cultivar or commercial-use recommendations are made. These findings indicate that selection should be based on a combination of marketable

fruit attributes, yield, edible recovery and biochemical quality rather than on a single trait. The data therefore provides useful preliminary evidence for identifying contrasting dragon-fruit collections for future evaluation, multi-location testing and breeding or selection programmes.

Acknowledgement

The authors express their gratitude to the Kerala Agricultural University, Thrissur, for financial assistance and support throughout this research.

References

Abirami, K., Swain S., Baskaran V., Venkatesan K., Sakthivel K. and Bommayasamy N. (2021). Distinguishing three Dragon fruit (*Hylocereus* spp.) species grown in Andaman and Nicobar Islands of India using morphological, biochemical and molecular traits. *Scientific Reports*, **11**, 2894. https://doi.org/10.1038/s41598-021-81682-x

Arivalagan, M., Karunakaran G., Roy T.K., Dinsha M., Sindhu B.C., Shilpashree V.M., Satisha G.C. and Shivashankara K.S. (2021). Biochemical and nutritional characterization of dragon fruit (*Hylocereus* species). *Food Chem.*, **353**, 129426. https://doi.org/10.1016/j.foodchem.2021.129426

Bishoyi, A.K., Saeed F., Shehzadi U., Shankar A., Balaji J., Kaur J., Afzaal M., Imran A., Rasheed M., Hussain B., Hussain M., Ahmed A., Islam F. and Kinki A.B. (2024). Nutritional composition, phytochemical profile, and health benefits of *Hylocereus undatus* (Pitaya): A comprehensive review. *eFood*, **5(5)**, e70017. https://doi.org/10.1002/efd2.70017

Dantas, A.C., Cavalcante M., da Silva Buarque J.T. and Melo V.S.T. (2025). Morphological characterization, genetic divergence and indication of crossings in dragon fruit. *Scientia Plena*, **21(12)**, 120202. https://doi.org/10.14808/sci.plena.2025.120202

Hisham, M.M., Chandran J. and Gopinath P.P. (2025). RAISINS: Integrating R and AI for Agricultural Data Analysis. *J. Sust. Technol. Agricult.*, **1(1)**. https://doi.org/10.5281/zenodo.15622128

Kumari, S., Thakur D., Singh S., Bakshi M. and Singh S.K. (2025). Dragon fruit: Exploring bioactive compounds and their promising role in functional food innovation and value-added products. *J. Food Composition and Analysis*, **141**, 107370. https://doi.org/10.1016/j.jfca.2025.107370

Lane, J.H. and Eynon L. (1923). Determination of reducing sugars by means of Fehling's solution with methylene blue as internal indicator. *J. Society of Chemical Industry*, **42**, 32T–37T.

Nur, M.A., Uddin M.R., Uddin M.J., Satter M.A. and Amin M.Z. (2023). Physiochemical and nutritional analysis of the two species of dragon fruits (*Hylocereus* sp.) cultivated in Bangladesh. *South Afr. J. Bot.*, **155**, 103–109. https://doi.org/10.1016/j.sajb.2023.02.006

R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Ranganna, S. (1986). Handbook of analysis and quality control for fruit and vegetable products (2nd ed.). Tata McGraw-Hill Publishing Company Limited.

Santos-Pelaez, J.C., Saravia-Navarro D., Cruz-Delgado J.H.I., del Carpio-Salas M.A., Barboza E. and Casanova Nuñez Melgar D.P. (2024). Phenotypic diversity of morphological traits of pitahaya (*Hylocereus* spp.) and its agronomic potential in the Amazonas region, Peru. *Agriculture*, **14(11)**, 1968. https://doi.org/10.3390/agriculture14111968.

Sethunath, K. and Bhaskar J. (2024). Evaluation of diversity in dragon fruit (*Hylocereus* spp.) genotypes grown in Kerala, India. *J. Appl. Horticult.*, **26(1)**, 127–131. https://doi.org/10.37855/jah.2024.v26i01.24

Tao, J., Qiao G., Wen X.-P., Gao G.-L., Liu T., Peng Z.-J., Cai Y.-Q., Chen N., Yan F.-X. and Zhang B.-X. (2014). Characterization of genetic relationship of dragon fruit accessions (*Hylocereus* spp.) by morphological traits and ISSR markers. *Scientia Horticulturae*, **170**, 82–88. https://doi.org/10.1016/j.scienta.2014.03.006