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Physicochemical and Quality Attributes of 'Possum Purple' Passion Fruit in Relation to Fruit Weight Categories

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Abstract. **This study aimed to evaluate the fruit quality and physicochemical attributes of purple passion fruit cv. Possum Purple based on the fruit weight into four categories including <40 g, 40 to 50 g, 50 to 60 g, and >60 g. Significant differences were observed in morphological traits, including fruit firmness, length, width, and weight-related parameters. Heavier fruit (>60 g) exhibited greater firmness, dimensions, and juice content compared with lighter categories (<40 g). Fruit length and width increased progressively with weight, while the fruit shape index remained unaffected. Larger fruit showed higher total soluble solids (TSS) and lower titratable acidity (TA), resulting in a higher TSS/TA ratio. Juice pH and volume increased with fruit size, whereas juice content was significantly lower in the <40 g group. Total carotenoid content (TCC) was significantly lower in the <40 g fruit, with no differences among heavier categories, whereas total phenolic content (TPC) and total antioxidant activity (TAA) were not significantly associated with fruit size. Colorimetric analysis revealed that peel *L** and *b** values were lowest in the >60 g group, whereas peel *a** and *C** values did not differ significantly. Juice *L** was lowest in the >60 g group; however, juice *b**, *h*°, and *C** were generally higher in the <40 g fruit. Multivariate statistical analyses [principal component analysis (PCA) and hierarchical cluster analysis (HCA)] confirmed that physicochemical attributes are strongly affected by fruit size and revealed that the larger and smaller fruit exhibit distinct physicochemical profiles. Overall, these findings highlight the relevance of fruit size as a key determinant of physicochemical quality in purple passion fruit and may guide selection strategies for both breeding and market preferences.**

Passion fruits (*Passiflora* spp.) are a group of tropical and subtropical fruits belonging to the Passifloraceae family (Morton 1987). There are two main commercial types of passion fruit: yellow (*Passiflora edulis* f. flavicarpa) and purple (*P. edulis* f. edulis), as well as several intraspecific hybrids that are commonly cultivated due to their desirable fruit quality (Schotsmans and Fischer 2011). Purple passion fruit is typically consumed fresh due to its sweeter flavor, whereas yellow passion fruit is commonly used for juice processing because of its higher yield and acidity (Fonseca et al. 2022). Purple passion fruit is valued for its unique flavor and rich nutritional profile including high content of vitamins, minerals, dietary fiber, carbohydrates, polyphenols, and carotenoids (Fonseca et al. 2022). The fruit pulp contains volatile compounds, including esters, aldehydes, ketones, and alcohols, as well as limonene, β-ionone, and linalool, which are key aroma compounds in passion fruit (Schotsmans and Fischer 2011).

Bioactive compounds and antioxidants of passion fruit are biologically active and provide several health benefits to consumers and are increasing in commercial demand (Fonseca et al. 2022). The health benefits of passion fruit include relief from anxiety, insomnia, bronchitis, urinary tract infections, and support in treating bronchial asthma and nervous gastrointestinal disorders, as its bioactive compounds also act as mild sedatives (Schotsmans and Fischer 2011). Passion fruit pulp is widely used in the food and beverage industry for juices and desserts due to its nutritional profile, antioxidants, and aromatic compounds (Shi et al. 2023). Its commercial importance encompasses both fresh consumption and processing industries, where fruit quality plays a pivotal role in consumer preference and market value (Fonseca et al. 2022).

In passion fruit, the size of the fruit can vary significantly, even on the same vine and within the same cultivar, when grown under similar cultivation practices (Fischer et al. 2018). Among the many attributes influencing fruit quality, fruit size is one of the key characteristics that not only affects grading and market classification, but also serves as a potential indicator of internal physicochemical traits (Viera et al. 2022). In this case, passion fruit is sorted into three size categories including small, medium, and large based on diameter or fruit weight (He et al. 2020). In addition, fruit weight is a key parameter not only for commercial grading but also as an indirect indicator of internal quality attributes (Fonseca et al. 2022). Parameters including juice content, juice yield, and nutritional value often can be varied across fruit size categories, impacting overall fruit acceptability (Wetzstein et al. 2011). Understanding the relationship between fruit size and quality attributes can therefore assist in the development of better sorting, packaging, and postharvest management strategies. Furthermore, such knowledge can play an important role in breeding programs aimed at improving fruit quality (Chavarria-Perez et al. 2020). By identifying specific size categories associated with desirable traits including higher juice content or balanced sugar-acid ratio, breeders can more effectively select parent lines or breeding populations that exhibit superior fruit quality (Cerqueira-Silva et al. 2018). This is particularly valuable for programs affecting consumer-oriented traits, industrial processing standards, and extended shelf life (Ribeiro et al. 2019).

Fruit size is often a key factor in postharvest processes and market preferences (Thokchom and Mandal 2017), yet its specific effects on the quality traits of purple passion fruit have not been widely studied. Understanding how different size categories influence physical and chemical characteristics of passion fruit can help identify important relationships among quality attributes. For example, it is still not well understood whether bioactive compounds or antioxidant capacity change with fruit size, or how parameters like firmness or the ratio of pulp to peel change with fruit weight. This information can help precise grading systems, improve postharvest quality, and enhance consumer satisfaction (Fischer et al. 2018). To address this, the aim of this study was to evaluate the physical, biochemical, and nutritional quality characteristics of purple passion fruit in relation to various fruit sizes. This approach can determine whether fruit weight is correlated with key fruit quality factors and how fruit weights affect overall fruit quality. This approach allowed us to explore whether fruit weight is linked to specific quality indicators.

Materials and Methods

Treatments and storage conditions. In this study, purple passion fruit cv. Possum Purple were harvested from 1-year-old vines at commercial maturity stage based on peel color from a research plot of the University of Florida's Institute of Food and Agricultural Sciences/ Plant Science Research and Education Unit

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(UF/IFAS PSREU) in Citra, FL, USA. Harvested fruit were immediately transported to the Fruit Crops laboratory at the University of Florida, Gainesville. Fruit were classified into four weight categories: 1) <40 g, 2) 40 to 50 g, 3) 50 to 60 g, and 4) >60 g. The experiment was conducted twice using fruit from two independent harvests, collected in Mar and Jun 2024, respectively. In both trials, fruit were harvested 1 d before evaluation, and the same experimental design and procedures were used. Each treatment included 20 fruit, arranged in four replications with five fruit each. The following parameters were evaluated for each individual fruit in both experiments.

Firmness. Fruit firmness was measured using a texture analyzer (Texture Technologies Corp., Surrey, UK) at the equatorial region of intact fruit. The instrument was equipped with a 5 kg load cell and a 45 mm-diameter flat plate to assess resistance to compression. Each fruit was compressed to a depth of 3 mm, and the resulting force-deformation data were recorded in Newtons (N) (Plaza et al. 2004).

Fruit dimensions and peel thickness. Fruit length, width, and peel thickness were measured using a digital caliper and expressed in millimeters. The fruit shape index was calculated as the ratio of fruit length to fruit width (Viera et al. 2022).

Fruit weight, peel weight, pulp weight, juice weight, number of seeds, juice volume, and juice content. The weights of the whole fruit, pulp, peel, and juice were measured using a digital balance (±0.01 g; Sartorius PRACTUM2102-1S, Göttingen, Germany) and expressed in grams. Each fruit was cut open and manually separated into peel and pulp. The pulp was placed inside a plastic bag, squeezed, and the extracted juice was filtered through cheesecloth. The filtered juice was then transferred to a graduated cylinder to measure its volume. Juice content was calculated as the ratio of juice weight to whole fruit weight and expressed as a percentage (%). Seeds were counted after juice extraction from each fruit (Viera et al. 2022).

Chemical attributes of juice. TSS, TA, the TSS/TA ratio (flavor index), and juice pH were evaluated using juice extracted from fruit in each replicate. TSS was determined using a handheld digital refractometer (Reichert AR200, Depew, NY, USA) with automatic temperature compensation. TA and pH were assessed using an automatic titrator (Metrohm 814 USB Sample Processor, Herisau, Switzerland). Samples were titrated with 0.1 N NaOH to pH 8.2, and TA was expressed as a percentage (%) of citric acid. The flavor index was calculated as the TSS/TA ratio.

Total carotenoid content. The TCC was determined following the method described by Talcott and Howard (1999), with slight modifications. Briefly, 2 mL of juice was mixed with 20 mL of an extraction solution prepared by combining ethanol and hexane in a 1:1 (v/v) ratio. The samples were vortexed and then centrifuged at 20,000 g_n for 20 min at 4 °C. After centrifugation, the samples were incubated at −20 °C for 24 h. Following incubation, the hexane phase was separated to the tube using a transfer pipette. This extraction step was repeated with the extraction solution, followed by washing with deionized (D.I.) water to remove any remaining supernatant. After complete removal of the hexane phase, 10 mL of D.I. water was added to the tubes and vortexed, which were then kept at −20 °C for 2 h. The hexane phase was subsequently transferred to a new tube and adjusted to a uniform volume using the extraction solution. Then, 250 μL of each sample and a blank (extraction solution only) were loaded in triplicate onto a microplate, and absorbance was measured at 470 nm using a microplate reader (SYNERGY HTX, Biotek, Shoreline, WA, USA). The TCC was calculated and expressed as β-carotene mg/100 g (Talcott and Howard 1999).

Total phenolic content. The TPC was measured using the Folin–Ciocalteu colorimetric method (Singleton and Rossi 1965). Briefly, 500 μL of diluted juice was mixed with Folin–Ciocalteu reagent under yellow light, followed by sodium carbonate after an 8 min incubation. The mixture was then heated at 45 °C for 15 min, cooled, and its absorbance was recorded at 765 nm. Gallic acid (GA) was used to create a standard curve, and results were expressed as $mg \cdot L^{-1}$ of GA equivalents (GAE).

Total antioxidant activity. The TAA was assessed using the ferric reducing antioxidant power (FRAP) assay (Benzie and Strain 1996). The FRAP reagent prepared by mixing the acetate buffer (pH = 3.6), TPTZ in HCl, and $FeCl_3$ in a 10:1:1 ratio. Under yellow light, 100 μL of sample and 50 μL of Trolox standards were each mixed with 180 μL of FRAP reagent. Absorbance was measured at 595 nm. Results were calculated from a standard curve with different Trolox equivalent (TE) concentrations and were expressed in μmol TE/L.

Color parameters. Peel and juice color were measured for each replicate using a colorimeter (Minolta CR-300, Tokyo, Japan). Peel color was assessed externally at the equator on opposite sides of the intact fruit. Juice color was measured using 3 mL of extracted juice placed in a plastic cap with a 1-cm diameter. Color values were recorded using the *CIEL*a*b** system, and the recorded *L**, *a**, and *b** values were converted to hue angle ($h°$) and chroma (C^*) for more meaningful interpretation (Jimenez-Cuesta et al. 1981; McGuire 1992).

Statistical analyses. Both experiments followed a completely randomized design. Data from the two experiments were pooled and analyzed using SAS software (version 9.4; IBM Corp, Armonk, NY, USA). PCA was conducted using Minitab (version 21). HCA was performed using the Ward linkage method with Euclidean distance in Minitab (version 21). Pearson's correlation coefficient analysis was carried out using the *corrplot* package in R.

Results

Fruit firmness, length, and width. Fruit firmness, length, and width were significantly affected by fruit weight category (Fig. 1). Fruit weighing more than 60 g exhibited the highest firmness. This category had significantly firmer fruit than the lighter categories (<40 g and 40 to 50 g), which showed the lowest firmness values (Fig. 1). Fruit length increased gradually with weight, with all four categories showing statistically distinct values. The largest fruit (>60 g) had the greatest length and the smallest fruit (<40 g) had the shortest (Fig. 1). Similarly, fruit width followed a significant upward trend across the weight categories. Fruit in the >60 g category had the widest diameter, followed by 50 to 60 g, 40 to 50 g, and <40 g, all of which were statistically different (Fig. 1). The fruit shape index did not differ significantly across weight categories (data not shown).

Peel weight, pulp weight, juice weight, peel thickness, and average number of seeds. Significant differences were observed among fruit weight categories in flesh weight, peel weight, juice weight, peel thickness, and average number of seeds (Fig. 1). Flesh weight and peel weight increased progressively across the categories, with each category being statistically different from the others ($P < 0.05$), and the >60 g fruit showing the greatest values (Fig. 1). Juice weight also increased significantly with fruit size, with the >60 g category yielding the highest juice content, followed by 50 to 60 g, 40 to 50 g, and <40 g fruit. Peel thickness did not show a consistent increasing or decreasing trend. The <40 g category had the highest peel thickness, although it was not statistically different from the >60 g group. The 40 to 50 g and 50 to 60 g categories had significantly thinner peels compared with the <40 and >60 g groups (Fig. 1).

The average number of seeds per fruit was significantly affected by fruit weight category. Fruit weighing more than 60 g had the highest seed number, followed by those in the 50 to 60 g and 40 to 50 g categories, while the <40 g group exhibited the lowest seed number. All categories differed significantly from one another (Fig. 1).

TSS, TA, TSS/TA ratio, juice pH, juice volume, and juice content. Fruit weight category significantly influenced several juice biochemical parameters. TSS values were slightly but significantly higher in fruits weighing more than 60 g, with no significant difference compared with the 40 to 50 g category, whereas the <40 g and 50 to 60 g categories showed the lowest TSS (Fig. 2).

TA was highest in the 50 to 60 g group, which was not significantly different from the <40 g category. The lowest TA was observed in the 40 to 50 g and >60 g categories. The TSS/TA ratio was lowest in the 40 to 50 g group and highest in the >60 g fruit, with no significant differences from the <40 g and 50 to 60 g categories (Fig. 2).

Juice pH was significantly higher in the 50 to 60 g and >60 g groups, with no significant difference between them. The <40 g and 40 to 50 g groups had the lowest pH compared with the heavier ones, also showing no significant difference between each other (Fig. 2).

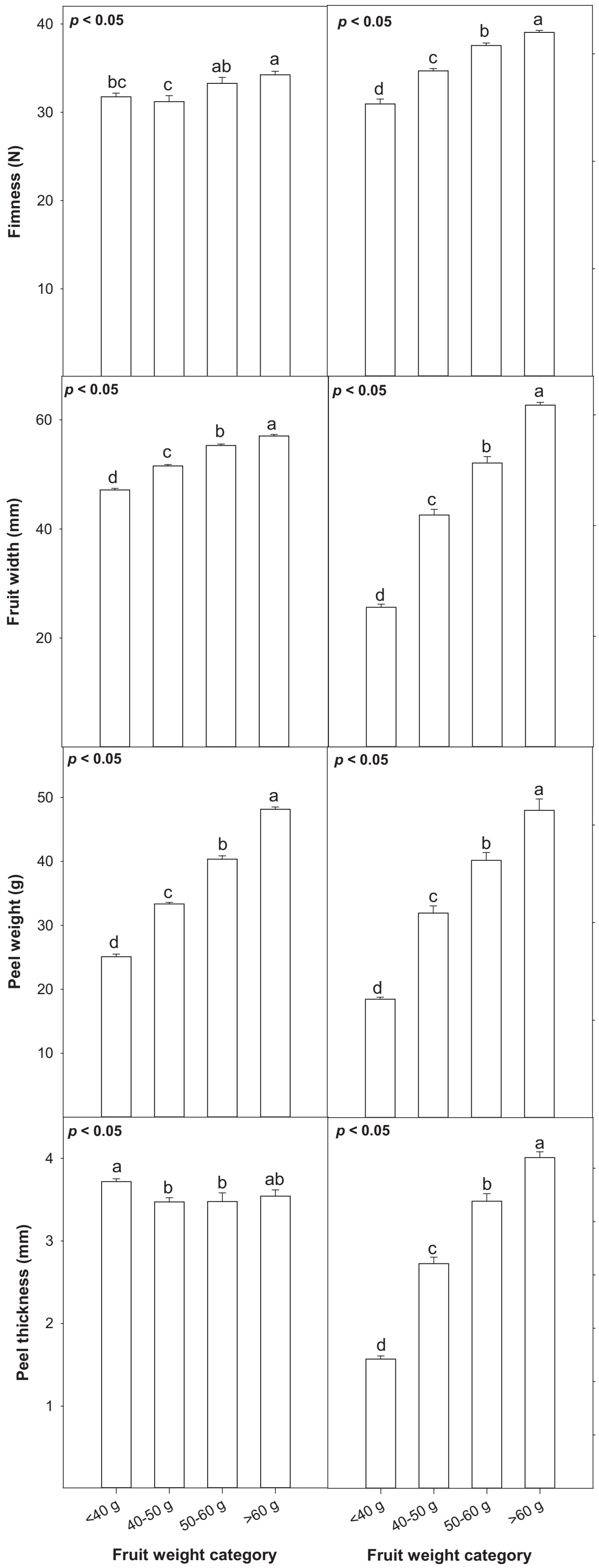

Fig. 1. Fruit firmness, length, width, peel weight, pulp weight, juice weight, peel thickness, and average number of seeds in purple passion fruit cv. Possum Purple. Vertical bars represent standard errors (±*SE*) of means. Different letters above the bars on columns indicate significant differences at $P < 0.05$.

Juice volume increased significantly with fruit weight, ranging from the lowest volume in the <40 g group to the highest in the >60 g group. All categories were significantly different from each other (Fig. 3). Juice content was significantly lower in the <40 g category compared with all others, which did not differ significantly among themselves (Fig. 2).

Total carotenoid content. TCC varied significantly among fruit weight categories (Fig. 3). Fruit weighing less than 40 g had significantly lower carotenoid content compared with all other categories. No significant differences were observed among the 40 to 50 g, 50 to 60 g, and >60 g categories, all of which showed similar carotenoid concentrations.

TPC and TAA showed no significant difference across weight classes, with ranges of 33 to 34 mg·L^{-1} GAE and 29 to 33 μmol TE/L, respectively (data not shown).

Peel and juice color parameters. Peel and juice color parameters were affected by fruit weight category (Table 1). For peel *L** and *b** values, the >60 g category exhibited the lowest lightness and the 40 to 50 g group had the highest values, with no significant differences from the <40 g and 50 to 60 g categories (Table 1). Fruit weighing more than 60 g and 50 to 60 g had the highest *h*°, with no significant difference between them. The <40 g and 40 to 50 g groups had the lowest *h*° values compared with the heavier ones, with no significant difference between them (Table 1). There were no significant differences in peel *a** and *C** values across the different weight categories.

Juice *L** was significantly affected, with the >60 g group showing the lowest values among all categories. Juice *a** was higher in the 40 to 50 g and >60 g groups, with no significant difference between them, whereas the <40 g and 50 to 60 g groups had lower values and did not differ significantly from each other. Juice *b**, *h*°, and *C** values were generally highest in fruit from the 40 to 50 g group, whereas the <40 g category showed lower values (Table 1).

Multivariate statistical analyses. The PCA revealed distinct separation among the different fruit weight categories, based on the evaluated physicochemical and quality attributes (Fig. 4A). The first two principal components (PC1 and PC2) accounted for 87.0% of the total variance, with PC1 explaining 68.1% and PC2 accounting for 18.9%. The >60 g and 50 to 60 g categories clustered closely on the positive side of PC1, associated with attributes including fruit weight, peel weight, fruit length, TSS, juice content, juice volume, average number of seeds, and pulp weight. These traits strongly contributed to PC1 and represent characteristics typical of larger fruit. Conversely, the 40 to 50 g category was located on the negative side of both PC1 and PC2, associated with TA and peel and juice color parameters. The <40 g group was positioned on the positive side of PC2, primarily associated with peel thickness, juice *h*°, and juice *L**.

The dendrogram generated through HCA based on physicochemical attributes of purple passion fruit grouped the fruit weight categories into two main clusters (Fig. 4B). The first cluster included the <40 and 40 to 50 g categories, indicating a high level of similarity among medium-weight fruit. The second cluster comprised the 50 to 60 g and >60 g categories, which were also closely related. These two primary clusters were then merged at a lower similarity level, suggesting that the larger and smaller fruit exhibit distinct physicochemical profiles. The cophenetic distance

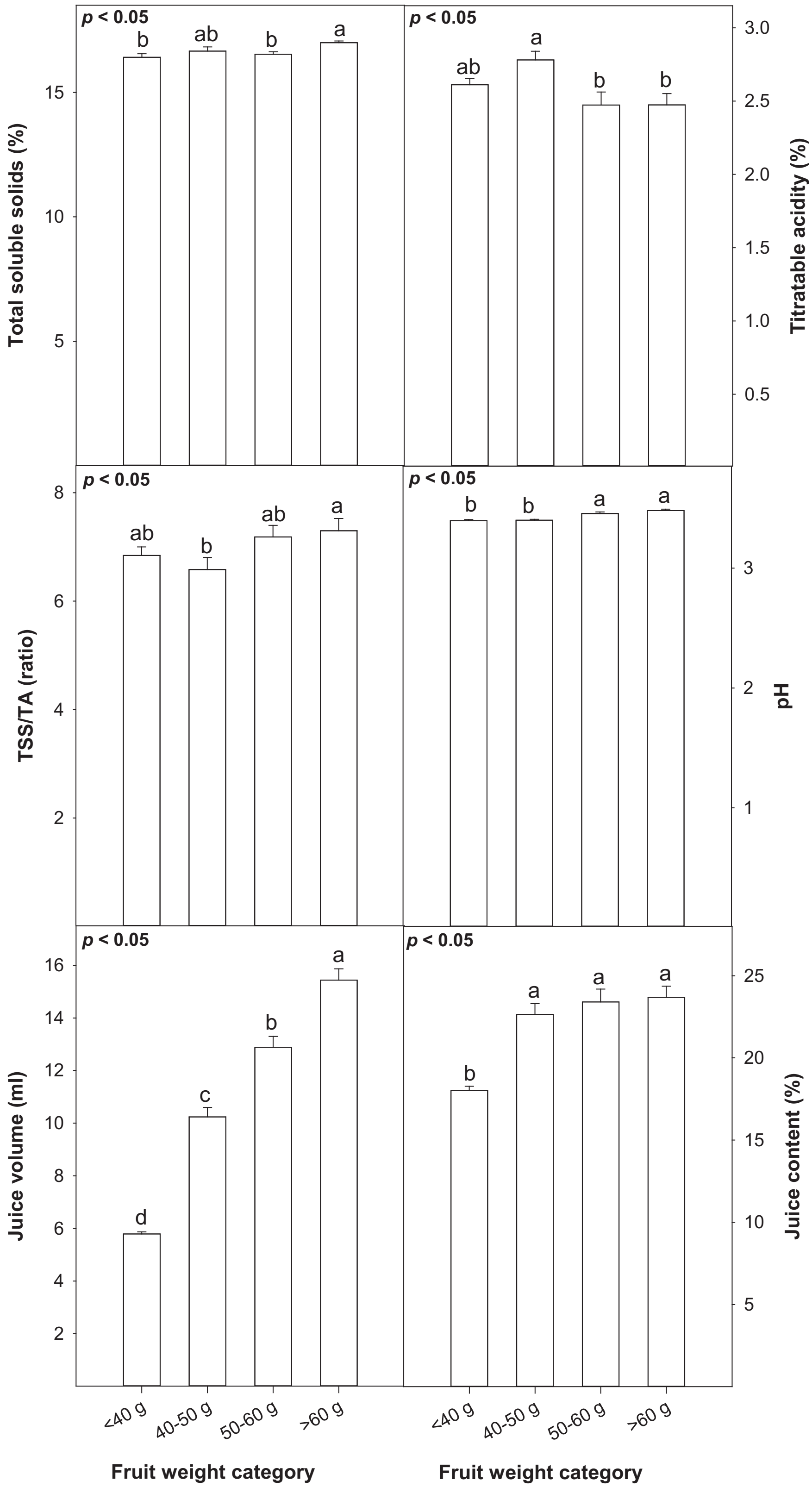

Fig. 2. Total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio, pH, juice volume, and juice content in purple passion fruit cv. Possum Purple. Vertical bars represent standard errors (±*SE*) of means. Different letters above the bars on columns indicate significant differences at $P < 0.05$.

indicates that the most similar groupings were between 50 to 60 g and >60 g, whereas the greatest dissimilarity was observed between the first cluster (<40 and 40 to 50 g) and the second cluster.

The Pearson correlation matrix revealed significant associations among the physicochemical and morphological attributes of purple passion fruit (Table 2). Strong positive correlations were observed between several weight-related parameters. Fruit weight showed high correlations with peel weight, pulp weight, juice weight, juice volume, and fruit length. In addition, juice content was positively correlated with juice weight and pulp weight, indicating that heavier fruit tend to yield more juice and have thicker pulp. Among biochemical parameters, TSS correlated positively with TSS/TA ratio, and pH. Total carotenoids also showed a strong positive correlation with juice a^*. On the other hand, negative correlations were observed between TA and TSS/TA ratio, as expected, since a higher acid concentration lowers the sweetness-to-acidity ratio.

Discussion

Information about the effect of fruit size on physical, biochemical, and nutritional traits of purple passion fruit can provide a comprehensive insight for grading and postharvest handling, fresh market, and juice processing industries as well as for breeding programs. This information also identifies which attributes are correlated with fruit size and how fruit size relates to other quality attributes, bioactive compounds, and antioxidant activity. Understanding these relationships can guide producers in selecting the optimal fruit size to meet specific market demands while ensuring desirable quality traits for both fresh consumption and industrial processing. Therefore, this study provides a valuation of how fruit weight in purple passion fruit impact the physicochemical attributes.

In this study, fruit size was strongly correlated with several morphological parameters, including fruit length and width. Larger fruit (>60 g) exhibited greater length and width that suggest larger fruit undergo extended cell division and elongation phases during development (Wetzstein et al. 2011). This likely reflects underlying genetic control of fruit growth patterns in which cell division and expansion are stimulated uniformly in both longitudinal and radial directions (Das et al. 2013). Interestingly, the shape index remained relatively constant across all categories, indicating that despite variations in size, the fruit maintain their general shape. This proportional growth pattern likely reflects genetically programmed developmental pathways that regulate cellular expansion uniformly across longitudinal and radial axes (Wetzstein et al. 2011). In pomegranate (*Punica granatum* L.), there was a positive correlation between fruit volume and weight, aril number to fruit size (Wetzstein et al. 2011).

The observed increase in fruit firmness with higher fruit weight categories may be attributed to enhanced cell wall development, increased turgor pressure, and a denser arrangement of parenchyma cells or reduced intercellular air spaces, contributing to greater resistance to mechanical deformation (Carrillo-López and Yahia 2019). Furthermore, heavier fruit may exhibit variations in enzymatic activity that affect cell wall degradation, thereby influencing texture and firmness (Wang et al. 2024).

Fruit weight showed strong positive correlations with peel, pulp, and juice weights,

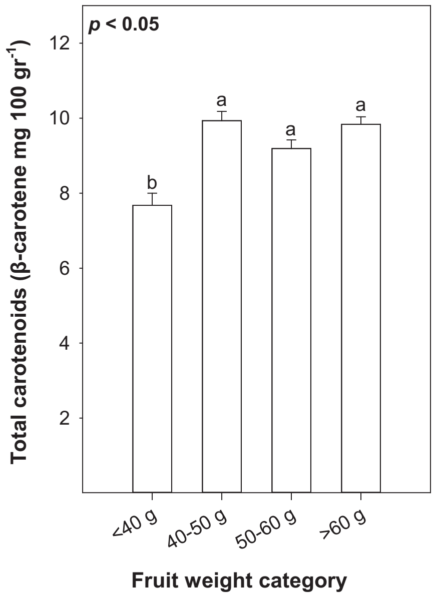

Fig. 3. Total carotenoid content (TCC) in purple passion fruit cv. Possum Purple. Vertical bars represent standard errors (±*SE*) of means. Different letters above the bars on columns indicate significant differences at $P < 0.05$.

confirming that as fruit grow larger, they accumulate more structural biomass (Carrillo-López and Yahia 2019). Juice weight and juice volume followed the same trend as pulp weight, supporting the importance of fruit size as a key determinant of juice content and processing purposes. Larger fruit may also have more developed vascular systems, enhancing water and solute transport, which contributes to higher juice content (Zhang et al. 2021). Although peel thickness remained relatively constant across categories, peel weight increased substantially, suggesting that larger fruit have more extensive surface areas rather than thicker pericarps. Interestingly, the number of seeds also rose significantly in heavier fruit, which could reflect a higher number of ovules fertilized (Wetzstein et al. 2011). This pattern suggests that seed development is closely linked to fruit size in purple passion fruit. Larger fruit not only accommodate more seeds but also benefit from the hormonal signals produced by developing seeds, which promote cell division, tissue expansion, and overall fruit growth (De Araujo et al. 2020). Furthermore, successful pollination is a prerequisite for seed development and, consequently, for optimal fruit set and size. Therefore, the increase in fruit weight observed in our study likely reflects, at least in part, enhanced seed development driven by effective fertilization and ovule formation (Wetzstein et al. 2011).

Biochemical juice attributes including TSS, TA, TSS/TA, and juice pH exhibited relatively different values among weight categories. Larger fruit tended to accumulate more TSS, although the differences were moderate. It suggests that larger purple passion fruit may accumulate more sugars and soluble compounds during development (Zhang et al. 2021). This could be attributed to enhanced vascular development or extended maturation periods in larger fruit (Carrillo-López and Yahia 2019). In contrast, TA declined with increasing fruit weight, likely due to the conversion of organic acids or their metabolic degradation as the fruit mature. In lighter fruit, higher acidity levels may suggest earlier developmental stages or slower acid degradation (Ramaiya et al. 2018). This trend not only reflects physiological ripening but also impacts flavor perception, favoring sweeter profiles in larger fruit. Consequently, TSS/TA ratio increased with fruit weight, particularly in the >60 g category. This suggests that larger fruit offer a more favorable balance between sweetness and acidity, which is often associated with better sensory quality and consumer preference (Carrillo-López and Yahia 2019). The elevated ratio may result from concurrent sugar accumulation and acid degradation in more mature, heavier fruit, supporting the idea that fruit size can be a useful indicator of internal quality within a given cultivar, although this relationship may vary across different cultivars (Wetzstein et al. 2011). The relatively stable pH across weight categories, with only a slight increase in the heaviest fruit, supports the observed decrease in TA and offered an inverse relationship between pH and TA (Ramaiya et al. 2018).

The TCC was significantly lower in the smallest fruit, whereas no differences were found among the larger categories. This pattern suggests that carotenoid biosynthesis is positively correlated with fruit developmental maturity and metabolic activity (Pertuzatti et al. 2015). The lower TCC in smaller fruit may reflect an earlier developmental stage or reduced metabolic efficiency, possibly due to differences in developmental maturity, influenced by shading or fruit competition, leading to delayed pigment accumulation. These results suggest that carotenoid accumulation can be influenced by fruit size.

The TPC remained relatively stable across the different fruit weight categories. This suggests that phenolic biosynthesis is less sensitive to size compared with other biochemical traits. On the other hand, the stability of TPC values indicates that phenolic compounds may be uniformly distributed across fruit sizes, or that their accumulation depends on days after fruit set and remains relatively unchanged thereafter (Dos Reis et al. 2018).

Like TPC, TAA had no distinct pattern with fruit weight. Because antioxidant capacity results from the combined and often synergistic effects of multiple compounds (Ramaiya et al. 2013), these results showed that antioxidant capacity in passion fruit is not necessarily associated with fruit size.

The colorimetric properties (L^*, a^*, b^*, $h°$, and C^*) of the peel and juice varied across fruit weight categories, indicating that fruit size exerts a noticeable influence on both external and internal color characteristics in purple passion fruit. Peel lightness (L^*) decreased slightly in larger fruit, possibly due to the anthocyanin pigments (Dos Reis et al. 2018). However, b^* values (yellowness) declined with weight, which may be due to the decreased synthesis or increased degradation of yellow carotenoids. The $h°$ had no clear trend in the peel but showed a slight decline in juice for larger fruit. This shift could indicate an experienced movement toward redder hues in juice or changes in pigment composition during ripening (Pongener et al. 2014). This suggests that although pigment concentration may shift slightly with fruit size, overall color intensity and perception remain largely uniform, preserving the visual appeal across different fruit sizes.

In conclusion, this study showed that fruit weight is a critical factor affecting the morphological, physicochemical, and nutritional attributes of purple passion fruit. Despite some attributes showing minimal dependence on fruit weight, multivariate analyses confirmed significant clustering of quality variables based on weight categories. As fruit size increased, there were consistent improvements in physical dimensions, pulp yield, juice volume, and juice content, which are critical traits for consumer preference and industrial processing. Although TA remained relatively stable across weight categories, larger fruit exhibited a higher TSS and TSS/TA ratio, suggesting a sweeter flavor profile. The number of seeds and carotenoid content also increased with fruit weight, indicating enhanced nutritional quality in heavier fruit. Although TPC and TAA did not vary significantly across weight groups, multivariate analyses revealed clear clustering patterns, confirming that fruit weight is a strong determinant of overall fruit quality. Color parameters of both peel and juice showed distinct variations across size categories. Larger fruit tended to have darker and less saturated peel and juice

Table 1. Peel and juice color parameters in purple passion fruit cv. Possum Purple.

	Color parameters							
Fruit weight	Peel L^*	Peel b^*	Peel $h°$	Juice L^*	Juice a^*	Juice b^*	Juice $h°$	Juice C^*
<40 g	38.66 ± 0.39 ab	7.73 ± 0.27 ab	22.56 ± 2.19 b	44.59 ± 0.17 a	13.28 ± 0.14 b	40.07 ± 0.37 a	71.52 ± 0.37 a	42.33 ± 0.32 ab
40–50 g	40.26 ± 1.39 a	8.98 ± 0.39 a	21.80 ± 1.55 b	44.37 ± 0.14 ab	14.18 ± 0.23 a	40.22 ± 0.41 a	70.46 ± 0.34 ab	42.78 ± 0.39 a
50–60 g	38.53 ± 0.66 ab	7.51 ± 0.4 ab	39.79 ± 1.87 a	44.63 ± 0.22 a	13.49 ± 0.23 b	39.10 ± 0.17 b	71.00 ± 0.33 a	41.44 ± 0.18 c
>60 g	37.28 ± 0.52 b	6.86 ± 0.27 b	48.28 ± 2.75 a	43.95 ± 0.26 b	14.51 ± 0.23 a	38.82 ± 0.13 b	69.60 ± 0.37 b	41.55 ± 0.11 bc

Different letters indicate significant differences at $P < 0.05$.

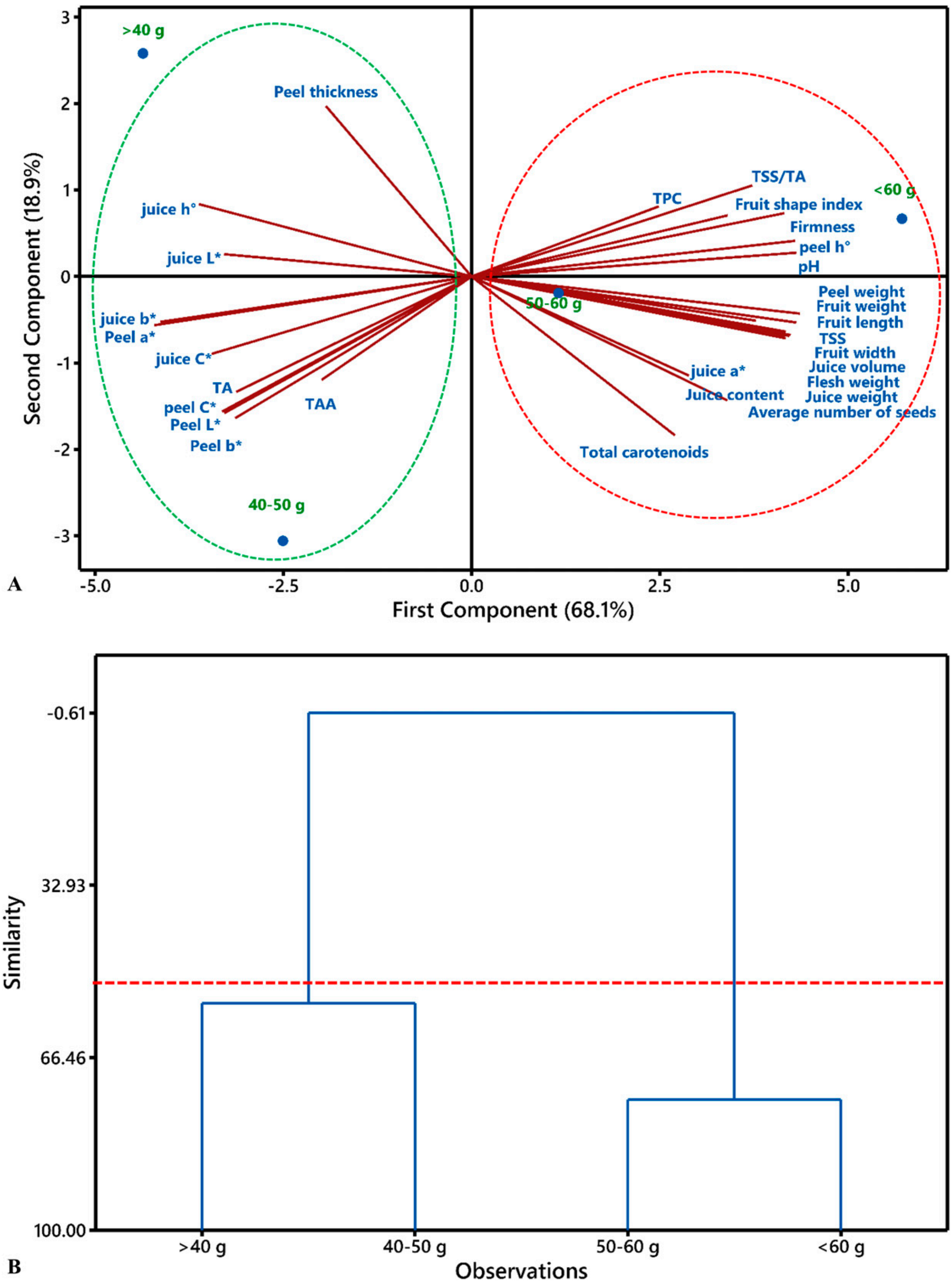

Fig. 4. Principal component analysis including score plot and biplot (**A**) and hierarchical clustering analysis (**B**) of purple passion fruit cv. Possum Purple. TA = titratable acidity; TAA = total antioxidant activity; TPC = total phenolic content; TSS = total soluble solids.

colors. Overall, fruit in the 50 to 60 g and >60 g categories showed superior quality in terms of juice yield, nutritional content, and market-relevant traits such as fruit size, peel thickness, and juice recovery. These findings support the importance of fruit size as an indicator of overall quality and suggest its potential use as a selection criterion in breeding, grading, and postharvest handling strategies for purple passion fruit, thus meeting the dual demands of the fresh market and juice processing industries. Promoting the cultivation and marketing of medium to large-sized fruit (i.e., >50 g in 'Possum Purple') may enhance consumer satisfaction and market value while supporting targeted quality improvement in passion fruit production systems.

Table 2. Pearson's correlation matrix among measured parameters of purple passion fruit cv. Possum Purple using a mixed corrplot. The values inside the squares represent the correlation coefficients (*r* values).

	TAA	Peel b	Peel L	Peel C	TA	Juice c	Peel a	Juice b	Juice L	Juice h	Peel thickness	TPC	TSS/TA	Fruit shape index	Firmness	Peel h	pH	Peel weight	Fruit weight	TSS	Fruit width	Flesh weight	Juice weight	Juice volume	Fruit length	Seed number	Juice a	Juice content
Peel b	0.59																											
Peel L	0.68	0.99																										
Peel C	0.69	0.99	1.00																									
TA	0.29	0.94	0.90	0.90																								
Juice c	0.17	0.87	0.83	0.83	0.98																							
Peel a	0.70	0.81	0.86	0.87	0.71	0.72																						
Juice b	0.31	0.85	0.84	0.84	0.91	0.95	0.87																					
Juice L	0.76	0.37	0.48	0.49	0.17	0.20	0.81	0.47																				
Juice h	0.52	0.27	0.36	0.38	0.17	0.27	0.78	0.54	0.95																			
Peel thickness	-0.47	-0.24	-0.25	-0.24	-0.04	0.18	0.14	0.31	0.20	0.51																		
TPC	-0.98	-0.55	-0.65	-0.66	-0.27	-0.19	-0.77	-0.38	-0.88	-0.68	0.29																	
TSS/TA	-0.38	-0.94	-0.92	-0.92	-0.98	-0.98	-0.84	-0.97	-0.37	-0.38	-0.09	0.39																
Fruit shape index	-0.91	-0.69	-0.77	-0.78	-0.47	-0.42	-0.92	-0.61	-0.91	-0.78	0.10	0.96	0.60															
Firmness	-0.45	-0.90	-0.90	-0.90	-0.91	-0.93	-0.92	-0.99	-0.54	-0.57	-0.20	0.50	0.98	0.71														
Peel h	-0.39	-0.83	-0.83	-0.83	-0.86	-0.91	-0.92	-0.99	-0.57	-0.64	-0.33	0.46	0.95	0.69	0.99													
pH	-0.34	-0.79	-0.79	-0.80	-0.84	-0.90	-0.90	-0.99	-0.56	-0.65	-0.39	0.42	0.93	0.66	0.98	1.00												
Peel weight	-0.30	-0.57	-0.60	-0.61	-0.61	-0.72	-0.87	-0.89	-0.70	-0.83	-0.60	0.44	0.76	0.66	0.87	0.93	0.94											
Fruit weight	-0.25	-0.54	-0.56	-0.57	-0.59	-0.71	-0.85	-0.88	-0.68	-0.83	-0.64	0.40	0.74	0.62	0.85	0.91	0.93	1.00										
TSS	-0.62	-0.39	-0.48	-0.50	-0.27	-0.34	-0.85	-0.60	-0.97	-0.99	-0.40	0.76	0.47	0.86	0.64	0.69	0.70	0.84	0.83									
Fruit width	-0.13	-0.50	-0.51	-0.52	-0.59	-0.73	-0.78	-0.87	-0.58	-0.77	-0.70	0.27	0.73	0.52	0.83	0.90	0.92	0.98	0.99	0.76								
Flesh weight	-0.21	-0.48	-0.51	-0.52	-0.54	-0.67	-0.82	-0.85	-0.68	-0.84	-0.69	0.37	0.70	0.59	0.82	0.89	0.91	0.99	1.00	0.83	0.99							
Juice weight	-0.20	-0.48	-0.51	-0.51	-0.55	-0.69	-0.81	-0.85	-0.66	-0.83	-0.69	0.35	0.70	0.58	0.82	0.89	0.91	0.99	1.00	0.82	1.00	1.00						
Juice volume	-0.19	-0.48	-0.50	-0.51	-0.55	-0.68	-0.81	-0.85	-0.66	-0.83	-0.70	0.35	0.70	0.57	0.81	0.89	0.91	0.99	1.00	0.82	0.99	1.00	1.00					
Fruit length	-0.12	-0.48	-0.49	-0.50	-0.58	-0.71	-0.77	-0.86	-0.59	-0.77	-0.72	0.27	0.71	0.51	0.82	0.89	0.92	0.98	0.99	0.76	1.00	0.99	1.00	1.00				
Seed number	-0.15	-0.47	-0.49	-0.49	-0.55	-0.69	-0.78	-0.85	-0.62	-0.80	-0.72	0.30	0.70	0.54	0.81	0.88	0.91	0.99	0.99	0.79	1.00	1.00	1.00	1.00	1.00			
Juice a	-0.47	-0.05	-0.15	-0.17	0.07	-0.02	-0.62	-0.32	-0.92	-0.97	-0.51	0.63	0.15	0.68	0.35	0.43	0.45	0.69	0.69	0.94	0.62	0.71	0.69	0.69	0.63	0.66		
Juice content	0.12	-0.14	-0.15	-0.16	-0.28	-0.46	-0.53	-0.63	-0.50	-0.75	-0.91	0.06	0.43	0.28	0.56	0.67	0.71	0.87	0.90	0.68	0.93	0.92	0.93	0.93	0.93	0.94	0.67	
Total carotenoids	0.03	0.13	0.08	0.07	0.07	-0.11	-0.41	-0.35	-0.62	-0.83	-0.88	0.17	0.12	0.30	0.30	0.43	0.47	0.73	0.76	0.75	0.76	0.79	0.79	0.79	0.77	0.79	0.85	0.92

TA = titratable acidity; TAA = total antioxidant activity; TPC = total phenolic content; TSS = total soluble solids.

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