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Effect of Sugar and Juice Concentration on Vitamin C Retention and Organoleptic of Tangerine (*Citrus Reticulata*) Powder

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Abstract
Converting tangerine juice into powder via sucrose crystallization yields shelf-stable products with appealing flavor and nutrients. We examined the independent and interactive effects of sucrose and juice concentrations on physicochemical properties and consumer acceptance of Citrus reticulata powder. A 3×3 factorial design evaluated sucrose at 45, 55, and 65% and juice at 45, 55, and 65% (three replications). Processing included extraction and filtration, sucrose addition, controlled heating to supersaturation, crystallization during cooling, milling, and sieving. Moisture content, vitamin C (UV–Vis, 245 nm), and hedonic ratings for texture, aroma, color, and taste (nine-point scale; 30 panelists) were measured. ANOVA and Duncan's Multiple Range Test assessed treatment effects. Moisture was 2.04–3.07% across treatments and did not differ significantly (p=0.924), meeting the SNI specification for powdered beverages (<5%). Vitamin C differed significantly (p=0.006); the 45% sucrose level consistently produced the highest values (≈42.9–43.8 mg/100 g). The A1B3 formulation (45% sucrose, 65% juice) combined high vitamin C (~43.2 mg/100 g) with acceptable moisture (3.07%) and the most preferred sensory profile. Patterns suggest that reducing sucrose limits thermal/Maillard losses of ascorbic acid, while very high sucrose lowers water activity and yields intermediate retention. Overall, sucrose crystallization produced shelf-stable powders with favorable reconstitution, nutritional, and liking properties. A low-sucrose, high-juice formula optimizes the balance of quality attributes, supporting use in instant citrus drinks and functional beverages.

Keywords: *Citrus Reticulata* Poder; Crystallization Method; Moisture Content; Organoleptic Evaluation; Vitamin C Retention

Introduction
Citrus fruits are globally important for their nutrition and consumer appeal. Among them, Citrus reticulata stands out for its sweet-tart flavor, vivid color, and high levels of vitamin C, flavonoids, dietary fiber, potassium, and calcium, making it a strong ingredient for value-added food and beverage products.

Indonesia, as a tropical country, is a leading producer of citrus in Southeast Asia, with Citrus reticulata cultivated widely across provinces. Favorable agro-climatic conditions average temperatures of 20–25 °C enable year-round production and high yields. Tangerines grown in

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South Sulawesi are recognized as superior cultivars due to their high vitamin C content and consumer-preferred sensory attributes. However, the high perishability of citrus limits shelf life and transport, prompting exploration of stable, nutrient-retaining processing options such as fruit-powder formulations.

The production of instant fruit powders has gained momentum as a practical and efficient solution to enhance fruit utilization, extend shelf life, and maintain nutritional value. Among dehydration and stabilization techniques, crystallization stands out for producing fruit powders with minimal nutrient degradation while preserving sensory quality and solubility. Crystallization involves transforming liquid or semi-liquid fruit extracts into solid crystal forms through controlled supersaturation, nucleation, and crystal growth. This method is increasingly favored in the food industry because it yields powders that are microbiologically stable while maintaining key nutrients such as vitamin C.

Despite the promise of crystallization, formulation composition especially sugar concentration plays a critical role in determining final powder quality. Sugar serves multiple functions: it reduces water activity, enhances sweetness and flavor, and influences texture and powder structure (Islam *et al*., 2017). However, excess sugar can also lead to unfavorable outcomes such as browning reactions, nutrient loss, and altered sensory perception; thus, determining the optimal sugar-to-fruit ratio is essential to meet nutritional standards and consumer preferences.

Previous studies have investigated the impact of sugar concentration on fruit-powder properties. Monica et al. optimized instant tangerine powder via crystallization and found that a 1:1 juice-to-sugar ratio yielded the highest hedonic scores while preserving a vitamin C content of 42.3 mg/100 g. Similarly, Husnani and Ningsih developed fruit–vegetable instant powders and concluded that both moisture and vitamin content were significantly influenced by sugar level and drying method. These findings underscore the complex interplay between sugar content, nutrient retention, and organoleptic acceptance, pointing to the need for further study across concentration combinations.

In general, the scientific problem centers on how sugar concentration affects the physicochemical and organoleptic properties of tangerine fruit powder produced by crystallization. While some level of sugar is essential for stability, identifying the range that balances preservation and quality enhancement remains challenging; moreover, variability in fruit content further complicates formulation optimization.

This study builds on prior findings and introduces a two-factor experimental design to assess how variations in both sugar and fruit concentrations affect final powder characteristics. The crystallization method is used as the core technique, with systematic evaluation of vitamin C retention and sensory quality under different formulation settings. Combinations of three sugar levels and three fruit-extract levels are evaluated using a completely randomized design with three replications per treatment.

Relevant literature highlights crystallization as an efficient approach to preserve antioxidants, vitamin C, and other bioactives in citrus. Almeida reported that optimized crystallization can retain vitamin C above 40 mg/100 g in citrus-based powders. Meanwhile, Lee et al. demonstrated that crystallization temperature and time significantly influence nutrient-degradation rates, indicating that process control is critical for product integrity. In addition, several studies show that higher sugar levels can either stabilize or accelerate vitamin C loss depending on heat exposure and process time: at storage-like or mild heating conditions, added sugars lower water activity and tend to protect ascorbic acid; whereas at higher processing temperatures and longer exposures, reducing sugars can promote non-enzymatic browning that degrades vitamin C (Galus

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et al., 2025; Yazidi *et al*., 2024).

Nevertheless, a research gap remains in pinpointing how precise combinations of sugar and fruit concentration affect both chemical and sensory outcomes in crystallized tangerine powder. Most studies focus on either nutrient retention or organoleptic properties; few provide an integrated analysis across both dimensions. Moreover, regional cultivars such as *Citrus reticulata* from South Sulawesi—possessing unique genetic and nutritional profiles—are underrepresented in crystallization-based processing research.

Accordingly, this study aims to evaluate how varying sugar and fruit concentrations influence physicochemical and organoleptic properties of tangerine fruit powder produced via crystallization. By applying a factorial experimental design and statistical analyses, including ANOVA and Duncan's Multiple Range Test, this research seeks to identify the optimal formulation that meets both Indonesian National Standard nutritional benchmarks and consumer-acceptability targets.

The novelty of this study lies in its integrated approach to optimizing citrus-powder formulation through crystallization, focusing on a local Indonesian cultivar of *Citrus reticulata*. The findings are expected to contribute to functional-food processing and provide practical insights for developing value-added citrus products with extended shelf life and preserved nutritional quality, offering guidance for agro-industrial enterprises and small-scale producers responding to demand for instant natural beverages and nutraceuticals.

Literature Review

Tangerine is rich in vitamin C, flavonoids, dietary fiber, and other bioactive compounds, supporting its use in functional, value-added foods (Shorbagi *et al*., 2022). The stability of vitamin C is strongly influenced by intermediate moisture levels, pH, oxygen, and reducing sugars; depending on conditions, added sugars may either slow or accelerate degradation (Rojas & Gerschenson, 2001). Baseline data on vitamin C in fresh tangerine and its juice, determined by iodometric titration, provide a useful reference for assessing retention across processing steps (Biltekin et al., 2024).

Sucrose crystallization is a viable route for producing stable fruit powders when supersaturation, nucleation, and crystal growth are properly controlled. In food applications, sucrose co-crystallization can encapsulate juice solids, improving the stability, solubility, and flowability of the resulting powder (Gonzales *et al*., 2017).

Water content and, in particular, water activity (a_w) are key determinants of stability during and after crystallization (Subbiah *et al*., 2020). In fruit powders, a_w–crystallization interactions affect the stability of pigments/carotenoids and other heat-sensitive constituents, underscoring the need for tight moisture control during drying and storage (Harnkarnsujarit & Charoenrein, 2011).

Sugar has multiple functions—binding water, structuring the crystal matrix, and acting as a flavor carrier—yet higher concentrations can have dual effects on ascorbic acid: in some regimes they protect, while in others they intensify browning pathways and accelerate vitamin C loss (Rojas & Gerschenson, 2001). Empirical studies in fruit systems show that varying sugar and fruit-solids levels shifts final moisture, solubility, and vitamin retention (Islam *et al*., 2017).

From a reaction-chemistry standpoint, Maillard kinetics—governed by the ratio of reducing sugars to amino compounds, temperature, time, and moisture—drive color formation and volatile generation that can alter citrus flavor quality (Li *et al*., 2016). Because ascorbic acid can act as a browning precursor, sugar dosing must be balanced against vitamin C-retention targets (Rojas &

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Gerschenson, 2001).

Crystal-network formation modulates particle size, mouthfeel, instant solubility, and the appearance of reconstituted beverages (Gonzales *et al*., 2017). Higher sugar generally increases perceived sweetness and body but risks masking the freshness associated with organic acids in citrus; thermal and sugar-driven shifts in the volatile profile may increase or reduce liking depending on the balance between citrus notes and cooked/caramel notes (El Hosry *et al*., 2025). The 9-point hedonic scale is a standard, appropriate method for evaluating flavor, aroma, color, and texture of powdered beverages, and evidence from fruit/vegetable instant-powder formulations shows that sugar level and drying approach significantly affect moisture, vitamin content, and hedonic scores—reinforcing the need for compositional optimization (Islam *et al*., 2017).

The Indonesian regulatory framework provides quality guidance for traditional powdered beverages, including moisture limits and safety/labeling requirements (SNI 3722:2018; SNI 01-4320-1996). Reviews of SNI-based expectations for vitamin C in fruit powders offer functional thresholds for product development, and for vitamin C quantification, iodometry is cost-effective for citrus matrices, while validated HPLC–UV at ~245 nm enables simultaneous determination of ascorbic and oxalic acids with suitable accuracy and precision in beverages/extracts. Method selection should consider high-sugar matrices, potential interferences, and limits of quantification compatible with post-process concentrations (Biltekin *et al*., 2024).

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Sucrose crystallization is a viable route for producing stable fruit powders when supersaturation, nucleation, and crystal growth are properly controlled. Industrial overviews emphasize that crystallization efficiency depends on dissolution–cooling profiles, sucrose purity, and crystal size distribution (Gonzales *et al*., 2017). In food applications, sucrose co-crystallization can encapsulate juice solids, improving the stability, solubility, and flowability of the resulting powder.

Water content and, in particular, water activity are key determinants of stability during and after crystallization. Consolidated aw data for sugars and polyols highlight characteristic sorption behavior and kinetic implications for reactions in the solid matrix (Subbiah *et al*., 2020). In fruit powders, aw–crystallization interactions affect the stability of pigments/carotenoids and other heat-sensitive constituents (Sen & Mukhopadhyay, 2016), underscoring the need for tight moisture control during drying and storage.

Sugar has multiple functions—binding water, structuring the crystal matrix, and acting as a flavor carrier—yet higher concentrations can have dual effects on ascorbic acid: in some regimes they protect, while in others they intensify browning pathways and accelerate vitamin C loss (Capuano *et al*., 2018). Empirical studies show that varying sugar and fruit-solids levels shifts final moisture, solubility, and vitamin retention.

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Crystal-network formation modulates particle size, mouthfeel, instant solubility, and the appearance of reconstituted beverages. Higher sugar generally increases perceived sweetness and body but risks masking the freshness associated with organic acids in citrus. Aroma is pivotal for acceptance of citrus products; thermal and sugar-driven shifts in the volatile profile may increase or reduce liking depending on the balance between citrus notes and cooked/caramel notes ((Li *et al*., 2016; El Hosry *et al*., 2025). The 9-point hedonic scale is a standard, appropriate method for evaluating flavor, aroma, color, and texture of powdered beverages. Evidence from fruit–vegetable instant-powder formulations further shows that sugar level and drying approach significantly affect moisture, vitamin content, and hedonic scores—reinforcing the need for compositional optimization.

The Indonesian regulatory framework provides quality guidance for traditional powdered beverages, including moisture limits and safety/labeling requirements. Reviews of SNI-based expectations for vitamin C in fruit powders offer functional thresholds for product development. For vitamin C quantification, iodometry is cost-effective for citrus matrices, while validated HPLC–UV at 245 nm enables simultaneous determination of ascorbic and oxalic acids with suitable accuracy and precision in beverages/extracts (Biltekin *et al*., 2024). Method selection should consider high-sugar matrices, potential interferences, and limits of quantification compatible with post-process concentrations.

Research Method

This study was conducted at the Agroindustry Workshop Laboratory and the Nutrition and Biochemistry Laboratory, Department of Aquaculture, Pangkep State Agricultural Polytechnic, during the period of March to August 2025. The research aimed to investigate the effect of sugar concentration and tangerine juice ratio on the physicochemical and organoleptic properties of fruit powder produced using the crystallization method. The entire experimental process was designed to maintain the integrity of key nutritional components, especially vitamin C, while also ensuring desirable sensory characteristics.

Materials and Equipment

The primary raw material used in this study was Citrus reticulata fruit obtained from a local Selayar tangerine retailers. Additional ingredients included granulated white sugar and clean water. For the crystallization process, various tools were employed, including a citrus squeezer, knives, fine strainers, stainless steel pans, blenders, and 30-mesh sieves. Analytical equipment used in the laboratory included an oven, analytical balance, desiccator, porcelain crucibles, UV-Vis spectrophotometer, micropipettes, volumetric flasks, and a hot plate. For chemical analysis, reagents such as 0.1% oxalic acid, Folin-Ciocalteu reagent, and standard vitamin C solutions were utilized.

Experimental Design

This research adopted an experimental design with a completely randomized factorial arrangement, employing two independent variables and three replications per treatment combination. The first factor was the concentration of granulated sugar, set at three levels: A1 = 45%, A2 = 55%, and A3 = 65%. The second factor was the concentration of tangerine juice, also set at three levels: B1 = 45%, B2 = 55%, and B3 = 65%. This resulted in a total of nine treatment combinations, allowing comprehensive observation of interaction effects between sugar and fruit ratios.

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The rationale for using these concentration levels was based on prior studies indicating that sugar not only acts as a sweetener but also influences water activity, texture, and nutrient stability (Gonzales *et al*., 2017). The factorial design permitted the identification of both main effects and interaction effects, providing a more nuanced understanding of formulation impacts on product quality.

Sample Preparation and Processing Procedure

The fruit processing protocol was standardized to ensure consistency across all treatment combinations. Initially, fresh tangerines were sorted to eliminate damaged or overripe fruits. The selected fruits were then washed thoroughly under running water to remove surface contaminants. After peeling, the fruits were juiced using a manual citrus squeezer. The extracted juice was filtered through a fine mesh to eliminate pulp and solid residues, resulting in a smooth tangerine juice base.

For each treatment, specific volumes of tangerine juice were weighed and placed into a stainless-steel pan. Once the juice reached a boil, measured quantities of sugar were added and continuously stirred over medium heat until a thick, homogeneous mixture was obtained. The heating process aimed to initiate supersaturation—a key step in crystallization—while avoiding excessive temperature that could degrade sensitive compounds such as vitamin C.

After achieving the desired consistency, the mixture was allowed to cool at room temperature, enabling crystal formation. This cooling phase was crucial for initiating nucleation and promoting stable crystal growth. Once crystallization was complete, the product was blended to obtain fine powder and subsequently sieved using a 30-mesh sieve to ensure uniform particle size distribution. The final powdered product was stored in airtight containers to prevent moisture absorption and oxidative degradation, following storage recommendations from Bhattacharya et al. for fruit powder stabilization.

Analytical Parameters

The study assessed three main categories of quality indicators: moisture content, vitamin C content, and organoleptic characteristics. These parameters were selected based on their relevance to product shelf life, nutritional value, and consumer acceptability.

Moisture Content

Moisture content was measured gravimetrically using an oven-drying method. Approximately 2–3 grams of fruit powder were weighed into a pre-dried and pre-weighed porcelain crucible. The sample was dried in an oven at 105°C for 3–4 hours, then cooled in a desiccator and reweighed. Moisture content was calculated using the formula:

$$\textbf{Moisture Content } (\%) = \frac{(\boldsymbol{W_2 - W_3})}{(\boldsymbol{W_2 - W_1})}\ \boldsymbol{x\ 100}$$

This method follows the standard protocol outlined by SNI 01-4320-1996, ensuring valid moisture content determination for powdered food products.

Vitamin C Content

Vitamin C levels were analyzed spectrophotometrically using the UV-Vis method. One gram of the powder sample was dissolved in 10 ml of 0.1% oxalic acid and filtered. The filtrate was treated with Folin-Ciocalteu reagent and compared against standard vitamin C solutions. Absorbance was measured at 245 nm using a UV-Vis spectrophotometer, and vitamin C concentration was

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interpolated from a standard calibration curve. This method was selected for its sensitivity and accuracy in measuring ascorbic acid content in citrus matrices.

Organoleptic Assessment

Sensory evaluation was conducted to determine consumer perception of the product's texture, aroma, color, and taste. The testing involved a panel of 30 untrained individuals, selected among students, following established practices in sensory analysis. Samples were presented in coded plates under standardized lighting and ambient conditions. Panelists rated the attributes using a 9-point hedonic scale, with 1 indicating extreme dislike and 9 indicating extreme like.

Each panelist evaluated all samples in random order to minimize bias. The average scores for each attribute were computed and statistically analyzed. Organoleptic results provide insight into consumer acceptability and help validate whether physicochemical optimization aligns with sensory expectations.

Statistical Analysis

All quantitative data were analyzed using ANOVA to identify significant differences between treatments. When significant effects were found, post hoc comparisons were performed using Duncan's Multiple Range Test to identify which treatment groups differed significantly from each other. This statistical approach is recommended for factorial experiments involving multiple treatments and interactions. The analysis was conducted using SPSS software to ensure accuracy and reproducibility of results.

The use of ANOVA and DMRT enabled the identification of optimal formulation combinations with statistically significant improvements in vitamin C retention and organoleptic quality. Moisture content differences were found to be statistically non-significant, suggesting homogeneity in water retention across treatments, likely due to controlled drying conditions.

Results and Discussion

Results

Moisture Content

Moisture content is a critical parameter in evaluating the stability and shelf life of powdered food products. In this study, the moisture content of tangerine fruit powder produced via crystallization varied according to the concentration of sugar and fruit juice used in the formulation. The highest moisture content was recorded in treatment A1B3, which combined the lowest sugar concentration with the highest tangerine concentration. Conversely, the lowest value was observed in treatment A3B1, where a high sugar concentration was paired with low tangerine content

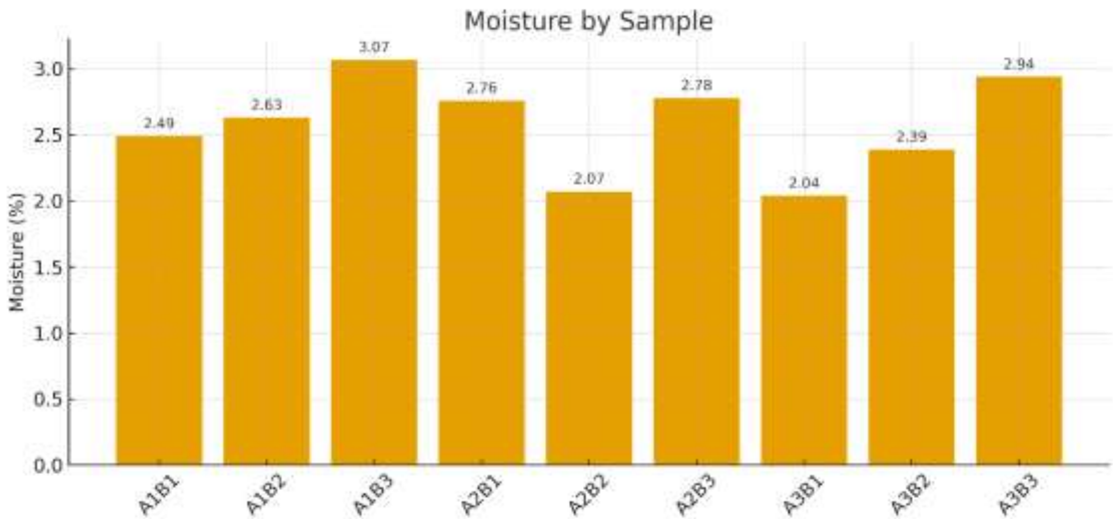

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Figure 1. Moisture by sample code. Bars show means; numeric labels give exact values. A and B denote the two formulation factors.

Across the 3×3 design (A = sugar level; B = tangerine juice level), moisture ranged from 2.04–3.07% and thus remained well below the SNI limit of 5%, indicating powders were sufficiently dry for commercial handling (SNI 01-4320-1996). Factor means clarify the pattern behind the cell-wise extremes: averaging across B, moisture decreased with sugar from A1 = 2.73% → A2 = 2.54% → A3 = 2.46% (≈10% drop from A1 to A3). Averaging across A, moisture rose with fruit solids, B1 = 2.43%, B2 = 2.36%, B3 = 2.93%—the B-effect (≈+0.50% absolute) was larger than the A-effect (≈−0.27% absolute).

Simple slopes of moisture vs. sugar within each fruit level were all negative (B1 ≈ −0.225; B2 ≈ −0.120; B3 ≈ −0.065 % moisture per A-step), indicating a consistent drying leverage by sugar even when tangerine concentration was high. Mechanistically, this aligns with the water-activity (a_w) and mobility framework: increasing sucrose binds water and lowers a_w, thereby reducing matrix mobility and facilitating water removal (Lee & Labuza, 1975). The counter-effect of higher tangerine load (B3) likely reflects more bound and occluded water in the juice solids and a greater tendency to resist complete water removal at identical drying endpoints.

Although the one-way ANOVA across the nine treatments reported $F = 0.368$, $p > 0.05$ for moisture, two points qualify this "non-significant" result:

1. The directional main effects (↓ with sugar; ↑ with fruit) are clear in the means and are practically relevant for process set-points; and
2. A two-way model (A, B, and A×B) with replication would be statistically more appropriate for factorial designs. The current one-way test over nine groups risks Type II error if within-cell variability is large or replication is limited.

From a processing standpoint, the A3B1 formulation (high sugar, low tangerine) yielded the lowest moisture (2.04%), while A1B3 (low sugar, high tangerine) gave the highest (3.07%). Despite this spread, all values sit below 3.1%, which—combined with the expected co-crystallization of sucrose—supports good powder flow and shelf handling (Harnkarnsujarit & Charoenrein, 2011).

Table 1. Average Moisture and Vitamin C Content by Treatment

Sample	Moisture_Mean	Vitamin C_Mean
A1B1	2.49	43.83
A1B2	2.63	42.91
A1B3	3.07	43.24
A2B1	2.76	36.64
A2B2	2.07	36.71
A2B3	2.78	35.87

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A3B1	2.04	40.02
A3B2	2.39	39.35
A3B3	2.94	39.90

Vitamin C Content

Vitamin C is a key nutritional component in citrus-based products and highly sensitive to heat, oxygen, and pH changes. The vitamin C content in the crystallized tangerine fruit powder varied significantly across treatment groups. The highest levels were observed in treatments A1B1, A1B2, and A1B3, all of which contained the lowest sugar concentration. The lowest levels occurred in A2B3, A2B1, and A2B2, which used a mid-level sugar concentration.

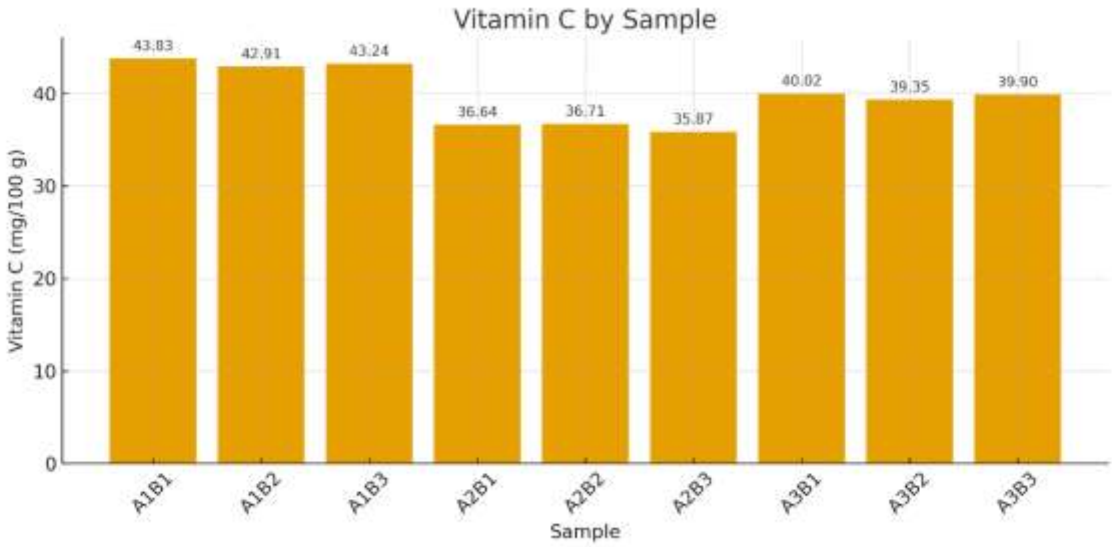

Figure 2. Vitamin C by sample code. Bars show means; numeric labels give exact values

Vitamin C (mg/100 g) exhibited a non-monotonic response to sugar:

- A1 (low sugar): 43.33
- A2 (mid sugar): 36.41
- A3 (high sugar): 39.76

Thus, A2 was the lowest, with A1 higher by +6.92 mg/100 g (≈+19%) and A3 higher by +3.35 mg/100 g (≈+9%). By contrast, fruit level B had little net effect (B1 = 40.16; B2 = 39.66; B3 = 39.67). Post-hoc grouping (Duncan) was consistent with these means: A1B1–A1B3 formed the high-retention subset, A2B1–A2B3 the low-retention subset, and A3 cells were intermediate (≈39–40 mg/100 g). All formulations exceeded the SNI minimum of 18 mg/100 g, preserving nutritional adequacy.

The U-shaped pattern across A is consistent with a_w-dependent kinetics of ascorbic acid (AA): at intermediate a_w (often achieved at mid sugar), molecular mobility and oxygen diffusion can maximize AA loss, whereas very low a_w (high sugar) or higher a_w (low sugar) can be less destructive depending on temperature and matrix composition (Lee & Labuza, 1975; Rojas & Gerschenson, 2001). At high sugar, additional protection may come from faster sucrose

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crystallization and reduced oxygen transport in the crystal network. At mid sugar, residual mobility plus more available reducing ends can accelerate Maillard-type pathways that consume AA or its degradation products (Rojas & Gerschenson, 2001).

Notably, the cross-sample correlation between moisture and vitamin C was weak (r ≈ +0.20), suggesting sugar-specific chemistry (a_w regime, crystallization, Maillard/oxidation) is the dominant driver rather than small differences in % moisture per se. This supports reporting a_w and (where possible) glass-transition indices alongside vitamin data for stronger mechanistic linkage.

Implication. To maximize AA, favor A1 (low sugar) when sensory permits; if sweetness or flow requires more sugar, A3 (high sugar) can partially recover AA relative to A2, presumably by pushing the matrix into a lower-mobility, more crystalline state (Lee & Labuza, 1975).

Organoleptic Evaluation

Organoleptic properties are essential for consumer acceptance of food products. In this study, the sensory qualities of tangerine powder were evaluated based on texture, aroma, color, and taste using a 9-point hedonic scale. Thirty untrained panelists participated in the evaluation.

Texture

Texture ratings ranged from 6.40 to 6.61. The highest score was obtained by treatment A1B1, suggesting that low sugar and low fruit concentrations produced a powder with a light, smooth texture that was well accepted. In contrast, treatment A2B3 received the lowest score, potentially due to the combined effect of high fruit concentration and moderate sugar, which may result in a denser, clumpier texture due to excessive moisture or improper crystal formation. The overall results indicate that lower sugar concentrations generally improved texture, while higher fruit content occasionally led to coarser structures. However, all treatments scored above 6.4, indicating acceptable texture across the board.

Texture scores clustered narrowly (6.40–6.61/9), with A1B1 highest and A2B3 lowest. Given the small spread (≈0.21 points), differences may be perceptually modest and potentially not statistically significant without larger panel size or replication. Still, the pattern is interpretable: lower sugar and lower fruit (A1B1) likely produced a lighter, less sticky matrix with fewer agglomerates, consistent with lower solids loading and reduced risk of caking near sugar's crystallization threshold (Harnkarnsujarit & Charoenrein, 2011). In contrast, A2B3 combines mid sugar (more mobile matrix) with high fruit (more hygroscopic juice solids), a combination that can encourage capillary bridging and clumping during/after drying.

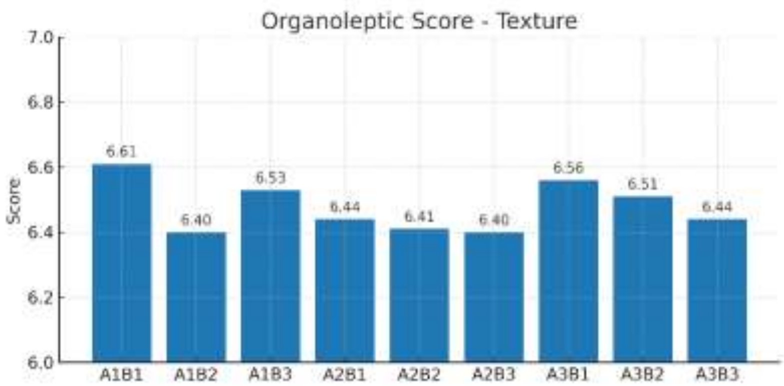

Figure 3. Organoleptic Score – Texture

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Aroma

Aroma scores ranged 6.21–6.53, with A1B3 (low sugar, high tangerine) preferred. This aligns with partitioning arguments: less sucrose means weaker "salting-out" or trapping of volatiles in the matrix, while more tangerine increases the pool of citrus terpenes/esters, both favoring aroma intensity in the cup. Conversely, A1B2 (lowest rating) suggests insufficient citrus load to drive headspace aroma at reconstitution. From a chemistry standpoint, avoiding over-harsh thermal exposure also limits formation of cooked/caramel notes via Maillard/oxidative pathways that can mask citrus freshness (Li et al., 2016; Rojas & Gerschenson, 2001).

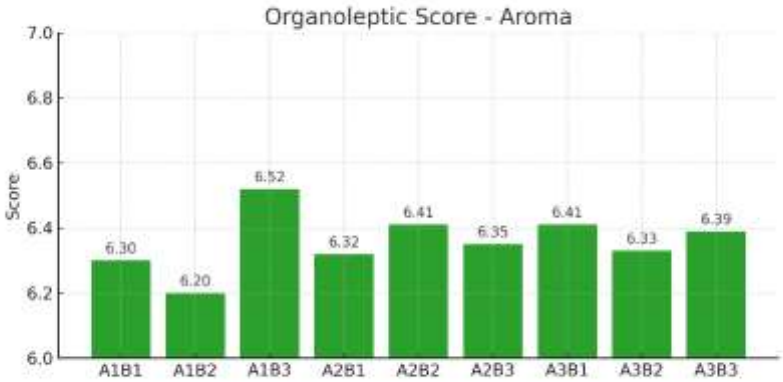

Figure 4. Organoleptic Score – Aroma

Color

Color is often the first attribute perceived by consumers and significantly influences product appeal. Treatment A1B3 again achieved the highest color score, attributed to the high tangerine concentration that enhanced natural pigmentation. The lowest score was recorded in A3B2, where high sugar and moderate fruit concentrations may have diluted natural color or altered it during heating. Overall, all treatments received scores above 6.5, suggesting that visual appearance was consistently well received.

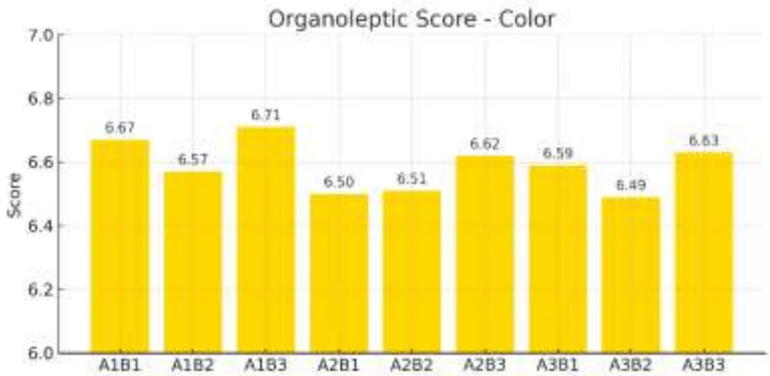

Figure 5. Organoleptic Score – Color

Taste

Taste evaluation revealed that A1B3 and A2B1 both received the highest score, indicating that the balance between sugar and fruit content was optimal in these treatments. A1B3, in particular, combined low sugar and high fruit, resulting in a fresh, tangy, and natural flavor. The lowest score

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was found in A1B1, where both sugar and fruit content were at their lowest, potentially resulting in a bland or underwhelming taste. The data affirm that taste perception benefits from high fruit content and a carefully moderated amount of sugar.

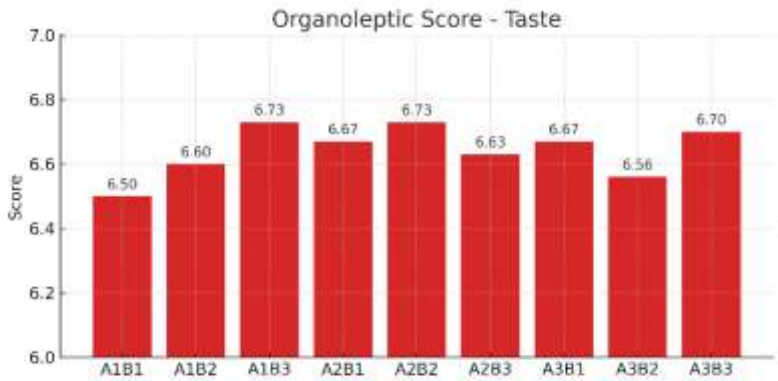

Figure 6. Organoleptic Score – Taste

Taken together, the results suggest that treatment A1B3—45% sugar and 65% tangerine juice, provided the best balance across all measured parameters. This formulation achieved the highest vitamin C content, strong organoleptic performance, and acceptable moisture content, meeting national standards for dried fruit products. These findings demonstrate that lower sugar concentrations, when combined with higher fruit input, not only enhance nutritional quality but also improve sensory attributes, making the product more appealing to health-conscious consumers.

Discussion

Moisture content

Moisture did not differ significantly across treatments. The 2.04–3.07% range is well below the SNI limit for fruit powders, supporting microbiological stability. Lower values in higher-sugar mixes are consistent with sucrose reducing free water via viscosity and lowered a_v (Ahmad & Kumar, 2019). Similar end-moisture ranges have been reported for instant fruit–vegetable powders under controlled drying, while reviews caution that excessive temperature/time fosters agglomeration and poorer solubility. Thus, even without statistical separation, moisture can be optimized through sugar level and drying profile.

Vitamin C

In contrast, vitamin C varied significantly. Low-sugar formulations retained the most vitamin C, aligning with reports that less sugar limits oxidative and Maillard-type losses. Moderately high values in high-sugar sets point to sugar's dual role: at sufficiently high levels it can lower a_v and indirectly protect ascorbic acid. This non-linear pattern agrees with findings that optimized crystallization/encapsulation can keep vitamin C >40 mg/100 g in citrus powders (Kaur & Ghosh, 2018). The comparatively small effect of raising fruit concentration suggests that thermal/oxidative loss during processing can offset higher initial vitamin inputs. Practically, minimizing sugar and tightening process control are more impactful for vitamin C retention than increasing fruit alone.

Sensory attributes

Overall acceptance was good, with low-sugar/high-fruit formulations tending to perform best.

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Texture. Scores of 6.40–6.61 favor low sugar, consistent with literature linking sugar level, crystallinity, and risks of stickiness/aggregation when sugar is excessive.

Aroma. The highest aroma at high fruit–low sugar supports evidence that citrus volatiles are best expressed when sugar does not mask them and when gentle heating limits thermal loss (Zhao et al., 2024).

Color. Uniformly high color scores indicate pigment retention; however, high sugar can drive Maillard darkening if not controlled.

Taste. Balanced formulations scored highest, echoing reports that sweet–acid balance governs liking in instant fruit beverages.

Integrated implication

Taken together, the data reinforce that crystallization can preserve nutritional and sensory quality when composition and processing are optimized. A lower-sugar, higher-fruit mix offers the best compromise—high vitamin C retention, preferred sensory profile, and moisture compliant with SNI—consistent with trends reported in prior studies (Kaur & Ghosh, 2018). The A1B3 formulation is a practical model for developing stable, nutrient-dense citrus powders for instant beverages and functional foods.

Conclusion

Crystallization proved effective for producing Citrus reticulata powder with stable physicochemical and sensory qualities. Across nine formulations, A1B3 performed best, combining the highest vitamin C, acceptable moisture, and superior texture, aroma, color, and taste. Statistics showed that sugar concentration significantly affected vitamin C, while moisture was not significantly different across treatments. All formulations met SNI thresholds for vitamin C and moisture, supporting their suitability for commercial use.

Practical implications for industry. Position A1B3 as the high–vitamin C, fresh-aroma SKU; when line efficiency and instant dissolution are priorities (e.g., vending/stick packs), use A3B1 (very low moisture) and avoid A2 (mid sugar) due to the observed vitamin C minimum. Set release specs at moisture ≤3.0% (margin under SNI 5%), a_w (25 °C) ≤0.30, and vitamin C ≥30 mg/100 g at pack-off. Control the process by running crystallization in the metastable zone with controlled seeding and uniform cooling; define endpoints using solids (°Brix/conductivity) plus time–temperature history rather than time alone; and minimize post-drying oxygen via closed transfer, N_2 sweep, and rapid pack-off. Pack in high-barrier laminates (low WVTR/OTR), nitrogen-flush with appropriately sized desiccant; specify storage ≤25 °C, ≤50% RH and, in humid markets, validate reclose performance or use smaller packs. Institutionalize QC: routine moisture, a_w (25 °C), rapid vitamin C (iodometry), and sensory (appearance/aroma, instant solubility); periodic/validation HPLC-UV vitamin C (~245 nm), particle-size distribution, flowability (angle of repose/shear cell), instant solubility time, and bulk/tapped density; apply SPC (X-bar/R) on moisture and a_w.

This work was bounded by a relatively narrow formulation space and a single cultivar/region observed in one production season, so generalizability beyond these conditions is limited. We applied one crystallization–drying protocol and did not directly measure mechanistic indicators such as water activity, particle-size distribution, flowability, instant solubility, or dissolution kinetics that could clarify structure–process–performance links. Analytically, vitamin C served as the primary nutrient marker and was determined with a single method; other bioactives and volatile profiles were not quantified, and method cross-validation was not performed. The

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assessment reflects immediate post-processing only—no real-time or accelerated storage, nor packaging–humidity interaction tests were conducted. Finally, the study did not address pilot-scale replication, cost considerations, or large consumer panels that would support translational claims.

Follow-up studies should widen the formulation window and systematically optimize temperature–time–cooling, seeding, and supersaturation control, ideally using response-surface/design-of-experiments approaches. Direct measurements of a_v, particle size and distribution, flowability, instant solubility, and dissolution rate are recommended to connect microstructure to performance. Analytical coverage should expand to HPLC-validated vitamin C and quantification of flavonoids, carotenoids, and GC–MS volatiles to explain sensory outcomes mechanistically. Storage stability should be tested under controlled relative humidity and temperature to model nutrient loss, color change, and caking while comparing packaging options such as oxygen-barrier films and desiccants. Pilot-scale runs, techno-economic analysis, and larger consumer tests in relevant use contexts will strengthen evidence for industrial adoption.

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