Journal of Biomedical Sciences and Health
e-ISSN: 3047-7182 | p-ISSN: 3062-6854
Available online at ejournal.unkaha.ac.id/index.php/jbsh

OPEN ACCESS

Vol. 3, No. 2, 2026 DOI: 10.34310/jbsh.v3.i2.361 Pages 95-104

ORIGINAL RESEARCH

Sugar-to-stevia substitution in strawberry jam (*Fragaria* × *ananassa*): effects on anthocyanin retention and sensory acceptability

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ABSTRACT

Background. Strawberry (*Fragaria* × *ananassa*) is a rich dietary source of anthocyanins—red-purple flavonoid pigments with antioxidant activity—but its high perishability means it is most often preserved as jam, a product that conventionally carries a heavy sucrose load. Replacing sucrose with the non-nutritive glycoside sweetener stevia (*Stevia rebaudiana*) could lower the sugar burden, yet its impact on both consumer acceptance and pigment retention in strawberry jam has not been characterised together in a single product. **Objective.** To quantify the effect of graded sugar-to-stevia substitution on (i) the sensory acceptability and (ii) the total anthocyanin content of strawberry jam. **Methods.** Five formulations were prepared: a sucrose control (F0) and four formulations substituting 1, 3, 5 and 7 g stevia per 100 g strawberry (F1–F4). Anthocyanin content was measured by the pH-differential method (UV-Vis spectrophotometry; cyanidin-3-glucoside equivalents) under a one-factor completely randomised design with three replicates per formulation. Acceptability of colour, aroma, taste and texture was rated by 30 untrained panellists on a five-point hedonic scale in a within-subject design. Anthocyanin data were analysed by one-way ANOVA with Tukey HSD post-hoc tests after verifying normality (Shapiro-Wilk) and variance homogeneity (Levene); hedonic data were analysed by the Kruskal-Wallis test. **Results.** Anthocyanin content differed markedly across formulations (one-way ANOVA $F(4,10) = 86.25$, $p < 0.001$, $\eta^2 = 0.97$). It was highest in the sucrose control F0 (66.93 ± 2.22 mg L^{-1}) and lowest in F3 (45.57 ± 0.89 mg L^{-1}), a 31.9% reduction, but rose again in F4 (52.71 ± 1.84 mg L^{-1}) despite its higher stevia dose, revealing a non-monotonic dose–response. Hedonic ratings differed significantly for every attribute (Kruskal-Wallis: taste $H = 23.08$, $p < 0.001$; colour $H = 17.80$, $p = 0.001$; texture $H = 16.87$, $p = 0.002$; aroma $H = 12.68$, $p = 0.013$), with acceptance declining as the stevia dose increased and F0 preferred throughout. **Conclusion.** Sugar-to-stevia substitution exerted a significant, formulation-dependent rather than strictly dose-dependent effect on both anthocyanin retention and sensory acceptability of strawberry jam. Moderate substitution offers the most workable compromise between sugar reduction and product quality, but a genuine "low-sugar" label claim would require direct sugar-composition analysis, which was outside the present scope.

Keywords: anthocyanin; strawberry jam; stevia; hedonic test; pH-differential method

Received: 1 August 2026 | **Revised:** 20 August 2026 | **Accepted:** 24 August 2026 | **Published:** 25 August 2026

Cite this article: Nahdah, A. A., Lestari, C. R., & Rarastiti, C. N. (2026). Sugar-to-stevia substitution in strawberry jam (*Fragaria* × *ananassa*): effects on anthocyanin retention and sensory acceptability. *Journal of Biomedical Sciences and Health*, *3*(2), 95-104. https://doi.org/10.34310/jbsh.v3.i2.361

1. INTRODUCTION

Strawberry (*Fragaria × ananassa*) is prized both as a dessert fruit and as a concentrated dietary source of vitamin C, dietary fibre and anthocyanins—water-soluble flavonoid pigments that give the fruit its red colour and contribute much of its antioxidant capacity (Golovinskaia & Wang, 2021). Epidemiological and mechanistic work links berry anthocyanins to reduced risk of several non-communicable diseases, including cardiovascular disease, type-2 diabetes, obesity and certain cancers, largely through the scavenging of reactive oxygen species and modulation of inflammatory signalling (Royhanaty et al., 2026; Prayogo, Royhanaty & Sari, 2025). It should be noted, however, that the health value of red fruit is not attributable to anthocyanins alone: comparing red and white strawberry tissue, Martínez-Ferri et al. (2024) found that anthocyanin-deprived white receptacle extracts protected cells from oxidative damage at least as effectively as red tissue, cautioning against equating pigment content with bioactivity. Anthocyanin content nonetheless remains a practical, widely used marker of the retention of a valuable class of phytochemicals during food processing.

A central limitation of fresh strawberry is its short shelf life: high water content and a rapid respiration rate promote quick spoilage (Brockelt et al., 2025), so processing into jam is a common strategy to extend usability and add economic value (Milosavljević et al., 2022). In conventional jam, sucrose is multifunctional—sweetener, gelling co-factor with pectin, and preservative through the lowering of water activity. The corollary is a high sugar load that runs counter to contemporary dietary guidance to limit free sugars.

Stevia (*Stevia rebaudiana*), whose steviol glycosides (chiefly stevioside and rebaudioside A) are 200–300 times sweeter than sucrose while contributing negligible calories or glycaemic load, is an attractive candidate to reduce that burden (Rahayu, 2024). Stevia has been applied across a range of processed foods with generally favourable results when its proportion is optimised, including butterfly -pea flower syrup, where sensory quality and colour stability were maintained (Marlina & Pujiastuti, 2024), and reduced-energy pineapple sheet jam, where sweetener type and proportion significantly shaped physicochemical and sensory outcomes (Khairanti, Widiany & Nareswara, 2023). Sucrose replacement can, however, alter the sensory profile of jam—colour, aroma, taste and texture—so hedonic testing is essential to gauge consumer acceptance (Ariska et al., 2022).

Sweetener choice may also influence anthocyanin stability, because anthocyanins are thermolabile and sensitive to pH, light and oxygen exposure during processing (Herlina, Mulyani & Anlika, 2023). Evidence on the direction of this effect is mixed and product-specific. In lingonberry jam, Scrob et al. (2023) reported that anthocyanin was in fact best preserved in formulations sweetened with fructose or stevia rather than coconut sugar, implying a potential protective role for stevia. More recently, and in the same product family and department as the present study, Izza, Lestari & Hidayat (2026) showed in roselle (*Hibiscus sabdariffa*) kombucha that lower sugar concentrations were associated with the highest retention of flavonoids, another phenolic antioxidant class. Whether sucrose or stevia better protects anthocyanin in strawberry jam specifically remains unresolved.

Research pairing stevia substitution with anthocyanin quantification in strawberry jam is scarce: national studies rarely measure the pigment, and international work linking sweetener type to anthocyanin stability in berry jams has largely addressed fruits other than strawberry, such as lingonberry (Scrob et al., 2023). The present study addresses that gap by evaluating both sensory acceptability and anthocyanin content in a single strawberry-jam system. Because the formulations were matched by ingredient dose rather than equalised for perceived sweetness, the study is framed as an evaluation of substituting sucrose with stevia at specific proportions rather than as an isolation of stevia as an independent factor (see Sections 2.1 and 4.4). Two objectives were pursued: (1) to determine the effect of sugar-to-stevia substitution on the sensory acceptability of strawberry jam, and (2) to determine its effect on the jam's total anthocyanin content.

2. MATERIALS AND METHODS

2.1 Study design

The study combined two complementary designs. Anthocyanin analysis followed a one-factor completely randomised design (CRD) with five formulations, each prepared in three independent replicates (F0R1–F0R3 through F4R1–F4R3), giving 15 experimental units. Sensory evaluation used a within-subject, repeated-measures design in which each of 30 panellists rated all five formulations. Because the two designs differ, they were analysed with different statistical models (Section 2.6). The formulation composition is summarised in Table 1. Formulations were matched on ingredient dose, not on equal perceived sweetness; consequently, the contrasts reflect the effect of substituting sucrose with stevia at these specific proportions (Section 4.4).

Table 1. Composition of the five strawberry-jam formulations (per 100 g of strawberry).

Formulation	Strawberry (g)	Granulated sugar (g)	Stevia (g)	Role
F0	100	10	0	Sucrose control
F1	100	0	1	Substitution
F2	100	0	3	Substitution
F3	100	0	5	Substitution
F4	100	0	7	Substitution

Replication increases the precision and reliability of estimates, permits calculation of means and standard deviations, and provides the basis for analysis of variance (Isnaini et al., 2025).

The study was conducted in April 2026 at Universitas Ivet Semarang, with anthocyanin analysis performed at the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang. Ethical clearance was granted under number 004567/Universitas Dian Nuswantoro/2025.

2.2 Materials

Holland-variety strawberries were obtained from the Kopeng–Getasan growing area; this variety is large, slightly conical, bright red, and denser and more acidic than many alternatives (Sondari, Amalia & Aminah, 2020). Powdered stevia was purchased from a commercial retailer. For sensory evaluation, each of the 30 untrained panellists received a 5 g portion of every formulation.

2.3 Jam preparation

Fresh strawberries (500 g per batch) were washed under running water, trimmed of stems and damaged tissue, weighed, and blended to a purée. The purée was heated in a stainless-steel pan over low heat with continuous stirring; upon boiling, sucrose (F0) or stevia (F1–F4) was added according to Table 1. Cooking continued for 10–20 min at approximately 105 °C until the target consistency was reached, judged by a cold-plate viscosity test (Suliartini et al., 2024). Jam was then cooled to room temperature and packed into sterile glass jars. Two procedural choices are acknowledged as limitations (Section 4.4): the cooking time was allowed to vary within a 10–20 min window rather than being fixed, and the cold-plate endpoint is operator-dependent; an instrumental gel-strength or viscosity endpoint is recommended for future work.

2.4 Sensory evaluation

Acceptability was assessed by 30 untrained panellists using a hedonic (preference) test, rating colour, aroma, taste and texture on a five-point scale (1 = strongly dislike, 2 = dislike, 3 = neutral, 4 = like, 5 = strongly like). Untrained panellists were appropriate because the objective was consumer preference rather than trained descriptive profiling (Usman et al., 2023). The five-point scale is narrower than the nine-point scale often used in hedonic work and is more prone to ceiling and floor effects; a nine-point scale is recommended for future studies to improve discrimination (Section 4.4).

2.5 Anthocyanin determination

Total anthocyanin content was determined by the pH-differential method. Samples were homogenised and extracted with an acidic solvent, then equilibrated in two buffers (pH 1.0 and pH 4.5). Absorbance was read on a UV-Vis spectrophotometer at 499 and 700 nm. Total anthocyanin content (expressed as mg L^{-1} cyanidin-3-glucoside equivalents) was calculated from the standard formula using the molar extinction coefficient (ε = 26 900 L mol^{-1}

cm^{-1}) and molecular weight (449.2 g mol^{-1}) of cyanidin-3-glucoside (Herlina, Mulyani & Anlika, 2023). Because jam is semi-solid, the mg L^{-1} value refers to the concentration in the liquid extract recovered after extraction rather than to a mass or volume of jam (Section 4.4).

2.6 Statistical analysis

Descriptive statistics (mean, standard deviation, range, and coefficient of variation) were computed for each formulation. For anthocyanin data, normality was assessed with the Shapiro-Wilk test and homogeneity of variance with Levene's test; because both assumptions were satisfied, groups were compared by one-way ANOVA, with effect size reported as eta-squared (η^2) and pairwise contrasts resolved by Tukey's HSD test (α = 0.05). Ordinal hedonic data were analysed with the non-parametric Kruskal-Wallis test (Ahmed & Jena, 2023; Clark et al., 2023). Statistical significance was set at $p < 0.05$. All anthocyanin statistics reported here were computed directly from the replicate-level measurements.

3. RESULTS

3.1 Anthocyanin content

Total anthocyanin content varied substantially across the five formulations (Table 2, Figure 1). The sucrose control F0 retained the most pigment (66.93 ± 2.22 mg L^{-1}), and content fell as stevia was introduced, reaching a minimum at F3 (45.57 ± 0.89 mg L^{-1})—a 31.9% reduction relative to F0. The response was not monotonic, however: F4, despite carrying the highest stevia dose, contained more anthocyanin (52.71 ± 1.84 mg L^{-1}) than either F2 or F3. Coefficients of variation were low throughout (2.0–3.6%), indicating good replicate precision.

Table 2. Descriptive statistics for total anthocyanin content by formulation (n = 3; cyanidin-3-glucoside equivalents). Change is relative to the F0 control.

Formulation	R1	R2	R3	Mean ± SD	Range	CV (%)	Δ vs F0
F0	69.47	65.96	65.35	66.93 ± 2.22	65.35–69.47	3.3	—
F1	64.79	63.29	61.51	63.20 ± 1.64	61.51–64.79	2.6	−5.6%
F2	47.59	50.60	47.48	48.56 ± 1.77	47.48–50.60	3.6	−27.4%
F3	44.92	46.59	45.20	45.57 ± 0.89	44.92–46.59	2.0	−31.9%
F4	50.93	52.60	54.61	52.71 ± 1.84	50.93–54.61	3.5	−21.2%

All values are in mg L^{-1}. Means and standard deviations were recomputed from the replicate measurements shown.

Both parametric assumptions were met. Shapiro-Wilk tests indicated no significant departure from normality within any group (all $p > 0.05$), and Levene's test confirmed homogeneous variances across groups (Table 3). Given three replicates per group, these tests have limited power and are interpreted as the absence of evidence against the assumptions rather than strong confirmation (Section 4.4).

Table 3. Assumption checks for anthocyanin data: within-group normality (Shapiro-Wilk) and homogeneity of variance (Levene, mean-based).

Test	F0	F1	F2	F3	F4	Decision
W	0.858	0.998	0.776	0.872	0.997	Normal
p	0.263	0.906	0.059	0.300	0.898	(p > 0.05)

Levene's test (based on the mean): $F = 0.71$, $p = 0.60$ → variances are homogeneous across F0–F4.

One-way ANOVA showed a highly significant difference among formulations (Table 4), with an exceptionally large effect size ($\eta^2 = 0.97$): 97% of the variance in anthocyanin content was attributable to formulation. Tukey HSD post-hoc comparisons (Table 5) localised these differences: F0 and F1 did not differ significantly from each other, and both exceeded all stevia-heavier formulations; F2, F3 and F4 formed a lower band in which F2 vs F3 and F2 vs F4 were statistically indistinguishable, whereas F3 was significantly lower than F4—quantifying the F4 rebound noted above. These groupings are shown as letters above the bars in Figure 1.

Table 4. One-way ANOVA for total anthocyanin content across the five formulations.

Source	Sum of squares	df	Mean square	F	p	η²
Between groups	1032.99	4	258.25	86.25	< 0.001	0.97
Within groups	29.94	10	2.99			
Total	1062.93	14				

Table 5. Tukey HSD pairwise comparisons (family-wise α = 0.05). "Sig." marks pairs that differ significantly.

Comparison	Mean difference	p (adjusted)	Result
F0 vs F1	−3.73	0.135	ns
F0 vs F2	−18.37	< 0.001	Sig.
F0 vs F3	−21.36	< 0.001	Sig.
F0 vs F4	−14.21	< 0.001	Sig.
F1 vs F2	−14.64	< 0.001	Sig.
F1 vs F3	−17.63	< 0.001	Sig.
F1 vs F4	−10.48	< 0.001	Sig.
F2 vs F3	−2.99	0.286	ns
F2 vs F4	+4.16	0.086	ns
F3 vs F4	+7.14	0.004	Sig.

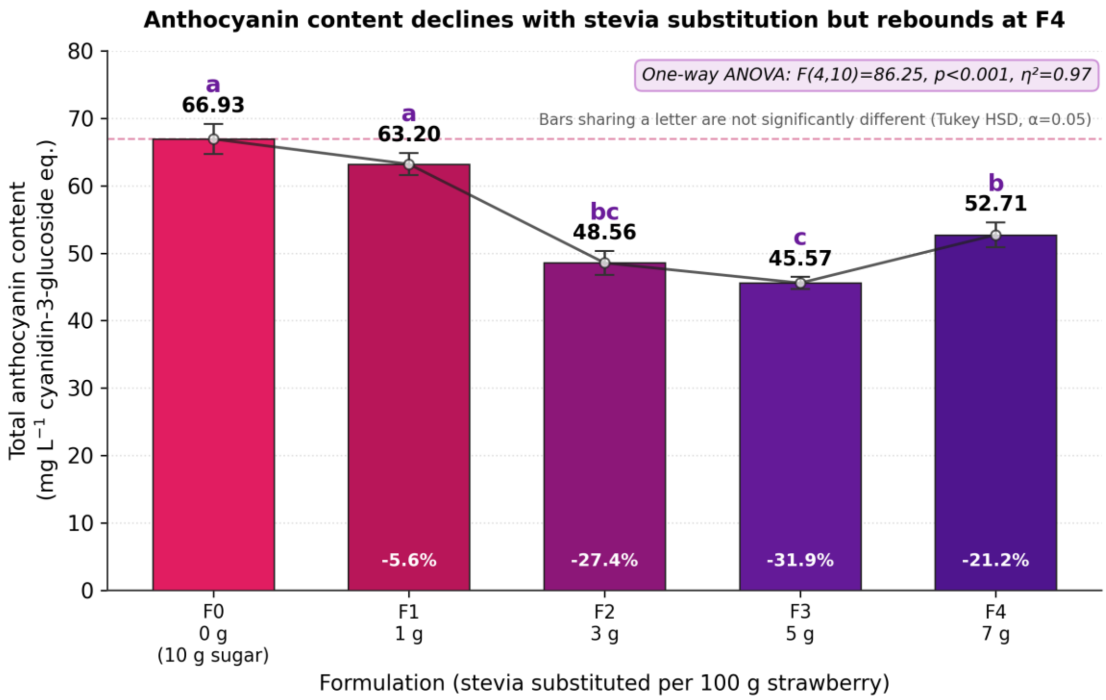

Figure 1. Total anthocyanin content (mean ± SD, n = 3) across formulations. Percentages give the change relative to the F0 control; bars sharing a letter are not significantly different (Tukey HSD, α = 0.05). The connecting line highlights the non-monotonic dose–response, with the minimum at F3 and a partial rebound at F4.

Figure 1. Total anthocyanin content (mean ± SD, n = 3) across formulations. Percentages give the change relative to the F0 control; bars sharing a letter are not significantly different (Tukey HSD, α = 0.05). The connecting line highlights the non-monotonic

dose–response, with the minimum at F3 and a partial rebound at F4.

3.2 Sensory acceptability

Kruskal-Wallis tests showed that panellist ratings differed significantly across formulations for all four attributes (Table 6, Figure 2):

taste showed the strongest separation ($H = 23.08$, $p < 0.001$), followed by colour ($H = 17.80$, $p = 0.001$), texture ($H = 16.87$, $p = 0.002$) and aroma ($H = 12.68$, $p = 0.013$); all exceeded the χ^2 critical value of 9.488 (df = 4). Because the sensory data were collected under a within-subject design, this independent-samples test is a conservative approximation, and its H values are not directly comparable across attributes without a standardised effect size (Section 4.4).

Across attributes, acceptance declined as stevia increased, and F0 was preferred throughout; the stevia-heavy formulations F3 and F4 drew the lowest ratings, most clearly for taste and aroma.

Table 6. Kruskal-Wallis test results for the four hedonic attributes (df = 4 for each).

Attribute	H statistic	Asymp. Sig. (p)	Interpretation
Taste	23.08	< 0.001	Significant
Colour	17.80	0.001	Significant
Texture	16.87	0.002	Significant
Aroma	12.68	0.013	Significant

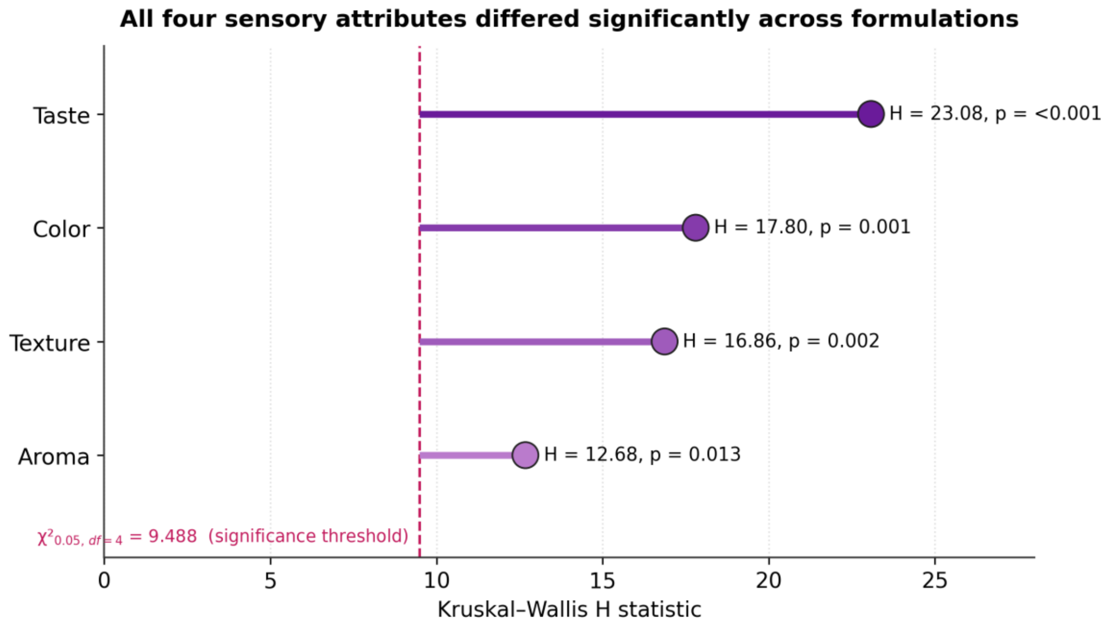

Figure 2. Kruskal-Wallis H statistics for the four sensory attributes. All lie beyond the $\chi^2_{0.05}$ (df = 4) threshold of 9.488 (dashed line), so all four differ significantly across formulations; taste separates most strongly and aroma least. Data-availability note. A descriptive hedonic table (median and interquartile range for each attribute × formulation) should accompany these inferential results in the final submission. Those per-panellist scores were not part of the dataset re-analysed here, so this table is left for the authors to insert from the raw sensory records rather than being reconstructed, to avoid introducing values not supported by the primary data.

4. DISCUSSION

4.1 Sensory acceptability declines with stevia dose

The clearest sensory signal was on taste, consistent with the well-documented sensory penalty of steviol glycosides at higher doses. Stevioside and rebaudioside A deliver sweetness without calories but are widely reported to impart a bitter, slightly astringent, liquorice-like aftertaste as concentration rises; this is a plausible account of the observed pattern rather than a mechanism measured here. Colour and texture acceptance also fell with increasing stevia. The colour effect may reflect interactions between stevia constituents and strawberry anthocyanins, and the texture effect is consistent with the loss of sucrose's role in gel formation—sucrose interacts with pectin and free water to build jam structure, so its removal is expected to weaken the gel and alter mouthfeel. Both explanations are hypotheses: neither pigment–sweetener interaction nor gel strength was instrumentally measured in this study (Section 4.4). That F0 was preferred across every attribute indicates that panellists still favoured the profile of a fully sucrose-sweetened jam and points to combination sweetening or flavour-masking as practical routes to improve acceptance of stevia formulations (Khairanti, Widiany & Nareswara, 2023).

4.2 Anthocyanin retention and the non-monotonic response

Anthocyanin content declined as sucrose was replaced by stevia, with the largest losses at F2 and F3. A parsimonious explanation combines thermal degradation with the loss of a sugar-related protective effect: anthocyanins are thermolabile phenolics, and sucrose is reported to lower water activity around the pigment, plausibly slowing degradation—so removing sucrose could both remove that protection and, because cooking time was not fixed (Section 2.3), expose some batches to longer effective heating. This aligns in direction with lingonberry work by Scrob et al. (2023), although with an important nuance: their study found stevia among the better sweeteners for preserving anthocyanin, whereas here the sucrose control retained the most. The contrast underscores that sweetener effects on anthocyanin are product- and process-specific rather than universal, and it is consistent with the broader observation of Izza, Lestari & Hidayat (2026) that sugar level itself shapes phenolic retention in a related Semarang-based food system.

The rebound at F4 is the most striking feature of the data: despite the highest stevia dose, F4 held significantly more anthocyanin than F3 (Tukey $p = 0.004$). Because steviol glycoside–anthocyanin interactions were not measured, a molecular complexation mechanism is not invoked here, as it would not be supported by the present evidence. More defensible explanations are prioritised: (i) the uncontrolled 10–20 min cooking window may have produced batch-to-batch differences in effective heat exposure independent of formulation; (ii) natural variation in the anthocyanin content of the raw strawberries across batches; and (iii) the small replicate number ($n = 3$), which limits the precision of each mean. The practical implication is that the stevia–anthocyanin relationship in this system is formulation-dependent rather than strictly dose-dependent, and reproducing the F4 pattern will require tightly controlled cooking time, standardised raw material and larger samples.

4.3 Interpretation of the statistical model

The ANOVA effect size was very large ($\eta^2 = 0.97$), and Tukey contrasts cleanly separated a high-pigment band (F0, F1) from a lower band (F2–F4). Two cautions temper a causal reading. First, formulations differ simultaneously in sucrose-to-stevia ratio and, potentially, in effective heat exposure and raw-material batch, so the significant differences are best read as formulation-level effects rather than proof of a causal effect of stevia isolated from these co-varying factors. Second, the sensory model (Kruskal-Wallis) assumes independent samples, which the within-subject design does not strictly satisfy; a Friedman test would be the design-appropriate alternative and is recommended for reanalysis (Section 4.4).

4.4 Limitations

Several limitations bound the interpretation of these findings and define priorities for future work:

1. Sweetness not equalised. Formulations were matched by ingredient dose, not by equal perceived sweetness; contrasts therefore reflect substitution at specific proportions rather than stevia isolated as an independent factor.
2. Uncontrolled cooking time. Cooking varied within a 10–20 min window, so differences in effective heat exposure may be confounded with formulation effects—particularly relevant to anthocyanin degradation.

3. Operator-dependent endpoint. The cold-plate consistency test is subjective; an instrumental viscosity or gel-strength endpoint would give a reproducible, objective cooking endpoint.
4. Small replicate number. Three replicates per formulation limit statistical power (including that of the normality tests) and the precision of each mean.
5. Coarse hedonic scale. The five-point scale is prone to ceiling and floor effects; a nine-point hedonic scale would improve discrimination among formulations.
6. Design–test mismatch. Within-subject sensory data were analysed with the independent-samples Kruskal-Wallis test; a Friedman test is the design-appropriate choice for reanalysis.
7. Units of measurement. Anthocyanin is expressed as mg L^{-1} of extract, not per unit mass of jam; standardising extraction ratios would allow content to be expressed per gram of product.
8. Unmeasured mechanisms. Proposed colour and texture mechanisms (pigment–sweetener interaction; weakened pectin gel) were not tested instrumentally and remain hypotheses.
9. No sugar-composition assay. A genuine "low-sugar" claim requires direct measurement of the sugar content of the finished jam, which was not performed here.

4.5 Implications

For product development, the data describe a trade-off surface rather than a single optimum. Full stevia substitution at high doses (F3) both alienated panellists and minimised pigment retention, whereas the lowest substitution (F1) preserved most of the anthocyanin and was sensorially closest to the control—at the cost of only modest sugar reduction. Moderate substitution is therefore the most promising target for a reduced-sugar strawberry jam aimed at consumers seeking lower free-sugar intake, provided that acceptance is lifted through combination sweetening or masking and that the sugar reduction is verified analytically. These directions echo the wider functional-food literature on preserving bioactive phenolics while reformulating for lower sugar (Royhanaty et al., 2026; Prayogo et al., 2025).

5. CONCLUSION

Sugar-to-stevia substitution significantly affected both the sensory acceptability and the anthocyanin content of strawberry jam. Acceptability fell across colour, aroma, taste and texture as the stevia dose rose, with the sucrose control (F0) preferred throughout. Anthocyanin content was highest in F0 (66.93 ± 2.22 mg L^{-1}) and lowest in F3 (45.57 ± 0.89 mg L^{-1}; $p < 0.001$), but the dose–response was non-monotonic, rebounding at F4. The effect of substitution was thus formulation-dependent rather than strictly dose-dependent. Stevia remains a viable low-calorie sweetener for strawberry jam, but balancing sensory acceptance against anthocyanin retention requires careful selection of the substitution level; moderate proportions are the most workable target for further development. Confirming a low-sugar positioning will require direct sugar-composition analysis, tighter process control, a design-matched sensory analysis, and larger samples.

DECLARATIONS

Acknowledgements.

The authors thank their research supervisors, Catur Retno Lestari and Chairunisa Nur Rarastiti, for guidance, and the Nutrition Study Program, Faculty of Health Sciences, Universitas Ivet Semarang, together with the Chemistry Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, for providing research facilities.

Ethics approval and informed consent. Conducted under ethical clearance number 004567/Universitas Dian Nuswantoro/2025. All panellists gave informed consent before the sensory evaluation.

Conflict of interest.

The authors declare no conflict of interest.

Funding.

This research received no external funding.

Author contributions.

A.A.N. designed and conducted the experiments, analysed the data, and drafted the manuscript; C.R.L. and C.N.R. supervised the study, contributed to interpretation, and revised the manuscript. All authors approved the final version.

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