

Viability of star apples (*Chrysophyllum cainito*) as a potential sweetener

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Abstract

Sugar in the Philippines is mainly sourced from sugarcane, but a sharp production decline in 2022 caused a major shortage, prompting the researchers to undertake the study. The objectives were to determine maturity indices and assess star apple as a sweetener through physicochemical analysis. Phase 1 analyzed rare-ripe (RRS), ripe (RS), and overripe (ORS) fruits for maturity indices. Phase 2 involved producing star apple sugar (SSA) via foam-mat drying and conducting physicochemical tests. Phase 1 showed star apple is non-climacteric, with sugar profiles varying by maturity: fructose was predominant in RRS and ORS, and sucrose in RS. Moreover, SSA samples were obtained across all maturity indices in Phase 2. Key findings highlighted the physicochemical changes during star apple ripening and the potential of star apples as a sweetener source.

1. Introduction

Sugars, the basic units of carbohydrates, occur naturally in foods such as milk, grains, fruits, and vegetables and are often added during processing (Clifford and Maloney, 2016). Carbohydrates include monosaccharides and polysaccharides with diverse nutritional and industrial functions (Zaitoun *et al.*, 2018). Natural sweeteners, for example, are sweet compounds from natural sources with some nutritional value (Saraiva *et al.*, 2020). In the Philippines, sugar is mainly produced from sugarcane. However, declining production outside major provinces (Negros Occidental, Negros Oriental, Bukidnon, Batangas, Iloilo) contributed to the 2022 sugar supply shortage (Briones, 2020).

On the other hand, fruits are essential due to their nutritional benefits, availability, and wide applications. Utilizing underutilized horticultural crops may address health, nutrition insecurity, poverty, and unemployment (Nandal and Bhardwaj, 2014). Despite losses from poor harvest timing, potential solutions exist. This study explores star apple (*Chrysophyllum cainito*), a sweet, non-climacteric fruit with high antioxidant and nutritional value, as a potential sweetener source. Recent Philippine export data show 16.43 million kg in 2023, a 68.07% increase from the previous year, despite limited commercial production areas (Tridge, 2023). In contrast,

sugarcane production in 2022 dropped to 23.46 million metric tons (Statista, 2023). Research on the sugar profile of star apples remains limited, though the fruit shows promise for dietary, medicinal, and economic applications (Ajayi *et al.*, 2020).

In this study, the potential of star apples as a sweetener at three different maturity stages of rare ripe, ripe and overripe are examined. The maturity indices were identified, while the potential star apple sugar's physicochemical properties were determined as well. Lastly, the researchers propose that *cainito* can be utilized as a source of sweetener.

2. Materials and methods

The study was divided into Phases 1 and 2: Phase 1 pertains to the characterization of star apples at different maturity, and Phase 2 denotes the preparation of star apple sugar.

2.1 Phase 1: Characterization of star apples at different maturity

Star apples of varying maturity were sourced from a farm in Arayat, Pampanga, harvested one day prior to transport to the Bulacan State University Food Laboratory. A sample was submitted to the Bureau of

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Plant Industry, Department of Agriculture, Manila, for authentication. Fruits were sorted and classified into three maturity stages based on peel color: rare-ripe (RRS) with more green than purple, ripe (RS) with dominant dark purple and green calyx, and overripe (ORS) uniformly dark purple). Ten (10) defect-free fruits were randomly selected from each stage.

2.1.1. Determination of maturity indices of star apples

2.1.1.1. Color

The color of the samples was determined using the Munsell color system. The fruit's apex was used, and the dominant purple color was recorded.

2.1.1.2 Fruit size and weight

The pulp length, thickness, and width (mm) were measured using a vernier caliper, while fruit weight (g) was measured gravimetrically.

2.1.1.3 Pulp yield

Pulp yield determination was based on methods from Shivani *et al.* (2021). Fresh pulp was weighed to calculate percent recovery, expressed as the ratio of pulp weight (W1) to total fruit weight (W2) (Eq. 1).

$$\text{Pulp Yield (\%)} = \frac{W1}{W2} \times 100\% \quad (1)$$

2.1.1.4 Starch index

Methods were adapted from Obiageli *et al.* (2016). Starch index was determined by dipping half-fruits in a solution of 1 g potassium iodide and 0.25 g iodine in 100 mL water; a purple color indicated a positive result.

2.1.1.5 Reducing sugars

Preparation used methods described by Obiageli *et al.* (2016). Approximately 2 mL of star apple puree at each maturity level was mixed with 2 mL Benedict's reagent in a test tube and heated in a 100°C water bath for 1 min. Green, yellow, orange-red, or brick-red color indicated a positive result.

2.1.1.6 Total soluble solids

Juice was extracted from star apple puree using cheesecloth. A digital refractometer (Bellingham Stanley™ OPTi Brix 95+) was used to measure °Brix by placing a few drops on the prism surface.

2.1.1.7 Sugar profile

Pureed star apples were submitted to DOST-ITDI to determine their sugar profile.

2.2 Phase 2: Preparation of star apple sugar at different maturity

Maltodextrin was sourced from Nueva Ecija, while egg white powder and carboxymethyl cellulose were purchased from a store in Malolos, Bulacan. Preparation methods were adapted from Thuy *et al.* (2022) and Gao *et al.* (2022) with few modifications. Pureed RRS, RS, and ORS were mixed with 15% maltodextrin (DE 10–12), 8% egg white powder, and 1% carboxymethyl cellulose, then diluted with distilled water (1:1 mass ratio). The foamed mixture was spread onto trays and dried in a hot-air oven at 75±5°C for 6 hours to reach 4–8% moisture content. Dried foam sheets were blended into granules and stored in airtight containers at 4°C prior to analyses.

2.2.1 Determination of physicochemical properties of star apple sugar samples

2.2.1.1 Extraction yield

Extraction yield refers to the amount of dry granules obtained after extraction. Methods were adapted from Rellosa *et al.* (2019). Yield was expressed as the ratio of dry granules (W1) to initial puree (W2) (Eq. 2).

$$\text{Extraction Yield (\%)} = \frac{W1}{W2} \times 100\% \quad (2)$$

2.2.1.2 Color

The skin color of the samples was determined using the Munsell color system. The hue, value, and chroma were measured, and the corresponding color, based on these values, was recorded.

2.2.1.3 Solubility Index

Solubility of star apple sugar was determined using the methods of Sathyashree *et al.* (2018). It was expressed as the ratio of final sample weight (M2) to initial weight (M1) (Eq. 3).

$$\text{Solubility Index (\%)} = \frac{10 \times M2}{M1} \times 100 \quad (3)$$

2.2.1.4 Total soluble solids

SSA samples were dissolved in distilled water to prepare a 2% (w/v) solution. A digital refractometer (Bellingham Stanley™ OPTi Brix 95+) was used to measure °Brix by placing a few drops on the prism surface.

2.2.1.5 Proximate content

Samples were submitted to Lipa Quality Control Center to determine their proximate contents.

2.3 Statistical analysis

Results of physicochemical analyses performed in

triplicate were statistically analyzed using One-Way Analysis of Variance (ANOVA) and Tukey HSD test to determine whether significant differences exist between samples at $p \leq 0.05$.

3. Results and discussion

3.1 Phase 1: Characterization of star apples at different maturity

The maturity indices of star apples are defined in the following sections.

3.1.1 Physicochemical changes in star apples as they mature

3.1.1.1 Color

Star apple's pulp was white in color with patches of purple, while its skin varied from red-purple to dark-purple or pale green (Crane and Balerdi, 2006). Yahia and Gutierrez-Orozco (2011) also explained that star apples may be picked when their base is still green to reduce physical damage, and a pale to dark purple color is noticeable in fully ripe fruits. As seen in Table 1, star apples across all maturity stages were purple in color based on the Munsell system readings. The purple hue may be attributed to the anthocyanin content in star apples. According to Moo-Huchin *et al.* (2014), anthocyanins can be found among fresh star apple fruits.

Table 1. Physicochemical properties of star apples at different maturity.

Properties	Maturity		
	RRS	RS	ORS
Color (Munsell Notation)	Purple	Purple	Purple
Length (mm)	5.03±0.40 ^a	5.24±0.30 ^a	5.34±0.18 ^a
Width (mm)	5.39±0.40 ^a	5.51±0.26 ^a	5.60±0.35 ^a
Thickness	4.15±0.22 ^a	4.42±0.21 ^b	4.54±0.07 ^b
Mass (g)	103.10±11.16 ^a	116.15±21.57 ^a	119.63±22.01 ^a
Pulp Yield (%)	43.44	44.67	46.39
Starch	+	+	+
Reducing	+	+	+
Total Soluble	28.90±0.61 ^a	66.63±0.55 ^b	78.70±1.15 ^c

Values are presented as mean±SD. Values with different superscripts in the same row are statistically significantly different at $p \leq 0.05$. RRS: rare ripe star apples, RS: ripe star apples, ORS: overripe star apples, +: present.

3.1.1.2 Fruit size, weight and pulp yield

Fruit mass and volume can increase up to 100-fold from fertilization to maturity (Sarma *et al.*, 2020). As shown in Table 1, ORS showed the highest mean length, width, thickness, and weight (5.34, 5.60, 4.54 mm;

119.63 g), followed by RS (5.24, 5.51, 4.42 mm; 116.15 g) and RRS (5.03, 5.39, 4.15 mm; 103.10 g). The increase is linked to higher moisture during ripening, as thicker peels reduce transpiration (Kinhal, 2023) and fruit dimensions correlate with moisture content (Onwe *et al.*, 2020). Significant differences ($p \leq 0.05$) occurred only in thickness, with RRS lower than RS and ORS. Pulp recovery was also highest in ORS (46.39%), followed by RS (44.67%) and RRS (43.44%), due to peel development reducing water loss (Lufu *et al.*, 2020). Similar findings were reported by Adi *et al.* (2019), attributing this to rising sugar levels that draw moisture into the pulp during ripening.

3.1.1.3 Starch index, reducing sugar and total soluble solids

Starch and reducing sugars were detected at all maturity stages, consistent with Obiageli *et al.* (2016). Maturity showed a direct relationship with TSS and an inverse relationship with starch index, reflected in lighter purple hues in RS and ORS. This indicates star apple is non-climacteric, as starch rapidly decreases after anthesis, accumulating soluble sugars during ripening (Williams and Benkeblia, 2018; Chervin, 2020). Pulp yield patterns also align with these changes, as ripening increases osmotic pressure driven by sugar accumulation (Aquino *et al.*, 2016). TSS differences were significant at $p \leq 0.05$ (Table 1).

3.1.1.4 Sugar profile

Fructose predominated in rare ripe and overripe stages, while sucrose was highest in ripe fruits (Table 2). Fructose, the key sugar influencing sweetness (Gonçalves *et al.*, 2018), decreased from 1.29% in RRS to 0.29% in RS, then increased to 4.26% in ORS. The RS decline corresponds to sucrose increase (2.45%), as fructose and glucose combine to form sucrose, explaining the glucose absence in RS. Glucose varied with maturity: 1.04% (RRS) and 3.05% (ORS). Sucrose was absent in RRS and ORS but present in RS. These changes align with invertase activity, which hydrolyzes sucrose into glucose and fructose during ripening (Beaudry *et al.*, 1989; Cordenunsi-Lysenko *et al.*, 2019; Phillips *et al.*, 2021). Similar patterns were observed in bananas, with sucrose peaking at ripeness then declining

Table 2. Sugar Profile of star apples at different maturity.

Maturity	Fructose (%w/w)	Glucose (%w/w)	Sucrose (%w/w)
RRS	1.29	1.04	ND
RS	0.29	ND	2.45
ORS	4.26	3.05	ND

RRS: rare ripe star apples, RS: ripe star apples, ORS: overripe star apples, ND: not detected. Limit of detection: 0.004% w/w for glucose and 0.02% w/w for sucrose.

(Phillips et al., 2021).

3.2 Phase 2: Preparation of star apple sugar at different maturity

In this phase, star apple sugars were successfully obtained from foam-mat drying technology, as seen in Figure 1. Each SSA sample's physicochemical properties are discussed in the following sections.



Figure 1. Appearance of SSA samples at different maturity. RRS: rare ripe star apples, RS: ripe star apples, ORS: overripe star apples, SSA: star apple sugar.

3.2.1 Physicochemical properties of star apple sugar

3.2.1.1 Extraction yield and color

ORS exhibited the highest powder/extraction yield of SSA at 38.40%, followed by RS at 26%, and RRS at 19.60%. This may be due to the higher percentage pulp yield among ORS than the others. Rellosa et al. (2020) reported the same results, where overripe chico fruits yielded higher amounts of dry granules than their ripe counterparts when spray dried. Further, the color of samples varies from red-purple (RRS) to yellow-red (RS and ORS). This may be due to carotenoids supplied by the fruit (Zulueta et al. 2007) (Table 3).

3.2.1.2 Solubility

The solubility index was highest in RS-SSA (87.21%), followed by RRS-SSA (80.86%) and ORS-SSA (65.04%), all significantly different ($p \leq 0.05$). Higher solubility corresponds to lower moisture content, consistent with findings by Kandasamy et al. (2019) for foam-mat dried fruit powders (Table 3).

3.2.1.3. Total soluble solids

Sample RS-SSA received the highest TSS content (3.03), which may be due to its significant amounts of sucrose and its higher total carbohydrate content among all SSA samples. However, ORS-SSA (2.70) had a higher Brix value than RRS-SSA (2.37) despite having a significantly lower total carbohydrate value, which may be attributed to its higher glucose and fructose contents than RS. These observed values were slightly higher than the findings by Kadam and Balusabramanian (2011), at 2 -2.4°Bx. Moreover, RRS-SSA's Brix value was statistically different ($p \leq 0.05$) from RS- and ORS-SSA, respectively (Table 3).

Table 3. Physicochemical properties of SSA samples at different maturity.

Properties	Maturity		
	RRS	RS	ORS
Extraction Yield	19.60	26.00	38.40
Color (Munsell Notation)	Red-Purple	Yellow-Red	Yellow-Red
Solubility (%)	80.86±0.79 ^a	87.21±0.20 ^b	65.04±0.16 ^c
Total Soluble Solids	2.37±0.15 ^a	3.03±0.15 ^b	2.70±0.17 ^b
Moisture (%)	4.21±0.08 ^a	5.02±0.07 ^b	7.77±0.04 ^c
Ash (%)	3.05±0.16 ^a	2.29±0.07 ^b	4.54±0.21 ^c
Crude Protein (%)	9.47±0.69 ^a	5.77±0.03 ^b	17.98±0.51 ^c
Crude Fiber (%)	4.54±0.18 ^a	5.20±0.20 ^b	2.61±0.11 ^c
Crude Fat (%)	7.14±0.40 ^a	7.18±0.20 ^a	4.77±0.16 ^b
Total Carbohydrates (%)	71.68±0.94 ^a	74.54±0.16 ^b	62.64±0.31 ^c

Values are presented as mean±SD. Values with different superscripts in the same row are statistically significantly different at $p \leq 0.05$. RRS: rare ripe star apples, RS: ripe star apples, ORS: overripe star apples, SSA: star sugar apple.

3.2.1.2. Proximate content

ORS-SSA had the highest moisture (7.77%), ash (4.54%), and crude protein (17.98%), compared to RRS-SSA (4.21%, 3.05%, 9.47%) and RS-SSA (5.02%, 2.29%, 5.77%). Crude fat (%) was similar in RRS-SSA (7.14%) and RS-SSA (7.18%), but lower in ORS-SSA (4.77%). Crude fiber and total carbohydrates were highest in RS-SSA (5.20%, 77.54%), followed by RRS-SSA (4.54%, 71.68%) and ORS-SSA (2.61%, 62.64%). Overall, significant differences ($p \leq 0.05$) exist between all SSA samples, except for the crude fat composition of RRS- and RS-SSA (Table 3).

4. Conclusion

In the present work, the physicochemical properties of rare-ripe, ripe and overripe star apples are determined. It can be inferred that star apples exhibit different physicochemical properties related to their stage of maturity, and further analysis also indicates that these fruits are non-climacteric, with ripe and overripe fruits showing higher levels of fructose as the primary sugar, while sucrose is notably prevalent in ripe fruits.

The researchers of the study recommend the star apple sugar produced from overripe star apples due to its higher extraction yield and superior levels of fructose, which is the most important sugar affecting the perception of sweetness.

Conflict of interest

The authors declare no conflict of interest.

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