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Sensory evaluation and acceptability of quinoa–stevia cookies: Promoting sustainable food choices for nutritional and social development

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ABSTRACT

Background: Quinoa flour and stevia-based sweeteners are increasingly used to reformulate bakery products, yet a reformulated product succeeds only if consumers find it acceptable. Sucrose performs structural and sensory roles in cookies, and its replacement by high-intensity sweeteners can alter taste, texture and appearance.

Objective: To determine how graded partial replacement of sucrose with a stevia-based sweetener affects the sensory acceptability of cookies containing quinoa flour.

Methods: Seven cookie formulations were prepared on a common base of refined wheat flour and quinoa flour (70:30, w/w). Sucrose (40 g in the reference, C₃S₀) was replaced gram-for-gram by a stevia-based sweetener at 5–30% (C₃S₁–C₃S₆). Twenty panelists rated all seven samples for colour, appearance, flavour, taste, texture, crispiness, mouthfeel and overall acceptability on a hedonic scale with a maximum of 9, giving a balanced complete-block design (1,120 observations). Data were analysed with Friedman tests, Kendall's coefficient of concordance (*W*), Holm-adjusted Wilcoxon signed-rank tests and repeated-measures correlation; repeated-measures ANOVA served as a sensitivity check.

Results: All attributes differed among formulations (Friedman χ^2 (6) = 80.75–100.58, $p < 0.001$; $W = 0.67$ –0.84). Liking rose progressively up to 20% sucrose replacement and declined at 25–30%. Formulation C₃S₄ (20% replacement) received the highest mean score for every attribute, with an overall acceptability of 8.65 ± 0.49 , compared with 6.40 ± 0.60 for the full-sugar reference. C₃S₄ exceeded every other formulation in overall acceptability, although its margin over C₃S₃ (15% replacement; 8.35 ± 0.59) was small (Holm-adjusted $p = 0.043$; 14 of 20 panelists gave identical scores). Sensory attributes were strongly inter-related ($r_{\text{tm}} = 0.58$ –0.77), with flavour showing the closest association with overall acceptability ($r_{\text{tm}} = 0.77$).

Conclusion: Under the conditions of this study, replacing 20% of sucrose with the stevia-based sweetener produced the highest sensory acceptance in quinoa-containing cookies, whereas higher replacement levels reduced liking. Nutritional, health, environmental and social outcomes were not measured and require dedicated investigation.

Keywords: Quinoa, Stevia, Steviol glycosides, Sugar reduction, Cookies, Sensory evaluation, Hedonic test, Friedman test

1. Introduction

1.1 Consumer interest in nutritionally oriented bakery products

Public health guidance has moved decisively towards limiting free sugars; the World Health Organization recommends that free sugars supply less than 10% of total energy intake, with further benefit expected below 5% (WHO, 2015) [1]. Sweet bakery products are an obvious target for reformulation because they are eaten frequently and rely on sucrose for more than sweetness. The practical difficulty is that consumers rarely trade enjoyment for nutritional intent: a reformulated product that tastes noticeably different is unlikely to be purchased twice. Reviews of sugar-reduction strategies conclude that large reductions without sensory penalties are hard to achieve, particularly when high-intensity sweeteners introduce bitter side-tastes or altered temporal sweetness profiles (Hutchings *et al.*, 2019) [2]. For this reason, sensory acceptance is not a secondary check in reformulation work but the criterion on which the whole exercise stands or falls.

1.2 Cookies as a vehicle for food product innovation

Cookies combine long shelf life, portion control and wide appeal across age groups, which makes them a convenient carrier for alternative flours and sweeteners. Their low-moisture, sugar- and fat-rich dough develops only a limited gluten network, so the formulation tolerates substantial changes to the flour fraction (Pareyt *et al.*, 2008) [3]. Sucrose, however, is far from inert in this system. It competes with flour components for water, delays dough setting, governs spread and surface cracking, and influences the internal cell

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structure and therefore the crispness of the baked product (Pareyt *et al.*, 2008; Pareyt *et al.*, 2009) [3, 4]. Replacing sucrose with a sweetener used at a small fraction of its mass removes bulk as well as sweetness, which is why sugar replacement in sweetened bakery goods typically requires attention to texture, volume and colour as well as taste (Struck *et al.*, 2014) [5].

1.3 Quinoa as a nutritionally valuable pseudocereal

Quinoa (*Chenopodium quinoa* Willd.) is an Andean pseudocereal whose grain is valued for protein of favourable amino acid balance, including a higher lysine content than common cereals, together with minerals, dietary fibre, unsaturated lipids and phenolic compounds (Vega-Gálvez *et al.*, 2010; Navruz-Varli *et al.*, 2016) [6, 7]. Being gluten-free, it has attracted interest as an ingredient for improving the nutritional profile of bakery and gluten-free products (Alvarez-Jubete *et al.*, 2010) [8]. Its incorporation into bread and cookies has been shown to raise lysine and other essential amino acids in the finished product (Stikic *et al.*, 2012; Watanabe *et al.*, 2014) [9, 10]. Cultivation has also spread well beyond the Andes, including trials and production in India, and the crop's tolerance of marginal conditions has made it a candidate for agricultural diversification (Bhargava *et al.*, 2006; Jacobsen, 2003; Bazile *et al.*, 2016) [11, 12, 13].

Quinoa is not, however, sensorially neutral. Saponins concentrated in the seed pericarp contribute bitterness and astringency, and quinoa-enriched products can suffer reduced acceptance unless the grain is washed, pearled or otherwise processed (Suárez-Estrella *et al.*, 2018) [14]. In cookies, substituting 15% of wheat flour with quinoa flour lowered flavour, taste and overall liking relative to a wheat control, even though the product remained acceptable (Watanabe *et al.*, 2014) [10]. Any strategy that improves the palatability of quinoa-containing cookies is therefore of direct practical relevance.

1.4 Stevia and sugar reduction

Stevia rebaudiana Berton produces steviol glycosides, principally stevioside and rebaudioside A, which are roughly 100–300 times sweeter than sucrose and contribute negligible energy at the concentrations used (Goyal *et al.*, 2010; Carakostas *et al.*, 2008) [15, 16]. Purified rebaudioside A is heat-stable and has been extensively evaluated for use in foods and beverages (Carakostas *et al.*, 2008) [16]. The sensory limitation of steviol glycosides is well documented: they activate the bitter taste receptors hTAS2R4 and hTAS2R14, giving a bitter or liquorice-like aftertaste, and some glycosides show a decline in sweetness at high concentration (Hellfrisch *et al.*, 2012) [17]. Consequently, their performance depends strongly on dose and on the food matrix, and stevia should be regarded as a formulation tool whose acceptability must be demonstrated rather than assumed. In bakery systems, partial rather than complete sucrose replacement has generally been more successful. Rebaudioside A combined with fibres permitted partial sucrose replacement in muffins (Zahn *et al.*, 2013) [18], and in biscuits a 50:50 sucrose–stevioside ratio received higher sensory scores than either full sugar or complete replacement (Vatankhah *et al.*, 2015) [19]. Sugar-reduced short-dough biscuits more broadly show changes in hardness, spread and liking that depend on the replacer used (Rodriguez-Garcia *et al.*, 2022) [20].

1.5 Importance of sensory evaluation

Hedonic testing asks assessors how much they like a product rather than how intense its attributes are, and the nine-point hedonic scale remains the most widely used instrument for this purpose (Peryam *et al.*, 1957; Lawless *et al.*, 2010) [21, 22]. ISO 11136 provides general guidance on conducting hedonic tests with consumers in a controlled area (ISO, 2014) [23]. For cookies, liking of colour and appearance governs first impressions, flavour and taste capture the sweetener's contribution and any off-notes, and texture, crispiness and mouthfeel reflect the structural role of sucrose. Rating these attributes alongside overall acceptability allows the source of any change in liking to be located.

1.6 Research gap

Studies of quinoa cookies have focused chiefly on flour substitution (Watanabe *et al.*, 2014) [10], whereas studies of stevia in baked goods have generally used wheat-based formulations (Zahn *et al.*, 2013; Vatankhah *et al.*, 2015) [18, 19]. Much less is known about how graded sucrose replacement behaves in a cookie that already contains a substantial proportion of quinoa flour, where the sweetener could interact with the grain's own flavour. In addition, hedonic data from such studies are frequently analysed with one-way ANOVA even when every panelist tastes every sample, an approach that ignores the repeated-measures structure of the design. The present work addresses both points.

1.7 Research objective

The objective of this study was to evaluate the effect of replacing 0–30% of sucrose with a stevia-based sweetener on the sensory acceptability of cookies containing 30% quinoa flour in the flour blend, to identify the formulation receiving the highest overall acceptability, and to describe how individual sensory attributes relate to overall liking.

2. Materials and Methods

2.1 Study design

The study formed the sugar-replacement stage of a sequential formulation programme in which the quinoa flour level had been fixed at 30% of the flour blend in an earlier stage. Seven formulations differing only in the sucrose:sweetener ratio were evaluated by the same 20 panelists, each of whom rated all seven samples for eight attributes. The design is therefore a balanced complete block, with panelists as blocks and formulations as the within-panelist factor.

2.2 Raw materials

The formulation comprised refined wheat flour (maida), quinoa flour, sucrose, a stevia-based sweetener, fat, baking powder and baking soda. Because the sweetener replaced sucrose on an equal-weight basis (Table 1), its composition determines the sweetness delivered and must be stated precisely.

2.4 Cookie preparation

The cookies were prepared according to the formulations presented in Table 1. The required ingredients for each formulation were weighed separately and combined using a conventional creaming and mixing procedure. The fat and sweetening ingredients were first mixed to obtain a uniform cream, followed by the gradual incorporation of the remaining dry ingredients. The mixture was blended until a homogeneous dough of suitable consistency was obtained. The prepared dough was subsequently sheeted to a uniform thickness and cut into circular pieces using a cookie cutter of consistent diameter. The shaped dough pieces were arranged on baking trays and baked in a preheated oven at 180 °C for 25 min, as specified in the formulation records. Baking was continued until the cookies developed the desired structural and surface characteristics. Following baking, the cookies were removed from the oven and allowed to cool to room temperature under ambient conditions. After cooling, the samples were packaged appropriately to minimize exposure to environmental moisture and other factors that could influence their sensory characteristics. The packaged cookies were maintained under the specified conditions until sensory evaluation.

2.5 Experimental formulations

The reference formulation (C₃S₀) contained 70 g refined wheat flour, 30 g quinoa flour, 40 g sucrose, 50 g fat, 2 g baking powder and 2 g baking soda. In C₃S₁–C₃S₆, sucrose was reduced in 2 g steps and replaced by the same mass of stevia-based sweetener, corresponding to 5–30% replacement of sucrose by weight (Table 1). All other ingredients were held constant.

C₃S₀ is the full-sugar reference; the 30% quinoa level is common to all samples. Sucrose replaced (%) = sweetener mass ÷ 40 g × 100.

2.6 Sensory evaluation

Sensory evaluation was conducted using 20 panellists (P01–P20), each of whom evaluated all seven cookie formulations. The samples were assessed for colour, flavour, taste, texture, crispiness, mouthfeel, and overall acceptability using a conventional nine-point hedonic scale (1 = dislike extremely; 9 = like extremely) (Peryam *et al.*, 1957) [21]. Samples were presented using random three-digit codes under comparable conditions, and panellists were provided drinking water for palate cleansing between samples. Individual scores were recorded for each attribute and formulation and subsequently used to calculate mean sensory scores and variability for statistical comparison of the developed quinoa–stevia cookies.

2.7 Sensory attributes

Eight attributes were rated: colour, appearance, flavour, taste, texture, crispiness, mouthfeel and overall acceptability. All eight present in the dataset were analysed.

2.8 Statistical analysis

The raw dataset was first audited for completeness, duplicate records, out-of-range values and consistency between the long-format and wide-format worksheets and the pre-computed summary sheets.

Descriptive statistics (mean, standard deviation, median) were calculated for each formulation $\times$ attribute combination ($n = 20$ per cell).

Because every panelist rated every formulation, observations are not independent, and one-way ANOVA was therefore inappropriate. Hedonic scores are ordinal with a restricted range, so the Friedman test, a rank-based analysis for complete block designs, was used as the primary test for each attribute (Friedman, 1937) [24]. Kendall's coefficient of concordance, $W = \chi^2 / [n(k - 1)]$, was reported as the effect size, indicating the degree of agreement among panelists in ranking the formulations (Kendall *et al.*, 1939) [25]. Where the Friedman test was significant, all 21 pairwise comparisons were made with Wilcoxon signed-rank tests (Pratt treatment of zero differences, normal approximation), and p -values were adjusted within each attribute using the Holm procedure [26]. Significance groupings were summarised as compact letter displays, which were checked against the adjusted pairwise results. Matched-pairs rank-biserial correlation (r_{rb}) and the median and mean paired difference were reported as effect sizes for key comparisons.

Table 1. Formulation of the reference and sucrose-replaced quinoa cookies (g per batch).

Sample	Refined wheat flour	Quinoa flour	Sucrose	Stevia-based sweetener	Sucrose re-placed (%)	Fat	Baking powder	Baking soda
C ₃ S ₀	70	30	40	0	0	50	2	2
C ₃ S ₁	70	30	38	2	5	50	2	2
C ₃ S ₂	70	30	36	4	10	50	2	2
C ₃ S ₃	70	30	34	6	15	50	2	2
C ₃ S ₄	70	30	32	8	20	50	2	2
C ₃ S ₅	70	30	30	10	25	50	2	2
C ₃ S ₆	70	30	28	12	30	50	2	2

As a sensitivity analysis, one-way repeated-measures ANOVA with Greenhouse–Geisser correction was also fitted for each attribute. To test whether the response to replacement level was non-monotonic, overall acceptability was modelled with a linear mixed model containing linear and quadratic terms for sweetener level and a random intercept for panelist; linear and quadratic models were compared with a likelihood-ratio test.

Associations between attributes were estimated with repeated-measures correlation (r_{rm}), which removes between-panelist differences in scale use and so avoids treating the 140 non-independent observations as independent (Bakdash *et al.*, 2017) [27]. Principal component analysis was considered but not performed, because the seven formulation means across eight highly inter-correlated attributes provide too few observations for a stable or informative multivariate solution. Analyses were carried out in Python 3 (SciPy, pingouin, statsmodels);

figures were generated with Matplotlib directly from the raw scores. Significance was set at $\alpha = 0.05$.

3. Results

3.1 Data quality and descriptive statistics

The dataset contained 1,120 scores (20 panelists $\times$ 7 formulations $\times$ 8 attributes) with no missing values, duplicate panelist–sample–attribute records or scores outside the scale. Long- and wide-format records agreed completely, and the pre-computed means, standard deviations and Friedman statistics in the workbook matched independent recalculation. Scores ranged from 5 to 9 (5: 9 scores; 6: 157; 7: 445; 8: 368; 9: 141); no formulation received a score below 5, indicating that none was disliked by any panelist. Mean scores per panelist ranged from 6.68 to 8.41, showing some individual differences in scale use that the within-panelist analyses account for. Means and standard deviations are presented in Table 2 and Figure 1.

Table 2. Sensory scores of quinoa cookies with graded sucrose replacement (mean $\pm$ SD, $n = 20$).

Sample	Colour	Appearance	Flavour	Taste	Texture	Crispiness	Mouthfeel	Overall accept.
C ₃ S ₀ (0%)	6.65 $\pm$ 0.88 ^e	6.45 $\pm$ 0.76 ^e	6.35 $\pm$ 0.75 ^d	6.35 $\pm$ 0.59 ^e	6.45 $\pm$ 0.60 ^d	6.50 $\pm$ 0.69 ^f	6.55 $\pm$ 0.60 ^e	6.40 $\pm$ 0.60 ^e
C ₃ S ₁ (5%)	6.90 $\pm$ 0.72 ^{de}	6.95 $\pm$ 0.60 ^{de}	6.80 $\pm$ 0.62 ^c	6.70 $\pm$ 0.66 ^{de}	7.00 $\pm$ 0.65 ^c	6.80 $\pm$ 0.62 ^{ef}	6.85 $\pm$ 0.81 ^{de}	7.10 $\pm$ 0.72 ^d
C ₃ S ₂ (10%)	7.20 $\pm$ 0.77 ^{cd}	7.35 $\pm$ 0.59 ^c	7.35 $\pm$ 0.75 ^b	7.55 $\pm$ 0.51 ^c	7.50 $\pm$ 0.61 ^b	7.10 $\pm$ 0.45 ^{de}	7.45 $\pm$ 0.60 ^c	7.65 $\pm$ 0.75 ^c
C ₃ S ₃ (15%)	7.90 $\pm$ 0.72 ^b	8.05 $\pm$ 0.60 ^{ab}	7.85 $\pm$ 0.67 ^{ab}	8.05 $\pm$ 0.83 ^{ab}	7.85 $\pm$ 0.67 ^b	7.75 $\pm$ 0.64 ^b	8.05 $\pm$ 0.69 ^b	8.35 $\pm$ 0.59 ^b
C ₃ S ₄ (20%)	8.50 $\pm$ 0.51 ^a	8.40 $\pm$ 0.60 ^a	8.10 $\pm$ 0.72 ^a	8.45 $\pm$ 0.60 ^a	8.20 $\pm$ 0.62 ^a	8.30 $\pm$ 0.57 ^a	8.60 $\pm$ 0.60 ^a	8.65 $\pm$ 0.49 ^a
C ₃ S ₅ (25%)	7.90 $\pm$ 0.64 ^b	7.70 $\pm$ 0.80 ^{bc}	7.60 $\pm$ 0.60 ^b	7.80 $\pm$ 0.77 ^{bc}	7.60 $\pm$ 0.75 ^b	7.60 $\pm$ 0.75 ^{bc}	7.95 $\pm$ 0.69 ^b	7.80 $\pm$ 0.52 ^c
C ₃ S ₆ (30%)	7.40 $\pm$ 0.60 ^c	7.35 $\pm$ 0.81 ^{cd}	6.80 $\pm$ 0.62 ^{cd}	7.05 $\pm$ 0.76 ^d	7.00 $\pm$ 0.73 ^c	7.15 $\pm$ 0.59 ^{cd}	7.00 $\pm$ 0.65 ^d	7.05 $\pm$ 0.51 ^d

(continued on next page)

Within each column, means sharing a superscript letter do not differ significantly (Holm-adjusted Wilcoxon signed-rank tests, $p \geq 0.05$). Letters are assigned in descending order of the mean (a = highest). Percentages indicate sucrose replaced.

3.2 Colour and appearance

Colour liking increased from 6.65 in C₃S₀ to 8.50 in C₃S₄ and then declined to 7.40 in C₃S₆ (Friedman $\chi^2(6) = 83.90$, $p < 0.001$, $W = 0.70$). C₃S₄ was rated significantly higher than every other formulation for colour. Appearance followed the same pattern (6.45 to 8.40, then 7.35; $\chi^2(6) = 84.13$, $p < 0.001$, $W = 0.70$), although for appearance C₃S₄ and C₃S₃ did not differ significantly. Visual attributes showed the smallest decline between 20% and 30% replacement (−1.10 for colour, −1.05 for appearance).

3.3 Flavour

Flavour scores rose from 6.35 (C₃S₀) to a maximum of 8.10 (C₃S₄) and fell to 6.80 at 30% replacement ($\chi^2(6) = 85.21$, $p < 0.001$, $W = 0.71$). C₃S₄ did not differ significantly from C₃S₃ (7.85). Notably, flavour liking of C₃S₆ was not significantly different from that of the full-sugar reference, making flavour the only attribute for which the 30% formulation lost its advantage over C₃S₀ entirely.

3.4 Taste

Taste produced a large formulation effect ($\chi^2(6) = 92.78$, $p < 0.001$, $W = 0.77$). Mean scores increased from 6.35 to 8.45 between C₃S₀ and C₃S₄, the largest rise of any attribute apart from overall acceptability

and mouthfeel (+2.10), and then fell to 7.05 at 30% replacement. C₃S₄ and C₃S₃ (8.05) formed the top group; C₃S₆ remained significantly above C₃S₀.

3.5 Texture, crispiness and mouthfeel

The textural attributes responded in the same inverted-U manner. Texture rose from 6.45 to 8.20 ($\chi^2(6) = 80.75$, $W = 0.67$), crispiness from 6.50 to 8.30 ($\chi^2(6) = 84.43$, $W = 0.70$) and mouthfeel from 6.55 to 8.60 ($\chi^2(6) = 95.43$, $W = 0.80$), all $p < 0.001$. For each of the three, C₃S₄ was significantly higher than all other formulations. Mouthfeel showed the steepest fall beyond the peak, from 8.60 at 20% to 7.00 at 30% replacement.

3.6 Overall acceptability

Overall acceptability showed the strongest formulation effect and the highest panel agreement of all attributes ($\chi^2(6) = 100.58$, $p < 0.001$, $W = 0.84$). C₃S₄ received the highest mean overall acceptability (8.65 $\pm$ 0.49; median 9), followed by C₃S₃ (8.35 $\pm$ 0.59), C₃S₅ (7.80 $\pm$ 0.52) and C₃S₂ (7.65 $\pm$ 0.75); C₃S₁ (7.10 $\pm$ 0.72) and C₃S₆ (7.05 $\pm$ 0.51) formed a lower group, and the full-sugar reference C₃S₀ scored lowest (6.40 $\pm$ 0.60) (Figure 2A). Every one of the 20 panelists gave C₃S₄ a higher overall acceptability score than C₃S₀, and C₃S₄ was the highest-rated or joint-highest sample for all 20 panelists. Thirteen panelists (65%) awarded C₃S₄ the maximum score of 9, whereas 13 panelists (65%) scored C₃S₀ at 6 (Figure 2B).

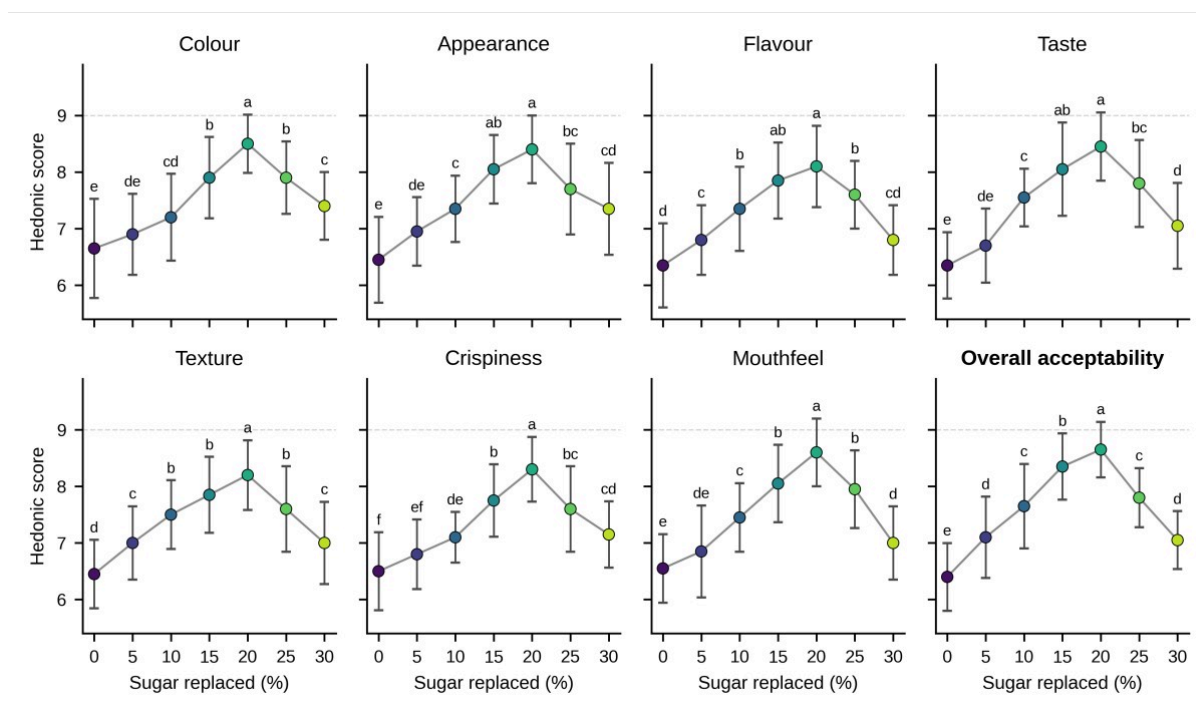


Figure 1. Mean hedonic scores ($\pm$ SD, $n = 20$) for each sensory attribute as a function of the percentage of sucrose replaced by the stevia-based sweetener. Letters above points denote Holm-adjusted Wilcoxon groupings within each attribute; points sharing a letter are not significantly different. The dashed line marks the scale maximum (9).

C₃S₄ was significantly preferred to every other formulation (Table 4). The difference from C₃S₃ must, however, be interpreted with care: the mean paired difference was only 0.30 points, 14 of the 20 panelists gave the two samples identical scores, and the Holm-adjusted p -value (0.043) lay close to the significance threshold. C₃S₃ and C₃S₄ are therefore best regarded as the two most accepted formulations, with C₃S₄ having the highest mean under the conditions of this study.

3.7 Statistical comparisons and robustness

Friedman results for all attributes are summarised in Table 3. Panel agreement was high throughout ($W = 0.67$ – 0.84), meaning that panelists ranked the formulations in broadly the same order. Repeated-measures ANOVA led to identical conclusions for every attribute (all Greenhouse–Geisser-corrected $p < 0.001$; generalised $\eta^2 = 0.42$ – 0.60), confirming that the findings do not depend on the choice between rank-based and parametric analysis.

Table 3. Friedman tests and repeated-measures ANOVA sensitivity analysis for each sensory attribute.

Attribute	Friedman χ^2 (df = 6)	<i>p</i>	Kendall's <i>W</i>	RM-ANOVA <i>F</i> (6, 114)	GG ϵ	<i>p</i> GG	η^2_G
Colour	83.90	0.001	0.699	42.20	0.83	0.001	0.435
Appearance	84.13	0.001	0.701	40.85	0.80	0.001	0.452
Flavour	85.21	0.001	0.710	39.88	0.75	0.001	0.445
Taste	92.78	0.001	0.773	56.39	0.81	0.001	0.525
Texture	80.75	0.001	0.673	34.91	0.75	0.001	0.419
Crispiness	84.43	0.001	0.704	38.78	0.82	0.001	0.467
Mouthfeel	95.43	0.001	0.795	57.20	0.69	0.001	0.527
Overall Acceptability	100.58	0.001	0.838	77.50	0.79	0.001	0.604

W, Kendall's coefficient of concordance (0 = no agreement, 1 = complete agreement); GG ϵ , Greenhouse–Geisser epsilon; η^2_G , gener-

alised eta-squared. The Friedman test is the primary analysis.

Table 4. Paired comparisons of overall acceptability between C₃S₄ (highest mean) and each other formulation.

Comparison	Mean difference	Median difference	Panelists higher / lower / tied for C ₃ S ₄	<i>r</i> _{rb}	Holm-adjusted <i>p</i>
C ₃ S ₄ vs C ₃ S ₀	2.25	2.0	20 / 0 / 0	1.00	0.001
C ₃ S ₄ vs C ₃ S ₁	1.55	1.5	20 / 0 / 0	1.00	0.001
C ₃ S ₄ vs C ₃ S ₂	1.00	1.0	16 / 0 / 4	1.00	0.001
C ₃ S ₄ vs C ₃ S ₃	0.30	0.0	6 / 0 / 14	1.00	0.043
C ₃ S ₄ vs C ₃ S ₅	0.85	1.0	16 / 0 / 4	1.00	0.001
C ₃ S ₄ vs C ₃ S ₆	1.60	2.0	20 / 0 / 0	1.00	0.001

Differences are C₃S₄ minus the comparator. *r*_{rb}, matched-pairs rank-biserial correlation, computed on non-tied pairs; a value of 1.00 indicates that every non-tied panelist favoured C₃S₄. Note the 14 ties in the C₃S₃ comparison.

The mixed model for overall acceptability confirmed significant curvature: adding a quadratic term for sweetener level improved fit sub-

stantially over a linear trend (likelihood-ratio $\chi^2(1) = 139.4$, *p* 0.001; quadratic coefficient negative). Because a symmetric quadratic under-predicted the observed peak at 20% replacement (predicted 8.26 vs observed 8.65), the model was used only to confirm the non-monotonic response and not to estimate an optimum replacement level.

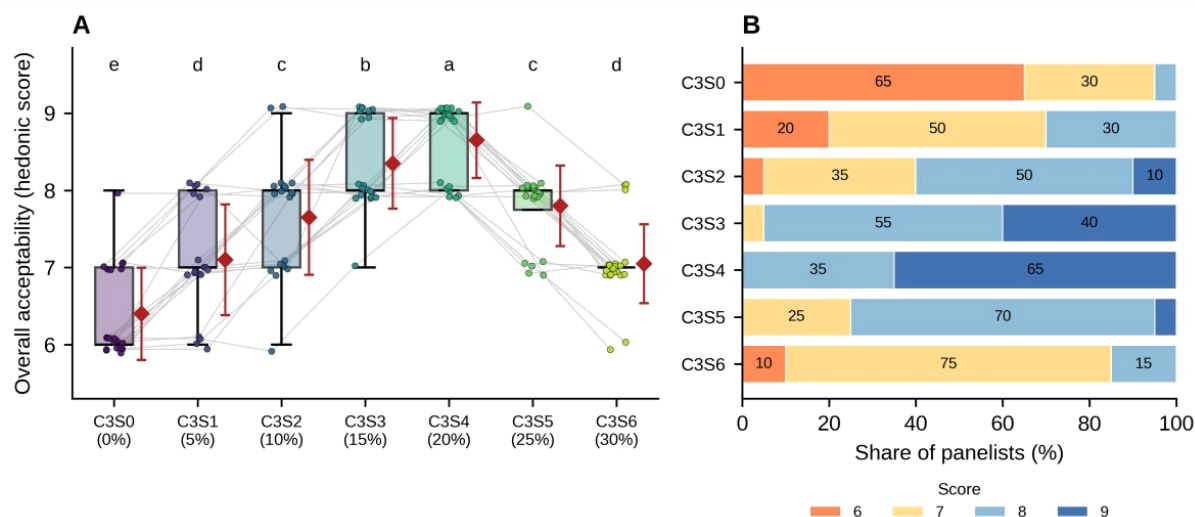


Figure 2. Overall acceptability of the seven formulations. (A) Box plots (median and interquartile range) with individual panelist scores (points, jittered for visibility) and grey lines linking each panelist's ratings; red diamonds show mean $\pm$ SD. Letters denote Holm-adjusted Wilcoxon groupings. Percentages indicate sucrose replaced. (B) Distribution of overall acceptability scores (% of panelists awarding each score); unlabelled segments are 10%.

3.8 Relationships among sensory attributes

All attributes were positively and strongly associated within panelists ($r_{\text{rm}} = 0.58\text{--}0.77$, *df* = 119, all *p* 0.001; Figure 3). Overall acceptability was most closely associated with flavour ($r_{\text{rm}} = 0.77$), mouthfeel (0.75), taste (0.74) and appearance (0.73), and less closely with tex-

ture (0.71), crispiness (0.69) and colour (0.66). The weakest association was between colour and texture (0.58). The narrow spread of coefficients indicates that panelists who liked a sample more tended to rate all of its attributes higher, so the correlations should not be read as evidence that any single attribute causes overall liking.

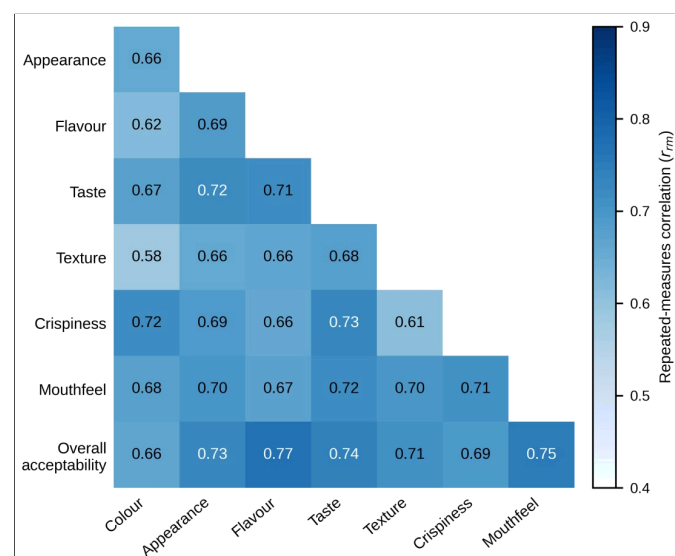


Figure 3. Repeated-measures correlations (r_{rm}) between sensory attributes, estimated within panelists across the seven formulations ($n = 20$ panelists, 140 observations, $df = 119$). All coefficients are significant at $p < 0.001$.

3.9 Multivariate analysis

Principal component analysis and preference mapping were not undertaken. With seven formulations and eight attributes that are strongly collinear (Figure 3), a PCA of mean scores would be dominated by a single overall-liking dimension already evident in Table 2 and Figure 1, and preference mapping requires descriptive or instrumental data that were not collected.

4. Discussion

4.1 Influence of quinoa on sensory characteristics

Because all seven formulations contained 30% quinoa flour, the present data cannot isolate the effect of quinoa on liking. What they do show is the starting point: the full-sugar 30%-quinoa reference was rated between like slightly and like moderately (6.40), a level broadly consistent with earlier reports that quinoa substitution in cookies reduces flavour and taste liking while leaving the product acceptable (Watanabe *et al.*, 2014) [10]. Bitter and astringent saponins are the most commonly cited cause of this penalty (Suárez-Estrella *et al.*, 2018) [14]. That every stevia-containing formulation up to 25% replacement exceeded the reference in all attributes suggests that the sugar-sweetener balance can partly offset the sensory limitations of a quinoa-rich base, although this interpretation remains to be tested directly against a quinoa-free control.

4.2 Influence of stevia on sensory acceptance

The most notable result is that moderate replacement of sucrose increased rather than decreased liking. This departs from the common expectation that sugar reduction carries a sensory cost (Hutchings *et al.*, 2019) [2], and it needs explanation. The data do not identify the mechanism, but several are plausible. First, the stevia-based sweetener was added on an equal-weight basis; because steviol glycosides are far sweeter than sucrose (Goyal *et al.*, 2010; Carakostas *et al.*, 2008) [15, 16], replacement may have increased perceived sweetness or improved the sweetness-bitterness balance of the quinoa base, depending on the sweetener's exact composition. Second, reducing sucrose alters dough setting, spread and cell structure (Pareyt *et al.*, 2008; Pareyt *et al.*, 2009) [3, 4], and moderate changes of this kind could have produced a texture or appearance that panelists preferred. Third, the strong inter-attribute correlations point to a general liking effect, in which a sample favoured for its taste is also rated more favourably for colour and texture (Lawless *et al.*, 2010) [22].

The decline beyond 20% replacement is consistent with known properties of steviol glycosides. As concentration rises, their bitter and

liquorice-like notes, mediated by hTAS2R4 and hTAS2R14, become more prominent, and sweetness may plateau or decline (Hellfrisch *et al.*, 2012) [17]. In this study the sharpest losses beyond the peak were in mouthfeel, overall acceptability, taste and flavour, while colour and appearance changed least, a pattern that fits an oral rather than a visual cause. Loss of sucrose bulk at higher replacement may also have contributed to the textural decline (Struck *et al.*, 2014) [5]. Instrumental texture, colour and sweetness-intensity measurements would be needed to separate these explanations.

4.3 Relationship between sensory attributes and overall acceptability

Flavour, mouthfeel and taste were the attributes most closely associated with overall acceptability, suggesting that oral perception carried more weight in liking than visual attributes did. The associations are correlational and, given how uniformly high they were, partly reflect panelists' general liking of each sample. They identify where formulation effort is most likely to pay off, namely controlling flavour and aftertaste at higher replacement levels, but they do not establish causal drivers.

4.4 Comparison with previous research

The inverted-U response agrees with work on stevioside in biscuits, where an intermediate 50:50 sucrose-stevioside ratio outperformed both full sugar and complete replacement (Vatankhah *et al.*, 2015) [19], and with reports that rebaudioside A performs best as a partial replacer in baked goods (Zahn *et al.*, 2013) [18]. It agrees partially with reviews concluding that large sugar reductions are difficult to achieve without sensory penalties (Hutchings *et al.*, 2019; Struck *et al.*, 2014) [2, 5]: the penalty appeared here only above 20%, and the replacement range tested was modest compared with complete-replacement studies. The finding that partial replacement actually raised liking above the full-sugar reference differs from much of the literature, in which the best-case outcome is usually parity with the control (Rodríguez-García *et al.*, 2022) [20]. Possible reasons include the quinoa-rich base, the equal-weight addition of a high-potency sweetener, and panel characteristics that are not yet documented (Section 5). The present results for quinoa cookies also differ from those of (Watanabe *et al.*) [10] in scale and design, as that study varied quinoa rather than sweetener and used a seven-point bipolar scale, so direct numerical comparison is not appropriate.

4.5 Product development implications

For product development, the data support replacing about 15–20% of sucrose with the stevia-based sweetener in this quinoa cookie base, with C₃S₄ (20%) giving the highest mean acceptance and C₃S₃ (15%) performing almost as well. Replacement of 25% or more reduced liking across all attributes and should not be adopted without reformulation, for example by adding bulking agents or flavour-masking strategies (Hutchings *et al.*, 2019; Struck *et al.*, 2014) [2, 5]. Because liking was consistently high and panel agreement strong, C₃S₄ is a reasonable base for the next stage of formulation work; its sugar content should nonetheless be verified analytically before any reduced-sugar claim is made.

4.6 Sustainability and social development perspective

This study measured sensory liking only. It did not measure nutritional composition, health outcomes, environmental impact, cost, or consumer behaviour, and its results cannot establish benefits in any of these areas. Externally, quinoa has been promoted as a crop for agricultural diversification, and its cultivation has expanded into many new regions, including India (Bhargava *et al.*, 2006; Bazile *et al.*, 2016) [11, 13], lowering free-sugar intake is also a recognised public-health goal (WHO, 2015) [1]. Acceptable reduced-sugar quinoa products are a necessary precondition for such benefits, because foods that are not eaten deliver nothing. Whether the formulations tested here contribute to sustainable food choices or to nutritional and social development is a question for future life-cycle, nutritional and consumer studies, not a finding of the present work.

5. Limitations

The study has several limitations that should be considered when interpreting the findings. The sensory panel was relatively small ($n = 20$), which may limit the generalisability of the results to broader consumer populations. The quinoa incorporation level was fixed at 30%, preventing assessment of the independent effect of different quinoa levels on sensory acceptance. In addition, the study focused exclusively on hedonic sensory responses and did not include descriptive sensory profiling or instrumental measurements of texture, colour, or sweetness intensity; therefore, explanations regarding the sensory mechanisms underlying the observed preferences should be interpreted cautiously. Nutritional composition, sugar reduction, shelf life, purchase intention, and environmental impacts were also outside the scope of the present investigation. Future studies should therefore employ larger and more diverse consumer panels and integrate sensory, instrumental, nutritional, and consumer-behavioural measurements to provide a more comprehensive evaluation of quinoa–stevia cookies.

6. Conclusion

Graded replacement of sucrose with a stevia-based sweetener had a strong and consistent effect on the sensory acceptability of cookies containing 30% quinoa flour. Liking of all eight attributes increased up to 20% replacement and declined at 25–30%, with high agreement among panelists. The 20% formulation (C₃S₄) received the highest mean score for every attribute and the highest overall acceptability (8.65 ± 0.49), significantly exceeding all other formulations, although its advantage over the 15% formulation was small. Flavour, mouth-feel and taste were the attributes most closely associated with overall liking. Under the conditions of this study, partial sucrose replacement in the range of 15–20% is therefore the most promising option for further development of this quinoa cookie. Nutritional, health, environmental and social benefits were not measured and should not be inferred from these results.

7. Future research

Future work should (i) repeat the hedonic test with a larger, demographically described consumer panel under randomised, blind presentation; (ii) add sweetness and bitterness intensity or just-about-right scales to locate the source of the decline above 20% replacement; (iii) measure instrumental texture, colour and spread to test the structural explanations proposed here; (iv) determine the sugar, energy and nutrient content of C₃S₃ and C₃S₄; (v) assess shelf stability; and (vi) evaluate purchase intention, cost and, where claims are intended, environmental footprint by life-cycle assessment.

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