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Effect of maltodextrin level on nutritional and physicochemical properties of spray-dried mandarin juice

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Tel.: +62-411-585868, ♥email: muhammadilhamahmad02@gmail.com
[2]Department of Agricultural Engineering, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia
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Abstract. *Ahmad I, Mursalim, Salengke, Waris A, Jassin E, Arisandi A. 2026. Effect of maltodextrin level on nutritional and physicochemical properties of spray-dried mandarin juice. Asian J Agric 10 (1): g100118. https://doi.org/10.13057/asianjagric/g100118.* Spray drying is widely used to transform heat-sensitive fruit juices into shelf-stable powders. However, the addition of carrier agents can diminish the retention of labile nutrients. The influence of maltodextrin-to-mandarin juice ratios ranging from 15:85 to 45:55 (w/w) on spray-dried powder properties was evaluated at a fixed inlet temperature of 130°C. Seven formulations of Selayar mandarin (Citrus reticulata) juice with food-grade maltodextrin (DE 10-12) were homogenized and spray-dried using a Büchi B-290 mini spray dryer (outlet 85-115 °C) with a two-fluid nozzle (6 bar), feed rate of ~5 mL/min, and 100% aspirator. Each formulation was processed in triplicate. Vitamin C content was determined by DCPIP titration, titratable acidity (TAT) was measured as percent citric acid, moisture content was determined by oven-drying at 105 °C, ash content by muffle furnace at 550°C, and soluble solids (°Brix) by digital refractometry. Results are reported as mean ± SD (n=3), and the effect of carrier level was analyzed by one-way ANOVA followed by Tukey's HSD test ($p < 0.05$). Vitamin C content of the powder was significantly reduced from 259.98 mg/100 g to 135.14 mg/100 g as the maltodextrin content increased, and titratable acidity was lowered from 1.28% to 0.35%. Moisture content remained low (3.54-4.47%), indicating that the powders were sufficiently dried for safe storage. Ash content increased from 0.13% to 0.48% at higher maltodextrin ratios, whereas °Brix values remained high (75.0-85.1), indicating strong retention of soluble solids. Overall, a clear trade-off was observed between nutrient preservation and powder stability: greater vitamin C retention was achieved at lower carrier-to-juice ratios, whereas higher ratios were associated with improved drying performance and powder handling. These findings provide practical guidance for optimizing carrier use in small-scale citrus powder production and underscore the need for further research on alternative carrier materials and their effects on sensory quality.

Keywords: Citrus powder, physicochemical properties, spray drying, vitamin C degradation

INTRODUCTION

Drying is a key operation in food processing because it lowers moisture content, suppresses microbial growth, and slows quality deterioration, thereby extending shelf life and improving storage and transport efficiency. In fruit-based systems, converting juice into powder reduces packaging volume, simplifies distribution, and enables incorporation into dry formulations as a standardized ingredient. Among available techniques, spray drying is widely used to transform heat-sensitive liquids such as fruit juices into shelf-stable powders with good dispersibility and low bulk density. The process involves atomizing liquid feed into a stream of hot air, allowing rapid water evaporation and particle formation within seconds. However, exposure to heat and oxygen can accelerate degradation of thermolabile nutrients such as vitamin C, promote loss of volatile aroma compounds, and alter color and acidity. Maintaining nutritional quality while achieving physical stability, therefore, requires careful control of formulation and process parameters (Saikia et al. 2014; Sathyashree and Ramachandra 2017).

Successful juice powder production is not defined solely by low moisture content. A marketable powder must remain functional during processing, storage, and consumer use. Desirable properties include good flowability for accurate filling, resistance to caking under humid conditions, and rapid, uniform reconstitution in water without excessive lumping or sedimentation. These characteristics are closely related to the physical state of solutes. Fruit juices rich in sugars and organic acids typically form amorphous matrices during drying. Such matrices are hygroscopic; even moderate moisture uptake can plasticize the structure, lower its glass transition temperature, and increase stickiness. For processors in tropical climates where temperature and humidity are difficult to control, enhancing physical robustness and reconstitution behavior can be as important as preserving nutrients (Phisut 2012; Igual et al. 2021).

Citrus juices, characterized by high concentrations of low-molecular-weight sugars and organic acids, are particularly prone to stickiness and low powder yield during spray drying due to their low glass transition temperature. As droplets lose moisture, partially dried particles may enter a rubbery, tacky state under typical drying conditions, leading to wall deposition, agglomeration, reduced recovery, and additional thermal exposure that can further degrade sensitive components. To mitigate these problems, carrier agents are commonly incorporated into the feed. Maltodextrin is the most widely used carrier due to its relatively high molecular weight, neutral flavor, low sweetness, and good film-forming ability. By increasing the effective glass transition temperature of the solids, maltodextrin reduces stickiness and improves yield and flowability. It may also encapsulate sensitive compounds within a glassy matrix, enhancing storage stability. Nevertheless, higher carrier levels dilute intrinsic nutrients and may reduce flavor intensity, making it essential to determine an optimal concentration that balances nutrient retention, solubility, and physical stability (Mahendran 2011; Phisut 2012; Igual et al. 2021).

Mandarin (*Citrus reticulata* Blanco) is a valuable citrus fruit known for its vitamin C content, organic acids, and characteristic aroma. However, many of these components-particularly vitamin C and volatile compounds-are susceptible to thermal degradation during drying. Although studies have examined spray-dried powders of sweet orange, lemon, and mixed citrus systems (Pino et al. 2018; Sarabandi et al. 2018; Joseph et al. 2025), region-specific mandarin varieties remain less extensively documented under controlled conditions. Selayar mandarin from South Sulawesi has received limited attention in the literature, and quantitative data describing how different maltodextrin concentrations influence the nutritional and physicochemical characteristics of spray-dried Selayar mandarin juice under constant thermal conditions remain scarce. This gap is practically relevant for small-scale processors in tropical regions who often operate with limited instrumentation and maintain a fixed inlet temperature across formulations. Understanding how variations in carrier concentration alone affect product quality under such constraints can support development of scalable and cost-effective processing protocols.

Given these gaps, the present study evaluates the effect of maltodextrin concentration on key nutritional and physicochemical properties of spray-dried Selayar mandarin juice-specifically vitamin C, titratable acidity, moisture, ash, and °Brix-using a single-factor experimental design at a fixed inlet temperature of 130°C. Maltodextrin concentration is systematically varied from 15% to 45% (w/w) while other process parameters are held constant to isolate formulation effects. By clarifying the trade-offs between nutrient preservation and powder stability, the findings are expected to provide practical guidance for small- and medium-scale fruit processors in selecting maltodextrin levels that balance product quality with process efficiency.

MATERIALS AND METHODS

Materials

Fresh *C. reticulata* var. Selayar mandarin and food-grade maltodextrin (DE 10-12) were used as primary materials. Ripe fruits were sourced from local farmers in Selayar District, South Sulawesi, Indonesia during July-August 2025. The juice was manually extracted and filtered prior to formulation. Maltodextrin acted as a carrier agent to improve powder yield and stability during drying. Seven maltodextrin-to-juice ratios were tested: 15:85, 20:80, 25:75, 30:70, 35:65, 40:60, and 45:55 (w/w), denoted as treatments A1-A7.

Spray drying procedure

Spray drying was performed using a laboratory-scale Büchi B-290 mini spray dryer (Büchi Labortechnik AG (2022), Flawil, Switzerland). Each feed mixture (500 mL) was homogenized in a high-speed blender for 3 minutes to ensure uniform dispersion. The inlet temperature was maintained at 130°C, and the outlet temperature ranged between 85-115°C, depending on feed concentration. A peristaltic pump delivered the feed at approximately 5 mL/min through a two-fluid nozzle (0.7 mm diameter) operated at 6 bar compressed air pressure. The aspirator setting was maintained at 100%. Dried powders were collected from the cyclone separator and stored in airtight containers at 4°C until further analysis. The selected inlet temperature (130°C) and feed solid adjustment using maltodextrin were based on commonly reported conditions for fruit juice powder production, where carrier concentration plays a dominant role in particle formation, stickiness reduction, and encapsulation efficiency (Kuck and Noreña 2016; Santiago-García et al. 2023; Zubaidi et al. 2025). Maltodextrin (DE 10-12) was chosen due to its wide application as a food-grade carrier capable of improving drying performance and stabilizing bioactive compounds in spray-dried fruit systems (Fonseca et al. 2024; Sithu et al. 2024).

Experimental design

A single-factor completely randomized design with seven carrier levels (A1-A7) was used. Each treatment was conducted in triplicate. The measured response variables included vitamin C, titratable acidity (TAT), moisture, ash, and total soluble solids (°Brix).

Analytical methods

All analyses were conducted at the Laboratory of Nutrition and Chemistry, State Agricultural Polytechnic of Pangkajene Islands, Indonesia (June-August 2025). Prior to testing, samples were equilibrated to room temperature. Analytical procedures followed Association of Official Analytical Collaboration (AOAC 2023) and ISO standards:

Vitamin C: Determined by redox titration using 2,6-dichlorophenolindophenol (DCPIP) (AOAC 967.21).

Titratable acidity (TAT): Determined by titration with 0.1 N NaOH, expressed as % citric acid (ISO 750:1998 (ISO 1998); AOAC 942.15).

Moisture: Determined by oven drying at 105°C to constant weight (AOAC 925.10).

Ash: Determined by dry ashing at 550°C (AOAC 940.26).

Total soluble solids (°Brix): Measured using a digital refractometer (±0.1°Bx accuracy) (ISO 2173:2003 (ISO 2003); AOAC 932.12).

The selected response variables (vitamin C, titratable acidity, moisture, ash, and total soluble solids) were chosen to represent both nutritional quality and physical stability parameters commonly evaluated in spray-dried fruit powders (Masum et al. 2020; Bashir et al. 2023). These indicators are frequently used to assess matrix stability, hygroscopic behavior, and compositional retention after spray drying.

Data analysis

Results are presented as mean ± Standard Deviation (SD). The effect of maltodextrin level (A1-A7) was analyzed using one-way ANOVA. When normality (Shapiro-Wilk) or homogeneity (Levene) assumptions were violated, Welch ANOVA and Kruskal-Wallis tests were applied. Pairwise differences were assessed using Tukey's HSD ($p<0.05$). Effect sizes (η^2, ω^2) were calculated to indicate the magnitude of treatment effects.

RESULTS AND DISCUSSION

Baseline composition of the control (A0, pre-drying)

A control sample (A0), consisting of fresh tangerine juice without maltodextrin (pre-drying), was analyzed to provide baseline composition prior to spray drying. The control contained 58.20±2.07 mg/100 g vitamin C, 0.738±0.001% TAT, 90.57±0.03% moisture, 0.29±0.01% ash, and 7.90±0.00°Brix. These values serve as a reference to contextualize the compositional shifts observed after drying and across carrier levels. Because A0 is a liquid matrix (pre-drying) while A1-A7 are powders, statistical comparisons were performed among powder formulations only.

Overview of powder responses and statistical comparisons (A1-A7)

Table 1 summarize the powder responses across formulations A1-A7 as mean ± SD (n=3). Differences among formulations are indicated by superscript letters and were evaluated using one-way ANOVA followed by Tukey's HSD ($p<0.05$). Overall, formulation significantly affected all measured responses, confirming that maltodextrin level altered both nutritional and physicochemical properties of the powder under the fixed inlet temperature condition.

Effect of formulation on vitamin C content

Vitamin C differed significantly among formulations ($p<0.05$), showing a clear decline from A1 to A7. The highest vitamin C content was observed in A1 (259.98 mg/100 g) and the lowest in A7 (135.14 mg/100 g) (Table 1 and Figure 1). Tukey's HSD separated the formulations into distinct groups, indicating a robust and consistent formulation effect. This trend is consistent with the thermolabile nature of ascorbic acid and dilution/protection effects associated with carrier addition in fruit powder systems (Saikia et al. 2014).

The consistent A1→A7 decrease suggests a strong formulation-driven effect rather than random variation. Increasing maltodextrin can reduce the mass fraction of fruit solids per unit powder and may also modify droplet drying behavior, which together can reduce apparent vitamin C per 100 g powder. Similar patterns have been reported in spray-dried citrus systems, where carrier concentration affects retention of labile nutrients and their distribution in the dried matrix (Phisut 2012; Igual et al. 2021).

Similar carrier-dependent dilution effects have been reported in spray-dried grape phenolic extracts and citrus-based systems, where increasing encapsulating agent concentration improves processability but reduces bioactive compound concentration per unit mass (Kuck and Noreña 2016; Zubaidi et al. 2025). Moreover, encapsulation efficiency and retention of thermolabile compounds such as anthocyanins and vitamin C are strongly influenced by the matrix composition and droplet solid distribution during drying (Santiago-García et al. 2023; Fonseca et al. 2024).

Effect of formulation on titratable acidity (TAT)

Titratable acidity varied significantly across formulations ($p < 0.05$). Mean TAT ranged from 0.35% (A1) to 1.28% (A4), showing an increase from A1 to A4 followed by a decrease at A5-A6 and a rise again at A7 (Table 1 and Figure 2). Tukey's HSD indicated broad pairwise differences, with A5 and A6 forming the closest pair, while A4 remained the most acidic formulation. A sensitivity check (Kruskal-Wallis) supported the same conclusion, indicating the formulation effect was robust to mild deviations from normality.

Higher TAT at certain carrier levels can reflect acid retention within a glassy matrix and concentration effects that limit losses of volatile or reactive components during drying. Prior work has shown that carrier composition and solids loading influence the retention and apparent concentration of acids in fruit powder matrices (Phisut 2012; Sarabandi et al. 2018; Igual et al. 2021).

Non-linear changes in acidity across carrier levels may reflect interactions between organic acids and the carbohydrate matrix during droplet dehydration. Comparable behavior has been observed in fruit-based spray-dried systems where carrier ratio influenced acid retention and matrix microstructure (Santiago-García et al. 2023; Zubaidi et al. 2025).

Effect of formulation on moisture content and physical stability

Moisture content differed significantly among formulations ($p<0.05$), but values remained within a relatively narrow range (~3.54-4.47%). The highest moisture was observed at A4 and A6 (~4.47%), whereas A5 produced the lowest moisture (~3.54%) (Figure 3). Tukey's HSD showed that several pairs were not significantly different, indicating partial overlap among intermediate formulations despite the overall ANOVA significance.

Moisture content is a critical determinant of powder flowability and caking behavior during storage. Bashir et al. (2023) demonstrated that slight differences in residual moisture significantly affect anticaking performance and shelf-life prediction in apricot powder systems. Likewise, Masum et al. (2020) reported that drying temperature and solids concentration influence water sorption and stability in dairy powders, suggesting that formulation-driven differences in moisture observed in this study may have practical implications for storage performance.

Although statistically different, the moisture levels across formulations remained within ranges commonly reported for spray-dried powders. Variation in moisture can be attributed to solids loading, atomization behavior, and crust formation during drying, which affect internal diffusion and final water removal (Bhandari et al. 1997; Chegini and Ghobadian 2007; Goula and Adamopoulos 2010). From a stability perspective, the measured moisture values suggest all formulations were generally within acceptable targets for storage performance, consistent with prior reports on powder stability thresholds (Islam et al. 2016).

Effect of formulation on ash content (mineral residue)

Ash content also differed significantly among formulations ($p < 0.05$). The highest mean ash occurred at A3 (~0.48%), while lower values were observed in A1 and A6 (~0.13%) (Figure 4). Tukey's HSD indicated multiple non-significant pairs, implying that mineral residue differences were concentrated in specific mid-level formulations rather than showing a strictly monotonic pattern.

Because maltodextrin contributes minimal ash, observed differences likely reflect the relative contribution and distribution of juice solids and minerals across formulations. Similar behavior has been observed in dried fruit systems where formulation affects concentration and partitioning of inorganic constituents (Tafti et al. 2013). Analytical procedures should follow recognized standards for ash determination (AOAC International 2023).

Variations in mineral residue may reflect differential distribution of juice solids across carrier ratios, consistent with observations in fruit-based spray-dried matrices where formulation affects compositional partitioning (Zubaidi et al. 2025).

Effect of formulation on total soluble solids (°Brix)

Total soluble solids (°Brix) showed strong formulation dependence ($p < 0.05$), forming two clear clusters. A4 and A7 exhibited the highest values (~85.0-85.1°Bx), whereas A1 and A6 had the lowest (~75.0-75.2°Bx), with A2-A5 grouped in the mid-to-lower range (Figure 5). Kruskal-Wallis again supported the effect, and Tukey's HSD indicated that A4 vs A7 and A1 vs A6 were not significantly different while most other comparisons differed.

Table 1. Powder responses across formulations A1-A7

Formulation	Vitamin C (mg/100 g)	Titratable acidity (TAT, %)	Moisture content (%)	Ash content (%)	Total soluble solids (°Brix)
A1	259.98±1.24^{a}	0.35±0.01^{f}	3.70±0.03^{c}	0.13±0.01^{d}	75.00±0.00^{d}
A2	193.68±0.45^{b}	0.47±0.01^{e}	3.59±0.06^{d}	0.27±0.02^{b}	77.25±0.25^{b}
A3	183.35±0.25^{c}	0.76±0.00^{c}	3.82±0.01^{b}	0.48±0.02^{a}	76.00±0.00^{c}
A4	169.07±0.28^{d}	1.28±0.00^{a}	4.47±0.02^{a}	0.28±0.01^{b}	85.00±0.00^{a}
A5	147.55±0.60^{e}	0.54±0.01^{d}	3.54±0.04^{d}	0.23±0.01^{bc}	76.10±0.10^{c}
A6	138.20±0.60^{f}	0.51±0.01^{d}	4.47±0.02^{a}	0.13±0.03^{d}	75.20±0.20^{d}
A7	135.14±0.58^{g}	0.94±0.03^{b}	3.85±0.05^{b}	0.14±0.01^{d}	85.10±0.10^{a}

Note: Values are mean ± SD (n=3). Different superscript letters within a column indicate significant differences among formulations (one-way ANOVA followed by Tukey's HSD, $p<0.05$)

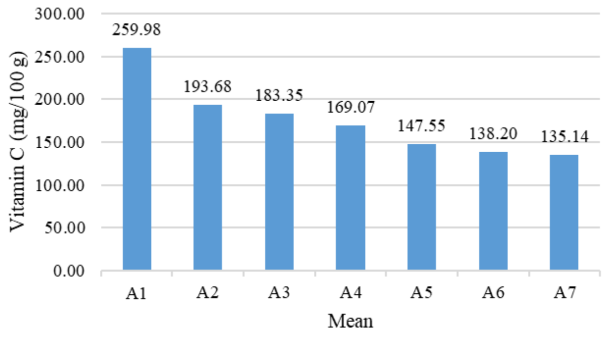

Figure 1. Mean vitamin C at seven maltodextrin levels (A1-A7) at 130°C inlet

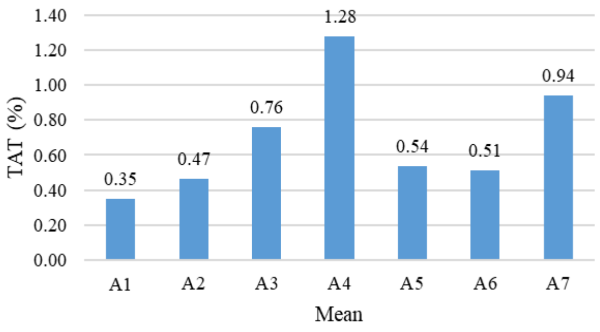

Figure 2. Mean TAT at seven maltodextrin levels (A1-A7) at 130°C inlet

Because maltodextrin has a low sweetness index, °Brix primarily tracks native sugars and soluble components from the fruit fraction; the carrier level may influence how these solutes are distributed and concentrated during drying rather than suppressing the measurement. Comparable findings have been reported in spray-dried fruit powders, where carrier and solids loading affect soluble-solids concentration and partitioning (Tze et al. 2012; Pino et al. 2018; Sarabandi et al. 2018; Igual et al. 2021).

Soluble solids retention patterns may also be influenced by matrix densification and encapsulation efficiency during atomization. Similar formulation-dependent behavior has been reported in spray-dried yogurt and fruit-fortified dairy systems using maltodextrin as carrier (Sithu et al. 2024; Jaya et al. 2025).

Comparison with the literature, practical implications for SMEs, and study limitations

Under a fixed inlet temperature (~130°C), the progressive decline in vitamin C with higher maltodextrin mirrors trends reported for citrus matrices in which carrier concentration and feed solids govern retention of labile nutrients and the distribution of soluble solids (Phisut 2012; Igual et al. 2021). Similar to orange/lemon model systems, increasing carrier/solids typically improves particle formation and process handling while diluting vitamin C on a mass basis (Bhandari et al. 1997; Chegini and Ghobadian 2007; Goula and Adamopoulos 2010). Overall, the low-carrier region (A1-A2) is better suited to nutrition-focused powders, while mid-carrier levels (≈A3-A6) align with handling and shelf-life targets commonly reported for citrus powders.

Collectively, recent studies emphasize that carrier concentration governs not only drying efficiency but also structural stabilization, encapsulation performance, and long-term powder functionality (Fonseca et al. 2024; Zubaidi et al. 2025). The present findings align with these reports, confirming that under fixed inlet temperature conditions typical of SME-scale processing, formulation control remains the primary lever for balancing nutrient retention and powder stability.

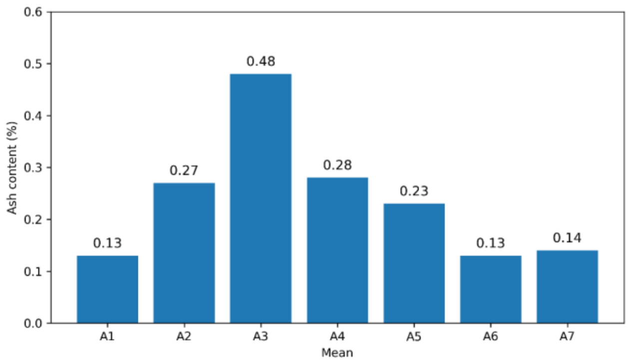

Figure 4. Mean Ash content at seven maltodextrin levels (A1-A7) at 130°C inlet

For SMEs operating benchtop/pilot spray dryers, these formulation trade-offs translate into practical guidance: (i) lower carrier levels can maximize labeled vitamin C but may increase stickiness risk; (ii) mid-level carrier addition can balance reconstitution, flowability, and moisture control; and (iii) routine QC based on °Brix and moisture can be used as rapid acceptance criteria, supported by periodic vitamin C assays for label substantiation. These ranges provide realistic benchmarks for production under a 130°C inlet condition.

This study varied carrier level at a single inlet temperature on a lab-scale dryer; therefore, extrapolation to other temperatures, throughputs, and dryer geometries should be made with caution. We did not assess aroma retention, color changes, glass transition temperature (Tg), hygroscopicity/caking during storage, or sensory outcomes after reconstitution. Mild deviations from normality in some responses motivated robustness checks rather than multi-factor modeling. Future work should jointly vary inlet temperature and feed solids, compare carrier blends (e.g., gum arabic, inulin, protein-based encapsulants), and include storage stability and sensory performance metrics alongside pilot-scale validation and SME-oriented techno-economic assessment.

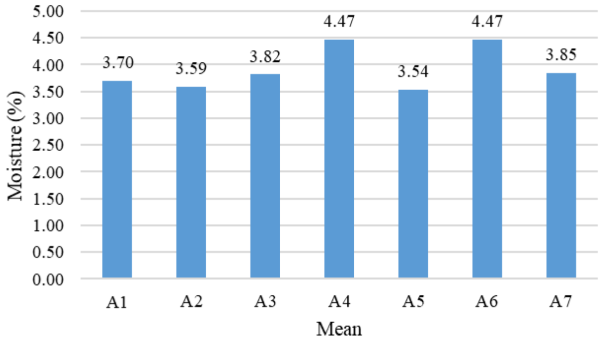

Figure 3. Mean moisture at seven maltodextrin levels (A1-A7) at 130°C inlet

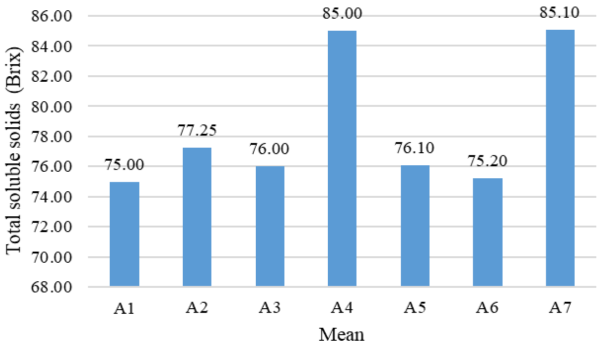

Figure 5. Mean soluble solids (°Brix) at seven maltodextrin levels (A1-A7) at 130°C inlet

In conclusion, the pre-drying control (A0) established the baseline composition of fresh tangerine juice without maltodextrin (58.20±2.07 mg/100 g vitamin C, 0.738±0.001% TAT, 90.57±0.03% moisture, 0.29±0.01% ash, and 7.90±0.00°Brix), providing context for compositional shifts after spray drying. Across powder formulations (A1-A7), one-way ANOVA with Tukey's HSD ($p<0.05$) confirmed that maltodextrin level significantly influenced all measured responses. Vitamin C decreased consistently from A1 to A7, indicating a strong formulation-driven effect and highlighting a nutrition-processing trade-off as carrier level increased. TAT varied nonlinearly with a peak at A4, moisture remained within a relatively narrow range (with the highest values at A4 and A6), and ash differences suggested formulation-dependent mineral distribution. Total soluble solids formed two clear clusters, with the highest °Brix in A4 and A7 and the lowest in A1 and A6. Overall, lower carrier levels (A1-A2) are most suitable for vitamin C-oriented products, whereas mid-level carriers (≈A3-A6) may better balance handling and stability needs; future work should expand the process design space beyond a single inlet temperature and include additional quality attributes (e.g., Tg, hygroscopicity, sensory performance) to support scale-up and SME implementation.

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