Alvarez *et al.*
*Food Production, Processing and Nutrition* (2025) 7:72
https://doi.org/10.1186/s43014-025-00323-2

Food Production, Processing and Nutrition

RESEARCH Open Access

# Sugar reduction and replacement of wheat flour with quinoa flour in shortcrust cookies: effects on nutritional, physical, and sensory properties

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## Abstract

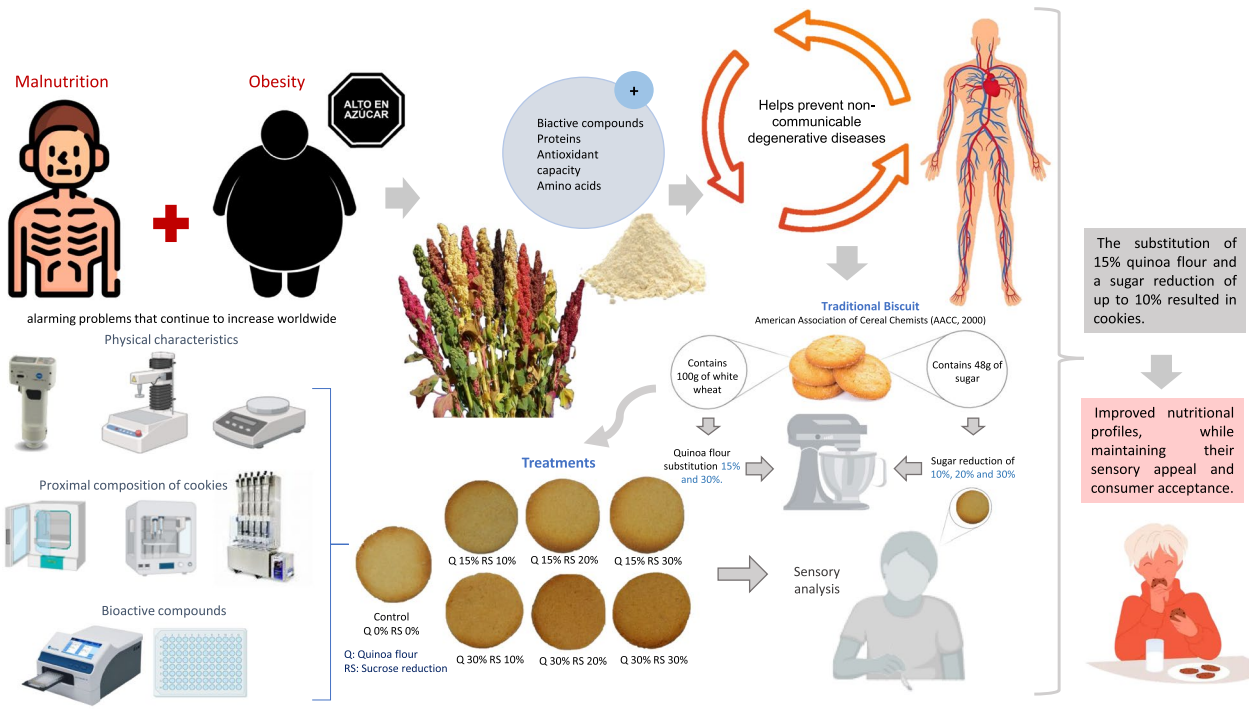
Malnutrition and obesity are global concerns. To overcome these issues, food reformulation was recommended as a cost-effective strategy. In this context, the objective of this study was to evaluate the impact of replacing wheat flour with quinoa flour (15% and 30%) and reducing sugar content (10%, 20%, 30%) on the physical, nutritional, and sensory properties of shortcrust pastry cookies. No significant differences were found in fat, protein, and ash contents, though slight variations occurred between formulations. Significant water and moisture activity differences were noted, except for formulation T15Q.30S. The highest polyphenol content (0.238 mg GAE) was achieved with a 10% sugar reduction and a 30% substitution of wheat flour with quinoa. The greatest antioxidant capacity was observed with a 20% sugar reduction and a 15% replacement of wheat flour with quinoa flour, based on DPPH and ORAC methods. From a physical perspective, higher levels of quinoa flour reduced the hardness, diameter, and dispersion factor of the cookies, while a slight decrease in baking weight loss and thickness was observed. Replacing with 15% quinoa flour and reducing 10% sugar resulted in cookies with the highest acceptance. On the other hand, cookies containing 30% quinoa and higher sugar reductions were less accepted due to their darker color, reduced sweetness, and increased brittleness. The findings of this study emphasize the potential of this reformulation strategy, as the sensory and instrumental quality was maintained, supporting its use in promoting healthier food choices in academia, industry, and among policymakers.

**Keywords** Reformulated cookies, Quinoa substitution, Sugar reduction, Sensory quality

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**Graphical Abstract**




## Introduction

In recent decades, non-communicable diseases (NCDs) such as overweight and obesity have been increasing at an alarming rate, contributing to 2.8 million deaths each year. Childhood obesity rates are also rising dramatically, with over 340 million children and adolescents worldwide classified as obese or overweight—conditions strongly linked to an increased risk of type II diabetes, cardiovascular disease, and other NCDs (World Health Organization, 2024). One of the main dietary factors contributing to obesity is the excessive consumption of added sugar, which is prevalent in processed foods, including cookies. The global per capita consumption of cookies is approximately 5.6 kg annually, with sugar content ranging from 20 to 75%. In response, health organizations around the world recommend reducing total energy intake from free sugars to less than 10% (WHO, 2016).

To address this issue, research has focused on strategies to reduce sugar in various food products such as dairy products and nectars (Lima et al., 2019; Velázquez et al., 2021), but there is still limited work on baked goods, particularly cookies. For example, Kawakami et al. (2025) evaluated the effect of sucrose reduction on the sensory properties of shortcrust cookies, finding that a 25% reduction was acceptable, whereas a 50% reduction resulted in rejection. Other studies have tested different sugar reduction levels in cookies, with varying impacts on consumer acceptance (Erdem et al., 2023; Lingiardi et al., 2023). Sugar not only provides sweetness but also contributes to the moisture retention, stability, viscosity, and solubility of minor ingredients (Voong & Westpha, 2023), as well as influencing water activity and delaying processes such as gluten denaturation and starch gelatinization during baking and the product's shelf life (Luo et al., 2019; Struck et al., 2014; van der Sman & Renzetti, 2019).

As consumer preferences shift towards foods with improved nutritional profiles, researchers are exploring non-conventional raw materials contributing to consumers'health and sustainability. The Food and Agriculture Organization of the United Nations (FAO, 2023) has emphasized the importance of increasing the nutritional quality of foods to combat undernutrition and obesity. One approach is to incorporate functional ingredients that enhance a product's nutritional value while maintaining its sensory appeal (Eduardo et al., 2024). Healthy food reformulations aim to balance reduced salt, sugar, and fat levels while preserving the original sensory experience, a key factor influencing consumer choices (Saldaña et al., 2024).

Quinoa (*Chenopodium quinoa Wild*) is an ancient Andean grain that has gained global recognition for its exceptional nutritional properties. It contains all the essential amino acids and, compared to wheat flour, quinoa provides a more balanced amino acid profile, with notably higher levels of lysine, methionine, and threonine, which are typically limited in cereals (Nguyen et al., 2023; Repo-Carrasco, 2011). Also, it contains bioactive compounds (Pereira et al., 2020), polyunsaturated fats, proteins, minerals, and dietary fiber (Chen et al., 2023). Due to this unique composition, quinoa is considered nutritionally superior to traditional cereals and has been linked to preventing NCDs such as obesity, diabetes, and some types of cancer (Navruz-Varli & Sanlier, 2016). Despite their nutritional benefits, quinoa-based products have not been used in consumers'daily diets, especially in urban environments, due to limited product variety such as cookies, breads, noodles and burgers (Eduardo et al., 2024), as well as its low sensory quality due to color, appearance, taste and mouthfeel (Chopra et al., 2018; Demir & Kilinç, 2017).

Previous studies have explored quinoa flour substitution in cookies, mainly from a nutritional and sensory characterization perspective. Watanabe et al. (2014) found that increasing quinoa flour content (7.5%–15%) enhanced the antioxidant capacity and amino acid profile but reduced sensory acceptance. Similarly, Goyat et al. (2018) observed that quinoa flour substitutions of 5%–15% improved polyphenol and antioxidant content but also increased cookie hardness, due to the absence of gluten, which normally provides elasticity and gas retention, with the 15% substitution receiving the highest acceptance score. Jan et al. (2018a, 2018b) evaluated wheat flour replacement with Indian quinoa flour at levels ranging from 10 to 50%, reporting that cookies with 30% quinoa flour achieved the highest sensory acceptance while improving their nutritional profile. The present study offers a novel contribution to developing quinoa-based products by integrating expert descriptive analysis with consumer sensory evaluation and hedonic assessment using acceptance and the check-all-that-apply (CATA) questionnaire, respectively. While previous research has primarily focused on nutritional composition or sensory profile with trained assessors, our approach provides a comprehensive sensory profile from experts and consumer perspectives. This dual approach enhances our understanding of sugar-reduced quinoa cookies' sensory drivers of liking, providing valuable insights for future innovations in quinoa-based food products.

In this context, the aim of this study was to assess the impact of replacing wheat flour with quinoa flour (15% and 30%) and reducing sugar content (10%, 20%, 30%) on the physical, nutritional, and sensory properties of shortcrust cookies. By reducing the sugar content and replacing wheat flour with quinoa flour in cookies, the study seeks to align with global recommendations to limit added sugars and promote healthier dietary patterns in consumers.

## Materials and methods

### Raw materials

Blanca de Juli quinoa flour was sourced from RENACER S.A.C. The production process involved several steps: classification, desaponification, drying, and texturization. To achieve a uniform particle size, the flour was sifted using a 60-mesh sieve, following the British Standard Sieve system, resulting in a fine, beige-colored flour. The flour was packaged in a polyethylene bag and then stored in a refrigerated, light-proof environment until use.

The other ingredients used in this study were purchased from a supermarket in Piracicaba, Brazil. These included wheat flour (Primor, Brazil), milk powder (Piracanjuba, Brazil), vegetable shortening (Coamo, Brazil), white sugar (Alto Alegre, Brazil), baking powder (Royal, Brazil), and salt (Sal Lebre, Brazil). The wheat flour had a protein content of 9%, a gluten content of 10%, and a gluten index of 40.

### Manufacture of cookies

The manufacturing process of the cookies was slightly modified from that of the 10-50D American Association of Cereal Chemists (AACC, 2000), using a randomized block design (RBD) with a factorial arrangement (*sucrose reduction X quinoa flour*), including an additional treatment. Seven formulations were prepared according to Table 1, reducing the sucrose content (10%, 20%, 30%) and substituting industrial wheat flour with quinoa flour (15% and 30%) alongside a control treatment with no modifications.

The process began by mixing wheat and quinoa flour according to the formulation. First, the sugar and vegetable shortening were blended, followed by adding the flour and other ingredients (Table 1). Subsequently, the dough was kneaded and manually rolled out with a dough sheeter until a uniform thickness of 0.5 cm was achieved, after which it was cut into circular shapes with a diameter of 5 cm. The cookies were baked in a preheated oven (Vipão, Model: 157BRF126A, Brazil) at 180 °C for 12 min. After baking, the cookies were left to cool at 25 °C. Finally, they were packaged in sealed polyethylene bags for further analysis. Ten cookies from each treatment were ground in triplicate for each block using a porcelain mortar for the proximate composition and extraction of antioxidant compounds. The resulting samples were then sieved through a 60-mesh screen to standardize the

**Table 1** Quinoa cookies formulation

| Ingredients (%) | Control | T15Q.10S | T15Q.20S | T15Q.30S | T30Q.10S | T30Q.20S | T30Q.30S |
|---|---|---|---|---|---|---|---|
| **White durum wheat flour** | **40.4** | **34.4** | **34.4** | **34.4** | **28.3** | **28.3** | **28.3** |
| **Quinoa flour** | **0.0** | **6.1** | **6.1** | **6.1** | **12.1** | **12.1** | **12.1** |
| Baking powder | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Salt | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Powdered milk | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 |
| Vegetable shortening | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 |
| **Sugar** | **19.4** | **17.5** | **15.5** | **13.6** | **17.5** | **15.5** | **13.6** |
| Water | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| Total | 100 | 98.1 | 96.1 | 94.2 | 98.1 | 96.1 | 94.2 |

Ingredients in bold were the factors modified according to a factorial scheme. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

particle size. For the physical analyses, cookies were used without any preparation.

### Proximal composition of quinoa flour and cookies

The proximate composition of quinoa flour and cookies was determined using standard methods from the Association of Official Analytical Chemists (AOAC, 2000) and the American Association of Cereal Chemists (AACC, 1999). Moisture content was analyzed using the oven-drying method at 105 °C until a constant weight was reached. Crude fat was quantified by the Soxhlet method, protein content was determined using the Kjeldahl method, applying a nitrogen conversion factor of 5.36, and ash content was measured by muffle furnace ashing at 550 °C. Additionally, water activity was measured using a water activity meter (AQUALAB 4TE, Decagon Devices Inc., USA) at 25 °C. All analyses were performed in triplicate to ensure accuracy and reproducibility.

### Instrumental color

Color measurements of the cookies were conducted according to the procedure specified by Duta et al. (2015). The color was measured using a Hunter colorimeter (MiniScan EZ, model: 4500 L, HunterLab Inc., Reston, VA, USA), set with D65 illumination and an observation angle of 10°. Before use, the colorimeter was calibrated with black and white squares. The colorimeter was positioned directly on the top surface of each cookie for evaluation, using four cookies per replicate. The average values for L* (0 = black, 100 = white), a* (-a = green, + a = red), and b* (-b = blue, + b = yellow) were recorded. The chroma ($C^* = (a^{*2} + b^{*2})^{0.5}$) and hue ($h = \arctan(b^*/a^*)$) values were also calculated for a complete color evaluation (Saldaña et al., 2014).

### Cookie dispersion factor

The cookie dispersion factor was measured according to Samakradhamrongthai et al. (2022) recommendations. The cookies'diameter and thickness were measured using a vernier (Mitutoyo, Model: 530–316, Japan) at three locations, and the average of these measurements was then calculated. Subsequently, the extension factor was calculated by dividing the diameter of the cookies by their height (Ahmad et al., 2022).

### Physical characteristics of the cookies

The physical characteristics of the cookies, including weight and baking loss, were determined using Yang et al. (2022) recommendations, with some adaptations. The weight of the cookies was calculated as the average of three individual cookies. Baking losses were assessed by weighing the cookies before and after baking.

#### *Hardness and fracturability of the cookies*

The hardness of the cookies was measured as a function of breaking strength using a Texturometer (TA-XT Plus, Stable Micro System, Surrey, UK). The cookies were placed under a 70 mm cutting gauge with a thickness of 0.4 mm. Measurements were carried out at 25 °C, with the following parameters set on the texture analysis instrument: a pre-test speed of 2 mm/s, a distance of 3 mm, a test speed of 2 mm/s, a post-test speed of 2 mm/s, a load cell pitch of 3 mm, and a force of 5 kg. Ten replicates per treatment were conducted, following the method described by Samakradhamrongthai et al. (2022).

### Functional and bioactive properties

#### *Extraction of antioxidant compounds*

The extraction of antioxidant compounds from defatted quinoa flour and cookie samples was conducted following the methods by Abderrahim et al. (2011) and Arranz

et al. (2009), with some modifications. A 1 mL mixture of methanol and water (1:1 v/v ratio, adjusted to a pH of 2.0) was added to 0.2 g of the sample. The solution was stirred for 1 h at 400 rpm and 30 °C on a microplate shaker (Labnet, Model: S2020-P2-B, Brazil). Afterward, the solution was vortexed for 10 min at 25°C and centrifuged at 10,000 rpm for 10 min at 4 °C. Finally, the supernatant was separated, yielding the phenolic extract, which was stored in a dark container at −20 °C until further use.

#### *Quantification of polyphenols*

The total phenolic content of the quinoa flour and cookie samples was quantified using the Folin-Ciocalteu method, as described by Magalhães et al. (2010). For the analysis, 70 µL of the samples and 70 µL of Folin-Ciocalteu reagent (diluted 1:5 v/v) were pipetted into a microplate, followed by incubation at room temperature for 2 min. The reaction was neutralized by adding 140 µL of 0.3 M NaOH, and the mixture was shaken, allowing it to rest for 15 min. Absorbance was recorded at a wavelength of 760 nm using a plate reader (Synergy/HTX, Biotek Instruments Inc, Winooski, VT, USA). A calibration curve based on gallic acid (0 to 50 mg/L) was employed for quantification. The analyses were conducted in triplicate, and the results were expressed as mg GAE/g of sample.

#### *Antioxidant capacity by DPPH approach*

The antioxidant capacity of the quinoa flour and cookie samples was evaluated using the methodology proposed by Abderrahim et al. (2013). A 10 mL aliquot of the extract was mixed with 200 µL of 2,2-diphenyl-1-picrylhydrazyl- (DPPH) solution (60 µmol/L in 10 mmol/L Tris Buffer, pH 7.5, 1:1 v/v (MT buffer)). The solution was then incubated at 24 °C in darkness for 30 min. DPPH reduction was measured at 517 nm using a microplate reader (Synergy/HTX, Biotek Instruments Inc, Winooski, VT, USA). Based on these absorbances (Abs), the percentage inhibition (%I) was calculated. Subsequently, the linear relationship involving the percentage of inhibition (%I), with coefficients a and b, was considered. Finally, the mean 50% inhibitory concentration (IC50), expressed in mg/mL, representing the effective concentration of extract required to inhibit 50% of the DPPH radical activity, was calculated using the equation of the line found for each extract.

#### *Antioxidant capacity by ORAC approach*

The Oxygen Radical Absorbance Capacity (ORAC) analysis of the extracts was conducted using a microplate reader (Synergy/HTX, Biotek Instruments Inc., Winooski, VT, USA) according to the method described by Dávalos et al. (2003), with some modifications. For that, 2,2'-azo-bis (2-amidino-propane) dihydrochloride (AAPH) was used as the peroxyl radical generator, with Trolox as the standard and fluorescein as the fluorescent probe, all diluted in phosphate-buffered saline (PBS) at 75 mM (pH 7.4). An aliquot of 20 µL of the antioxidant solution was added to the wells of the microplate, and the automatic injector of the kit dispensed 150 µL of fluorescein (100 mM) into each well. The mixture was preincubated for 10 min at 37 °C. Then, 30 µL of AAPH solution (12 mM) was added. Fluorescence was recorded immediately, measuring at 485 nm (excitation) and 520 nm (emission) every minute for 60 min. ORAC values were calculated as the area under the curve and expressed in µmol Trolox equivalents/g.

### Sensory characteristics of cookies

Before the start of the study, ethical approval was obtained from the Universidad Nacional de Moquegua (Letter N° 001–2024-PCEIC/UNAM). All participants provided informed consent before taking part in the sensory evaluation. The sensory properties of the cookies were analyzed using descriptive analysis (DA) performed by a panel of expert judges and CATA questionnaire, coupled with the acceptance test with regular cookie consumers. All sensory procedures were conducted in individual sensory booths designed according to ISO standards (ISO8589, 2007) with white light and positive pressure ventilation. Data collection was conducted entirely using the *Compusense Cloud* software on Android tablets. In both sensory procedures, the samples (8 g of cookies) were served in disposable plates coded with 3-digit random numbers in a sequential monadic manner, following a Williams Latin square design (Williams, 1949). Water was also provided to clean the palate between samples.

#### *Descriptive analysis with experts*

The DA was performed following the recommendations of Lawless et al. (2010). A panel of 20 trained experts (8 men, 12 women; aged 18–35) with experience in sensory evaluation (Saldaña et al., 2015), assessed the cookie samples using a word association task to generate a list of sensory attributes. Panelists described each sample in their own words. The frequency of each attribute was recorded, and the most frequently mentioned were selected. These attributes were used in subsequent training and formal analysis.

The training for sensory descriptions of sweet cookie intensities followed a structured process to ensure accurate and reproducible results, according to guidelines in ISO 8586:2012. The previously defined descriptors were discussed in group sessions to reach a consensus definition of attributes, with the panel leader introducing

mental references like specific ingredients or food products to clarify the meaning and anchors of the sensory attributes. The panelists then created a scoring sheet using a 10 cm unstructured line scale anchored with terms such as"weak"and"strong". The evaluation sequence started with the repeated evaluation of visual attributes, followed by aroma, taste, flavor-by-mouth, and mouthfeel. The training sessions concluded with experts demonstrating the ability to discriminate samples, maintain repeatability in their evaluations, and agree with other panel members'assessments (Saldaña et al., 2018). Then, the panel (20 experts) formally evaluated cookies. Each expert analyzed all samples in duplicate, assessing sensory attributes during two separate sessions using a 10 cm unstructured line scale to express the intensity of attributes, with the same anchor terms established during the training phase.

#### *Acceptance and consumer's sensory profile*

One hundred consumers participated in the study, comprising 50 men and 50 women, according to the recommendations of ISO 11136 (2016). All of them were over 18 years old and consumed cookies frequently. The participants were recruited around the Department of Food Science and Technology (LCA) at the Escola Superior de Agricultura"Luiz de Queiroz"(ESALQ), Universidade de São Paulo (USP). The study assessed the acceptance of cookie samples using a nine-point hedonic scale varying from "dislike extremely" to "like extremely" (Peryam & Pilgrim, 1957). Then, participants described the samples sensorially by employing the CATA questionnaire, which allowed them to select attributes that best characterized the cookie samples (Rios-Mera et al., 2021; Saldaña et al., 2018).

### Data analysis

The instrumental results were analyzed using analysis of variance (ANOVA), considering the following statistical model: $Y_{ijkl}=\mu+B_i+Q_j+S_k+Q\times S_{jk}+T_l+\varepsilon_{ijkl}$, where $Y_{ijkl}$ is the response variable analyzed, $\mu$ is the overall mean, $B_i$ is the effect of the processing block, $Q_j$ is the effect of quinoa substitution level, $S_k$ is the effect of sugar reduction level, $Q\times S_{jk}$ is the interaction between quinoa and sugar factors, $T_l$ is the effect of the additional treatment (control), and finally $\varepsilon_{ijkl}$ is the experimental error. Residual normality (Shapiro–Wilk test) and variance homogeneity (Breusch-Pagan test) were verified before conducting ANOVA. Significant factors of the ANOVA model ($Q_j$, $S_k$, $Q\times S_{jk,}$ *and* $T_l$) were further analyzed using Tukey's test for pairwise comparisons at a 5% significance level.

ANOVA was applied to the sensory descriptive results, considering the experts and presentation order as random factors, while sucrose reduction and quinoa flour incorporation as fixed factors. Significant differences between treatments were evaluated using Tukey's test at 5% significance. Subsequently, Principal Component Analysis (PCA) was used to explore the multivariate representation of samples based on sensory attributes, allowing the identification of patterns in the panel responses. Consumer acceptance was analyzed using ANOVA, considering treatments (fixed), presentation order (random), and consumers (random) as factors. Tukey's test was applied to compare the acceptance among treatments. CATA data were analyzed at the univariate level using Cochran's Q test to identify significant differences in the frequency of sensory terms among different samples. At the multivariate level, Correspondence Analysis (CA) was conducted using the frequency of sensory terms and Chi-square distances to explore the relationships between consumer responses, identifying sensory perception patterns across the samples. Data analysis was performed in XLSTAT and R software.

## Results and discussion

Quinoa flour exhibits an exceptional nutritional and bioactive content, with a fat content of 4.23%, moisture of 5.74%, ash of 2.45%, and 11.97% crude protein. This last value coincides with that indicated by Repo-Carrasco-Valencia et al., (2010), who point out that the protein content of quinoa flour can vary between 11.0% and 15.0%. The water activity (Aw) was 0.49, indicating a low availability of free water in the product. Regarding its antioxidant capacity, the flour contains 0.231 mg GAE/g of polyphenols. Furthermore, its antioxidant capacity evaluated by the DPPH method is 105.320 mg/mL, while the ORAC method reports a value of 31.98 µmol ET/g. This suggests that, although quinoa flour is effective as an antioxidant, its effectiveness may vary depending on the type of radical considered in the analysis. The combination of both methods provides a comprehensive evaluation, with DPPH under controlled conditions and ORAC being more representative of real biological conditions (Piñuel et al., 2019).

### Proximal composition of cookies

Table 2 shows the results of the proximate composition of cookies formulated with different levels of sugar reduction (10%, 20%, and 30%) and the substitution of wheat flour with quinoa flour at proportions of 15% and 30%.

Although no significant differences were observed in the fat content of cookies with quinoa flour and reduced sugar, slight numerical variations were noted. Other studies (Chopra et al., 2018; Mousa, 2022; Pourshahidi et al., 2020) suggest that substituting wheat flour with quinoa flour can increase fat content due to its oil absorption

**Table 2** Proximate composition of cookies manufactured by varying the substitution of wheat flour with quinoa flour, and sugar reduction

| Variables | Levels | 10% sugar reduction | 20% sugar reduction | 30% sugar reduction | Average | Factorial | Control |
|---|---|---|---|---|---|---|---|
| **Fat (%)** | **Quinoa 15%** | 24.31 ± 1.32 | 24.95 ± 1.75 | 25.90 ± 1.79 | 25.05 ± 1.58 | 25.08 ± 1.38 | 24.96 ± 2.79 |
| | **Quinoa 30%** | 24.23 ± 0.45 | 24.60 ± 0.61 | 26.51 ± 1.07 | 25.12 ± 1.25 | | |
| | **Average** | 24.27 ± 0.88 | 24.77 ± 1.19 | 26.20 ± 1.36 | | | |
| **Moisture (%)** | **Quinoa 15%** | 4.04 ± 0.13 | 4.10 ± 0.37 | 3.73 ± 0.40 | 3.96 ± 0.37 | **4.13 ± 0.45$^{a}$** | **3.46 ± 0.13$^{b}$** |
| | **Quinoa 30%** | 4.15 ± 0.34 | 4.14 ± 0.48 | 4.59 ± 0.52 | 4.29 ± 0.47 | | |
| | **Average** | 4.09 ± 0.39 | 4.12 ± 0.42 | 4.16 ± 0.03 | | | |
| **Ash (%)** | **Quinoa 15%** | 8.45 ± 0.37 | 7.14 ± 0.81 | 5.70 ± 0.46 | 7.10 ± 1.29 | 7.19 ± 1.11 | 7.01 ± 0.71 |
| | **Quinoa 30%** | 8.16 ± 1.12 | 6.80 ± 0.50 | 6.87 ± 0.65 | 7.28 ± 0.96 | | |
| | **Average** | 8.30 ± 0.76$^{a}$ | 6.97 ± 0.63$^{b}$ | 6.29 ± 0.81$^{b}$ | | | |
| **Aw** | **Quinoa 15%** | 0.31 ± 0.03 | 0.33 ± 0.04 | 0.29 ± 0.02 | 0.31 ± 0.03$^{b}$ | **0.33 ± 0.04$^{a}$** | **0.28 ± 0.03$^{b}$** |
| | **Quinoa 30%** | 0.34 ± 0.04 | 0.34 ± 0.02 | 0.37 ± 0.03 | 0.35 ± 0.03$^{a}$ | | |
| | **Average** | 0.33 ± 0.04 | 0.34 ± 0.03 | 0.33 ± 0.05 | | | |
| **Proteins** | **Quinoa 15%** | 8.25 ± 0.23 | 8.30 ± 0.08 | 8.50 ± 0.24 | 8.35 ± 0.21 | 8.26 ± 0.24 | 8.28 ± 0.38 |
| | **Quinoa 30%** | 8.20 ± 0.34 | 8.12 ± 0.22 | 8.20 ± 0.29 | 8.17 ± 0.25 | | |
| | **Average** | 8.23 ± 0.26 | 8.21 ± 0.18 | 8.35 ± 0.29 | | | |

All values are presented as mean ± SD, and those with different superscripts are significantly different ($p < 0.05$). Uppercase letters indicate significant changes in sugar reduction levels, and lowercase letters indicate significant changes in different percentages of quinoa. Bold values with different letters in the same row indicate that the factorial mean differs from the control at a significance level of 5%. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

capacity and essential fatty acids, particularly linoleic and alpha-linolenic acids (Chen et al., 2023). Regarding moisture content and water activity, no significant differences were seen among treatments, although some treatments had a notable increase compared to the control. Sample Q15S30 showed no difference, likely due to reduced sugar content, as sugar helps retain moisture (Milner et al., 2020).

On the other hand, reducing the sugar content in the cookies by 20% and 30% significantly affected their ash content compared to the control sample. According to the findings reported by Panghal et al. (2018). A variation in the sugar content of baked goods can lead to a reduction in ash content. This occurs because sugar acts as a diluent; when its content is decreased, it alters the relative proportions of other mineral ingredients, resulting in lower ash content in cookies. In terms of protein content, no significant differences were observed, which was attributed to the low concentrations of quinoa flour to avoid adverse sensory effects. Jan et al. (2018b) and Demir & Kılınç (2017) recommend using at least 30% quinoa flour in cookie production, as higher proportions may decrease consumer acceptance. Furthermore, Demir & Kılınç (2017) and Chopra et al. (2018) reported significant differences in protein content when substituting higher levels of wheat flour (50%) with quinoa flour. This is likely due to quinoa flour's higher nutritional value than wheat flour, as it contains approximately 1.5 times more protein, 3 times more ash, and 4 times more crude fat (FAO, 2023).

### Textural and technological characteristics

Table 3 presents the physical characteristics of cookies produced with varying levels of sugar reduction and the addition of quinoa flour.

Hardness is regarded as the most important characteristic of cookie quality, as it directly impacts consumer acceptance (Jan et al., 2018a). In this research, the hardness of quinoa cookies ranged from 27.31 to 30.95 N, while wheat cookies presented a higher value (41.07 N) (Table 3). It was observed that the incorporation of quinoa flour decreased the hardness compared to the control, similar to the findings of Brito et al. (2015), Nadian et al. (2021), and Singla et al. (2024). According to Jan et al. (2018a, 2018b), this decrease in hardness could be attributed to the fat encapsulating the flour particles, which isolates them from one another, making them easier to separate. The higher fat content may also have a softening effect that contributes to this reduction. Another reason for the decrease in hardness with increased quinoa levels is the starch morphology and the variations in the amounts of amylose and amylopectin found in quinoa (Nadian et al., 2021). Quinoa starch granules are spherical and polygonal, with submicron sizes and a less smooth surface than wheat ones. Quinoa comprises approximately 12% amylose, with the

**Table 3** Physical characteristics of cookie samples

| Physical properties | Levels | 10% sugar reduction | 20% sugar reduction | 30% sugar reduction | Average | Factorial | Control |
|---|---|---|---|---|---|---|---|
| **Hardness** (*N*) | **Quinoa 15%** | 30.95 ± 2.25 | 30.77 ± 2.24 | 27.89 ± 2.07 | 29.87 ± 2.41$^{a}$ | **28.82 ± 2.24$^{b}$** | **41.07 ± 1.77$^{a}$** |
| | **Quinoa 30%** | 27.31 ± 2.08 | 27.62 ± 2.04 | 28.43 ± 0.478 | 27.78 ± 1.56$^{b}$ | | |
| | **Average** | 29.13 ± 2.78 | 29.19 ± 2.58 | 28.16 ± 1.38 | | | |
| **Fracturability** (*N*) | **Quinoa 15%** | 61.44 ± 2.07 | 68.78 ± 4.57 | 62.93 ± 1.22 | 64.38 ± 4.24$^{a}$ | **60.82 ± 4.84$^{b}$** | **79.61 ± 2.61$^{a}$** |
| | **Quinoa 30%** | 57.08 ± 0.67 | 59.13 ± 1.79 | 55.57 ± 0.297 | 57.26 ± 1.82$^{b}$ | | |
| | **Average** | 59.25 ± 2.75$^{b}$ | 63.95 ± 6.13$^{a}$ | 59.25 ± 4.10$^{b}$ | | | |
| **Cooking weight loss (%)** | **Quinoa 15%** | 17.44 ± 1.75 | 16.34 ± 0.68 | 16.79 ± 2.02 | 16.86 ± 1.46 | 16.82 ± 1.37 | 17.63 ± 0.97 |
| | **Quinoa 30%** | 17.02 ± 0.69 | 16.20 ± 1.55 | 17.14 ± 1.96 | 16.78 ± 1.37 | | |
| | **Average** | 17.23 ± 1.21 | 16.27 ± 1.07 | 16.96 ± 1.79 | | | |
| **Diameter (cm)** | **Quinoa 15%** | 4.62 ± 0.16 | 4.60 ± 0.11 | 4.60 ± 0.12 | 4.60 ± 0.12 | **4.58 ± 0.090$^{b}$** | **4.94 ± 0.47$^{a}$** |
| | **Quinoa 30%** | 4.60 ± 0.08 | 4.56 ± 0.03 | 4.52 ± 0.02 | 4.56 ± 0.05 | | |
| | **Average** | 4.61 ± 0.12 | 4.58 ± 0.07 | 4.56 ± 0.09 | | | |
| **Thickness (mm)** | **Quinoa 15%** | 0.64 ± 0.03 | 0.68 ± 0.03 | 0.64 ± 0.03 | 0.65 ± 0.03 | 0.65 ± 0.03 | 0.67 ± 0.06 |
| | **Quinoa 30%** | 0.60 ± 0.05 | 0.64 ± 0.02 | 0.66 ± 0.003 | 0.63 ± 0.04 | | |
| | **Average** | 0.62 ± 0.04 | 0.66 ± 0.03 | 0.65 ± 0.02 | | | |
| **Weight of cooked cookies (g)** | **Quinoa 15%** | 8.99 ± 0.49 | 9.04 ± 0.83 | 8.90 ± 0.56 | 8.97 ± 0.56 | 8.90 ± 0.51 | 9.10 ± 0.88 |
| | **Quinoa 30%** | 8.58 ± 0.72 | 9.10 ± 0.33 | 8.80 ± 0.17 | 8.82 ± 0.47 | | |
| | **Average** | 8.78 ± 0.59 | 9.07 ± 0.57 | 8.85 ± 0.38 | | | |
| **Dispersion factor (cm)** | **Quinoa 15%** | 7.18 ± 0.41$^{aA}$ | 6.90 ± 0.23 $^{aA}$ | 7.22 ± 0.16 $^{aA}$ | 7.10 ± 0.29 | **7.15 ± 0.39$^{b}$** | **7.27 ± 0.08$^{a}$** |
| | **Quinoa 30%** | 7.64 ± 0.58 $^{aA}$ | 7.15 ± 0.24 $^{aAB}$ | 6.83 ± 0.01 $^{aB}$ | 7.20 ± 0.47 | | |
| | **Average** | 7.41 ± 0.51 | 7.02 ± 0.25 | 7.02 ± 0.24 | | | |

All values are presented as mean ± SD, and those with different superscripts are significantly different ($p < 0.05$). Uppercase letters indicate significant changes in sugar reduction levels, and lowercase letters indicate significant changes in different percentages of quinoa. Bold values with different letters in the same row indicate that the factorial mean differs from the control at a significance level of 5%. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

remaining portion being amylopectin (Jiao et al., 2020). These variations and the amylose-to-amylopectin ratio affect starch's physicochemical and functional properties. This, in turn, influences the characteristics of the final product. A higher proportion of amylose tends to increase hardness, while more amylopectin results in a softer and more gelatinous texture (Valdez-Arana et al., 2020). On the other hand, sugar reduction did not have a significant effect on hardness.

Fracturability is an important textural property in evaluating baked goods, as it closely relates to how we perceive freshness. Ideally, these parameters should be kept as low as possible (Kuchtová et al., 2018). The addition of quinoa flour and a reduction in sugar resulted in a notable decrease in the strength needed to break the cookies, with fracturability values ranging from 55.57 N to 68.78 N. In contrast, cookies made solely with wheat exhibited a firmness of 79.61 N.

No significant differences were observed among the evaluated treatments regarding cooking weight loss, thickness, and cooked cookie weight. However, there was a slight reduction when comparing the factorial treatments to the control. Regarding cookie diameter, no significant differences were found among the factorial treatments, even though this parameter decreased considerably compared to the control. The interaction between incorporating quinoa flour and reducing sugar significantly affected the cookies'dispersion factor, also showing a notable reduction compared to the control sample (Jan et al., 2018a). This may be since quinoa flour does not contain gluten, which causes the dough to tend to be less elastic and less able to retain air, resulting in less expansion in cookies (Machado Alencar et al., 2015; Turkut et al., 2016). Previous studies reported that as the quinoa flour content increases, the thickness of the cookies increases. However, the samples'diameter and expansion index values decreased under these conditions (Yeşil & Levent, 2022). The rate of spread decreases with the addition of quinoa flour, which has a higher water absorption capacity than wheat flour. This is due to the rapid binding of free water molecules at hydrophilic sites, increasing the dough's viscosity and limiting the expansion of the cookies (Chopra et al., 2018). By forming aggregates with hydrophilic sites, this flour competes for available water, reducing the

expansion factor (Yamsaengsung et al., 2012). Furthermore, the higher fiber content in quinoa flour not only affects water retention but also contributes to an increase in the weight of the cookies (Demir & Kilinç, 2017).

### Instrumental color of cookies

Table 4 displays the color of cookies prepared with varying levels of sugar reduction (10%, 20%, and 30%) and the addition of quinoa flour in ratios of 15% and 30%.

The incorporation of quinoa flour and sugar reduction in the cookie dough resulted in noticeable changes in the color characteristics of the cookies (Table 4 and Fig. 1). Specifically, the L* and h* values decreased, while the a*, b*, and c* values increased (Table 4). The control treatment exhibited higher L* values, indicating a lighter color than the other treatments. This difference may be due to the color attributed to quinoa flour, as well as to the lower protein content of wheat flour (8%), in contrast to quinoa flour (11.97%), which has a higher protein content, likely contributing to the browning of the cookies (Brito et al., 2015; Demir & Kilinç, 2017; Hidalgo et al., 2018; Wang et al., 2015). This color variation may also be linked to the formation of Maillard products, which are known to influence darkening (Nadian et al., 2021).

The increase in a* values is likely due to the higher phenolic pigments and amino acid content in quinoa flour (Demir & Kilinç, 2017). Previous studies have shown that the ash content in flour is positively correlated with a* value (Wang et al., 2015). These findings align with earlier research indicating that quinoa flour can alter the color parameters of cookies. For instance, cookie samples containing 50% quinoa flour exhibited the highest a* and b* values, while those without quinoa flour had the highest L*, a*, and b* values (Brito et al., 2015; Demir & Kilinç, 2017; Wang et al., 2015).

### Bioactive compounds

Table 5 presents the bioactive compounds in cookie samples formulated with reduced sugar content and added quinoa flour.

When incorporating 30% quinoa flour, a 10% sugar reduction resulted in the highest polyphenol content of 2.382 mg GAE/g, significantly exceeding the values obtained with sugar reductions at 20% (1.857 mgGAE/g) and 30% (1.694 mg GAE/g). On the other hand, the 15% quinoa flour treatments are very similar to the control cookies, so no significant differences were observed in the polyphenol content between the 10%, 20% and 30% sugar reductions. These results indicate that both quinoa flour incorporation and sugar reduction significantly affect polyphenol content, showing significant differences from the control sample. Previous studies by Demir and Kilinç (2017) and Goyat et al. (2018) have reported that increasing quinoa flour in cookies improves the polyphenolic potential of baked composite cereal products. This

**Table 4** Cookie color with quinoa flour substitution and sugar reduction

| Variables | Levels | 10% sugar reduction | 20% sugar reduction | 30% sugar reduction | Average | Factorial | Control |
|---|---|---|---|---|---|---|---|
| **L*** | **Quinoa 15%** | 62.85 ± 0.66 | 62.23 ± 2.99 | 62.79 ± 1.25 | 62.62 ± 1.68$^{a}$ | 60.32 ± 2.76$^{b}$ | 69.45 ± 0.50$^{a}$ |
| | **Quinoa 30%** | 58.87 ± 0.83 | 57.63 ± 1.66 | 57.58 ± 0.99 | 58.02 ± 1.23$^{b}$ | | |
| | **Average** | 60.86 ± 2.28 | 59.93 ± 3.32 | 60.18 ± 3.02 | | | |
| **a*** | **Quinoa 15%** | 5.93 ± 0.14 | 5.94 ± 0.43 | 6.25 ± 0.42 | 6.04 ± 0.35 $^{b}$ | **7.20 ± 1.27$^{a}$** | **2.48 ± 0.25$^{b}$** |
| | **Quinoa 30%** | 8.24 ± 0.53 | 8.48 ± 0.70 | 8.36 ± 0.47 | 8.36 ± 0.51$^{a}$ | | |
| | **Average** | 7.08 ± 1.31 | 7.21 ± 1.48 | 7.31 ± 1.22 | | | |
| **b*** | **Quinoa 15%** | 32.29 ± 0.40 | 32.38 ± 0.99 | 32.45 ± 0.70 | 32.37 ± 0.64 | 32.65 ± 0.88 | 32.09 ± 0.80 |
| | **Quinoa 30%** | 33.09 ± 0.31 | 33.07 ± 1.83 | 32.61 ± 0.73 | 32.92 ± 1.02 | | |
| | **Average** | 32.69 ± 0.54 | 32.73 ± 1.37 | 32.53 ± 0.64 | | | |
| **c*** | **Quinoa 15%** | 32.82 ± 0.42 | 32.92 ± 1.05 | 33.05 ± 0.75 | 32.93 ± 0.68$^{b}$ | **33.45 ± 1.02$^{a}$** | **32.09 ± 0.82$^{b}$** |
| | **Quinoa 30%** | 34.10 ± 0.43 | 34.14 ± 1.90 | 33.67 ± 0.69 | 33.97 ± 1.06$^{a}$ | | |
| | **Average** | 33.46 ± 0.79 | 33.53 ± 1.53 | 33.36 ± 0.73 | | | |
| **h*** | **Quinoa 15%** | 79.59 ± 0.14 | 79.61 ± 0.42 | 79.10 ± 0.55 | 79.43 ± 0.43$^{a}$ | **77.59 ± 1.98$^{b}$** | **85.60 ± 0.34$^{a}$** |
| | **Quinoa 30%** | 76.02 ± 0.75 | 75.62 ± 0.80 | 75.61 ± 0.88 | 75.75 ± 0.73$^{b}$ | | |
| | **Average** | 77.81 ± 2.02$^{a}$ | 77.62 ± 2.26$^{a}$ | 77.36 ± 2.02$^{b}$ | | | |

All values are presented as mean ± SD, and those with different superscripts are significantly different ($p < 0.05$). Uppercase letters indicate significant changes in sugar reduction levels, and lowercase letters indicate significant changes in different percentages of quinoa. Bold values with different letters in the same row indicate that the factorial mean differs from the control at a significance level of 5%. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

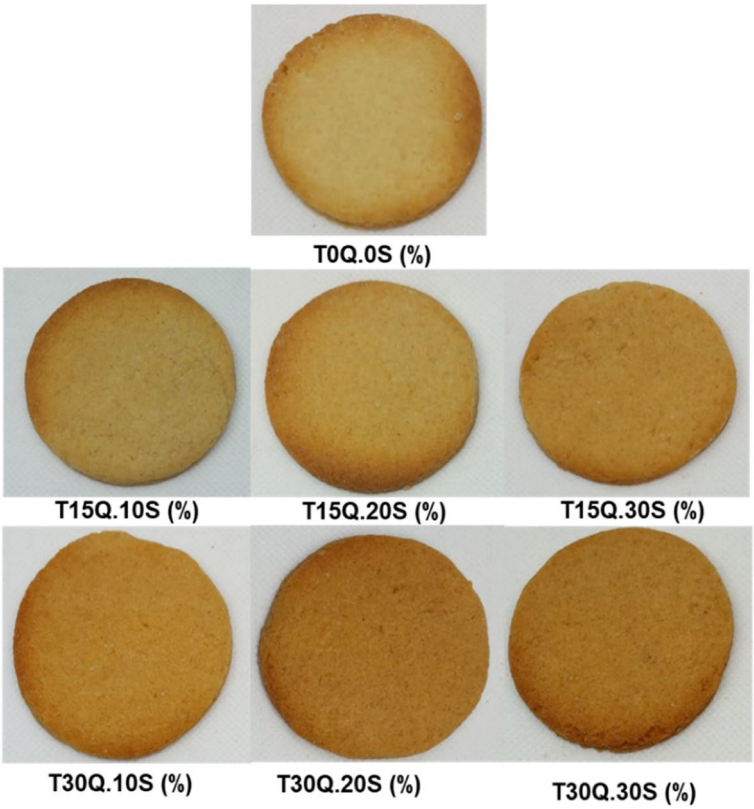



**Fig. 1** Cookies with quinoa flour incorporation and sugar reduction. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

**Table 5** Bioactive compounds of cookies based on sugar reduction and quinoa addition

| Variables | Levels | 10% sugar reduction | 20% sugar reduction | 30% sugar reduction | Average | Factorial | Control |
|---|---|---|---|---|---|---|---|
| **Polyphenols (mg GAE/g)** | **Quinoa 15%** | $1.364 \pm 0.117^{bA}$ | $1.326 \pm 0.112^{bA}$ | $1.445 \pm 0.061^{aA}$ | $1.376 \pm 0.101$ | $1.678 \pm 0.395^{a}$ | $1.245 \pm 0.119^{b}$ |
| | **Quinoa 30%** | $2.382 \pm 0.222^{aA}$ | $1.857 \pm 0.137^{aB}$ | $1.694 \pm 0.137^{aB}$ | $1.966 \pm 0.344$ | | |
| | **Average** | $1.873 \pm 0.580$ | $1.591 \pm 0.312$ | $1.569 \pm 0.166$ | | | |
| **DPPH ((mg/mL)** | **Quinoa 15%** | $48.622 \pm 1.175^{aA}$ | $29.688 \pm 1.565^{bC}$ | $38.670 \pm 1.340^{bB}$ | $38.993 \pm 8.288$ | $48.940 \pm 14.87^{b}$ | $60.662 \pm 5.425^{a}$ |
| | **Quinoa 30%** | $41.499 \pm 1.482^{bB}$ | $66.753 \pm 3.068^{aA}$ | $68.410.4 \pm 4.499^{aA}$ | $58.887 \pm 13.362$ | | |
| | **Average** | $45.060 \pm 4.081$ | $48.220 \pm 20.418$ | $53.540 \pm 16.558$ | | | |
| **ORAC (µmol ET/g)** | **Quinoa 15%** | $18.634 \pm 0.390$ | $27.753 \pm 2.757$ | $25.886 \pm 2.586$ | $24.091 \pm 4.584$ | $26.909 \pm 4.045^{a}$ | $15.840 \pm 0.663^{b}$ |
| | **Quinoa 30%** | $20.078 \pm 1.719$ | $27.723 \pm 2.245$ | $23.379 \pm 1.621$ | $23.726 \pm 3.699$ | | |
| | **Average** | $19.356 \pm 1.367^{a}$ | $27.723 \pm 2.249^{a}$ | $24.632 \pm 2.369^{b}$ | | | |

All values are presented as mean ± SD, and those with different superscripts are significantly different ($p < 0.05$). Uppercase letters indicate significant changes in sugar reduction levels, and lowercase letters indicate significant changes in different percentages of quinoa. Bold values with different letters in the same row indicate that the factorial mean differs from the control at a significance level of 5%. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

is due to the polyphenolic compounds found in quinoa, including phenolic acids, flavonoids, lignans, stilbenes, and tannins (Pellegrini et al., 2018). The main phenolic acids identified were ferulic, caffeic, p-coumaric, and benzoic, while the most important flavonoids are kaempferol, myricetin, and quercetin (Gómez-Caravaca et al., 2012).

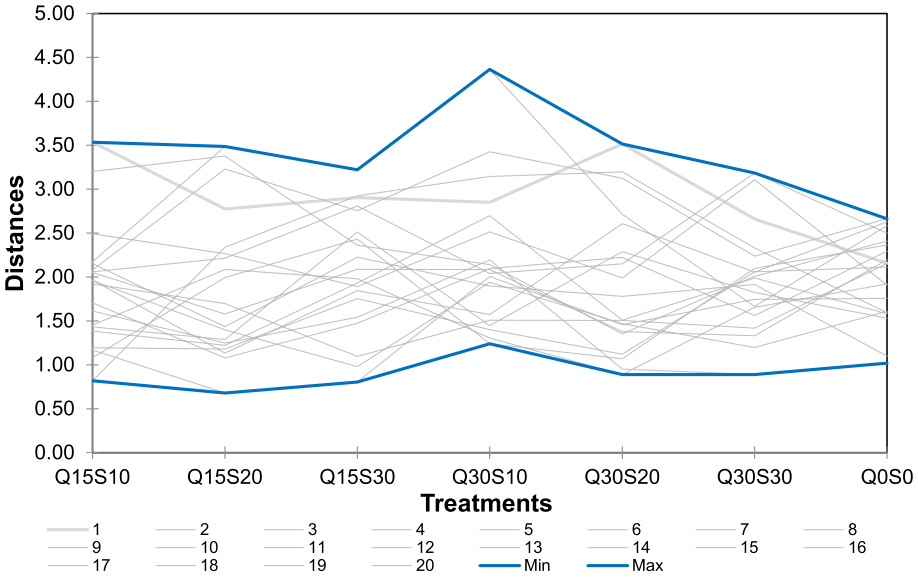



**Fig. 2** Panel performance of experts expressed in distances between experts by treatment

The interaction between incorporating quinoa flour and reducing sugar significantly affected the antioxidant capacity of the cookies, as indicated by DPPH results when compared to the control sample. The combination of 15% quinoa flour and a 20% reduction in sugar showed a higher antioxidant capacity, reaching 29.7 mg/mL. The presence of sugar in baking can help protect antioxidant compounds from heat, so reducing sugar may diminish this protective effect. Additionally, the processes of hydrolysis and caramelization of sucrose create compounds that enhance the final product's antioxidant capacity. Therefore, lowering the amount of sugar can lead to a reduction in this antioxidant capacity (Tsai et al., 2005). According to ORAC results, it was observed that incorporating quinoa flour at 15% and 30% did not demonstrate significant differences in the cookies'antioxidant activity, regardless of the sugar reduction levels. Furthermore, a 10% reduction in sugar negatively impacted antioxidant capacity, while the 20% and 30% reductions did not show significant differences. Nonetheless, previous studies have indicated that adding quinoa flour to cookies enhanced their antioxidant potential (Demir & Kilinç, 2017; Hidalgo et al., 2018; Watanabe et al., 2014), which is due to the bioactive compounds that quinoa possesses (Pereira et al., 2020), mainly phenolic acids and flavonoids, which suggest their use as functional ingredients to improve antioxidant activity and contribute to NCDs control (Pellegrini et al., 2018).

### Sensory descriptive profile of cookies with experts

Figure 2 illustrates the panel performance of experts assessing various cookie treatments (Q represents the percentage of quinoa flour incorporation, and S represents the percentage of sugar reduction) in terms of distance (perceived differences). The vertical axis represents the average distance, indicating how similar or different the evaluations were. The blue lines mark the acceptable limits, while the gray lines show each expert's response. Based on these results, we can conclude that the experts'responses were unanimous, assessing the intensity of the attributes between the upper and lower limits. Thus, the experts'evaluations can be regarded as a consensus.

The results obtained from the sensory evaluation conducted by expert panelists are shown in Table 6. The cookie samples exhibited statistical differences in dark, sweet, and honey attributes, indicating that the experts could detect differences among them. The addition of quinoa flour made the cookies appear darker; this behavior aligns with the instrumental results where incorporating quinoa flour increased the darkness of the cookies, as evidenced by the decrease in lightness (L*) according to previous studies (Demir & Kilinç, 2017; Wang et al., 2015; Watanabe et al., 2014). In agreement with the instrumental results, cookies with quinoa flour and sugar reduction were perceived as less hard than the control sample. This finding is consistent with the literature (Brito et al., 2015; Jan et al., 2018a; Nadian et al., 2021; Singla et al., 2024). Conversely, reducing the sugar content decreased the cookies'sweetness, leading to significant differences from the control sample. This outcome is expected since the amount of sugar significantly affects the sweetness (Erdem et al., 2023; Kawakami et al., 2025; Lingiardi et al., 2023). The honey attribute in cookies may be due to

**Table 6** Sensory attributes of cookie treatments

| Variables | Levels | 10% sugar reduction | 20% sugar reduction | 30% sugar reduction | Average | Factorial | Control |
|---|---|---|---|---|---|---|---|
| **Dark** | **Quinoa 15%** | 4.08 ± 2.03 | 4.70 ± 2.34 | 4.28 ± 2.34 | 4.35 ± 2.22$^{b}$ | 4.96 ± 2.37$^{a}$ | 2.45 ± 1.97$^{b}$ |
| | **Quinoa 30%** | 4.99 ± 2.50 | 5.35 ± 2.28 | 6.38 ± 2.22 | 5.57 ± 2.37$^{a}$ | | |
| | **Average** | 4.54 ± 2.29 | 5.02 ± 2.30 | 5.33 ± 2.49 | | | |
| **Sweet** | **Quinoa 15%** | 4.35 ± 1.80 | 2.91 ± 2.31 | 2.66 ± 1.98 | 3.31 ± 2.14 | 3.20 ± 2.22$^{b}$ | 5.27 ± 2.72$^{a}$ |
| | **Quinoa 30%** | 4.19 ± 2.79 | 2.92 ± 2.06 | 2.15 ± 1.53 | 3.09 ± 2.31 | | |
| | **Average** | 4.27 ± 2.32$^{a}$ | 2.92 ± 2.16$^{b}$ | 2.41 ± 1.77$^{b}$ | | | |
| **Greasy** | **Quinoa 15%** | 3.55 ± 2.33 | 3.80 ± 2.81 | 3.26 ± 2.24 | 3.54 ± 2.44 | 3.43 ± 2.37 | 3.08 ± 2.73 |
| | **Quinoa 30%** | 3.46 ± 2.42 | 3.34 ± 2.44 | 3.21 ± 2.20 | 3.33 ± 2.32 | | |
| | **Average** | 3.50 ± 2.35 | 3.57 ± 2.61 | 3.24 ± 2.19 | | | |
| **Salty** | **Quinoa 15%** | 1.47 ± 1.46 | 1.71 ± 1.97 | 1.79 ± 2.01 | 1.66 ± 1.80 | 1.89 ± 1.99 | 1.02 ± 0.96 |
| | **Quinoa 30%** | 1.66 ± 2.16 | 2.29 ± 2.00 | 2.44 ± 2.33 | 2.13 ± 2.16 | | |
| | **Average** | 1.56 ± 1.82 | 2.00 ± 1.98 | 2.12 ± 2.17 | | | |
| **Butter** | **Quinoa 15%** | 4.62 ± 2.34 | 4.07 ± 2.71 | 3.38 ± 2.19 | 4.02 ± 2.44 | 3.92 ± 2.25 | 3.81 ± 2.82 |
| | **Quinoa 30%** | 4.02 ± 2.06 | 3.81 ± 1.93 | 3.64 ± 2.28 | 3.82 ± 2.07 | | |
| | **Average** | 4.32 ± 2.20 | 3.94 ± 2.33 | 3.51 ± 2.21 | | | |
| **Honey** | **Quinoa 15%** | 1.23 ± 1.87 | 0.87 ± 1.21 | 0.92 ± 1.21 | 1.00 ± 1.45 | 1.20 ± 1.55 | 0.61 ± 0.63 |
| | **Quinoa 30%** | 1.65 ± 1.87 | 1.530 ± 1.90 | 1.035 ± 0.93 | 1.41 ± 1.63 | | |
| | **Average** | 1.44 ± 1.86 | 1.20 ± 1.61 | 0.98 ± 1.07 | | | |
| **Hard** | **Quinoa 15%** | 2.28 ± 2.00 | 3.25 ± 2.21 | 3.47 ± 2.83 | 3.00 ± 2.39 | 3.29 ± 2.45$^{b}$ | 5.84 ± 2.89$^{a}$ |
| | **Quinoa 30%** | 2.69 ± 2.33 | 3.19 ± 2.06 | 4.87 ± 2.62 | 3.58 ± 2.49 | | |
| | **Average** | 2.49 ± 2.15$^{b}$ | 3.22 ± 2.11$^{ab}$ | 4.17 ± 2.79$^{a}$ | | | |
| **Brittle** | **Quinoa 15%** | 3.06 ± 2.59 | 3.20 ± 2.53 | 2.38 ± 1.77 | 2.88 ± 2.32 | 2.96 ± 2.37 | 3.48 ± 2.95 |
| | **Quinoa 30%** | 3.08 ± 2.73 | 3.25 ± 2.26 | 2.82 ± 2.38 | 3.05 ± 2.43 | | |
| | **Average** | 3.07 ± 2.63 | 3.22 ± 2.37 | 2.60 ± 2.08 | | | |
| **Crunchy** | **Quinoa 15%** | 5.48 ± 2.80 | 5.47 ± 2.34 | 4.39 ± 2.66 | 5.11 ± 2.61 | 4.83 ± 2.51 | 6.64 ± 2.41 |
| | **Quinoa 30%** | 4.69 ± 2.54 | 4.59 ± 2.36 | 4.38 ± 2.35 | 4.55 ± 2.38 | | |
| | **Average** | 5.08 ± 2.67 | 5.03 ± 2.36 | 4.38 ± 2.48 | | | |

All values are presented as mean ± SD, and those with different superscripts are significantly different ($p < 0.05$). Uppercase letters indicate significant changes in sugar reduction levels, and lowercase letters indicate significant changes in different percentages of quinoa. Bold values with different letters in the same row indicate that the factorial mean differs from the control at a significance level of 5%. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

caramelization and the Maillard reaction, where sugars break down and generate melty compounds that create that sweet and characteristic flavor (Kathuria et al., 2023).

No significant differences among the samples were found in the butter and fat attributes. However, the salty attribute increased with adding quinoa flour, while the crunchy attribute decreased as the amount of quinoa flour increased and the sugar content was reduced. This aligns with the results obtained in the instrumental part, where the fracturability of the cookies showed a decreasing variation compared to the control sample, a finding similarly reported by Jan et al. (2018a, 2018b). Furthermore, a study indicated that decreasing sugar may influence the crystalline structure and moisture retention, resulting in lower fracturability (Luo et al., 2019).

Figure 3 presents the PCA biplot illustrating the sensory attributes that characterized the cookie samples. The first two principal components (Dim 1: 48.68% and Dim 2: 28.83%) explain 77.51% of the total variance. The red vectors represent the sensory attributes, while the blue labels indicate the percentage of quinoa flour incorporation, and the green labels show the percentages of sugar reduction for the different treatments. The control sample (Q0S0) is positioned far from the other formulations, suggesting a distinctive sensory profile, being perceived as harder. This behavior is consistent with the instrumental results and aligns with the findings of previous studies (Brito et al., 2015; Jan et al., 2018a, 2018b; Nadian et al., 2021; Singla et al., 2024). Treatments with higher sucrose reduction (S30) and greater quinoa flour incorporation (Q30) cluster separately, indicating significant changes in sensory perception. Higher sucrose reduction (S30) was associated with hard and dark attributes, while formulations with

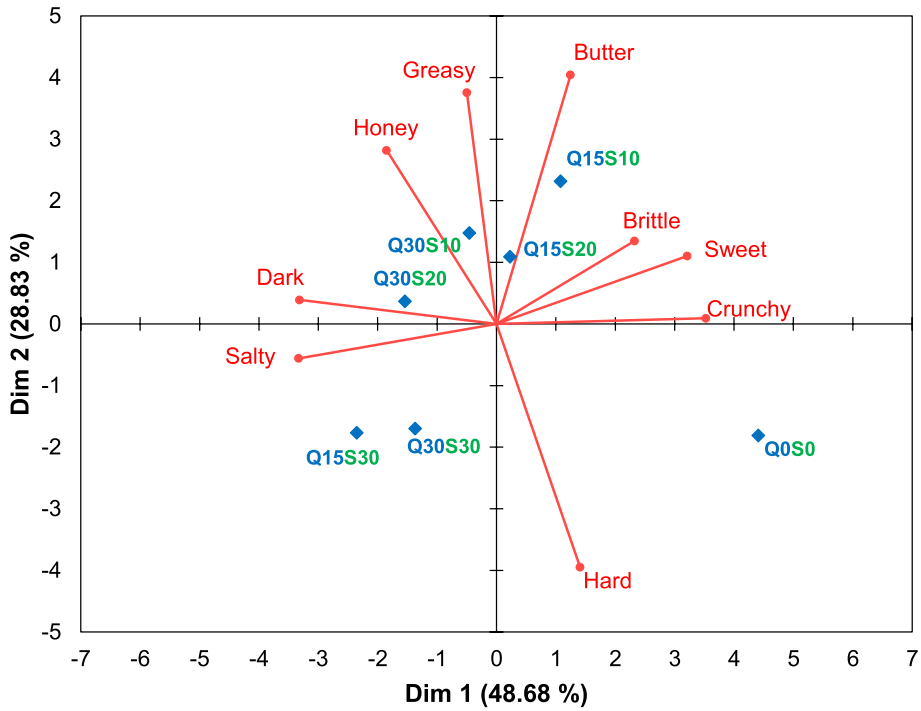



**Fig. 3** PCA biplot of attributes that characterized the cookie samples based on DA results. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

higher quinoa flour addition (Q30) tend to align with salty, dark, honey, and greasy attributes. These findings are consistent with previous studies, such as those by Wagoner et al. (2018) and McKenzie et al. (2022), which reported that sugar reduction alters texture and sweetness perception, while quinoa flour influences color due to its protein and fiber content (Demir & Kilinç, 2017; Wang et al., 2015; Watanabe et al., 2014). On the other hand, the salty attribute could be linked to the minerals and salts present in quinoa, which influence flavor perception, along with plant proteins that contribute to the saltiness (Rosell et al., 2010).

On the other hand, treatments with quinoa incorporation (Q15) and sucrose reduction (S10, S20) were perceived as crunchy, buttery, sweet, and crumbly. These results are consistent with previous studies (Azizi et al., 2020; Demir & Kilinç, 2017) which highlight quinoa flour's fiber, protein, and essential fatty acids as contributors to a crunchy, brittle texture that crumbles easily. In addition, the products are perceived as sweet, suggesting up to a 20% reduction in sucrose without affecting taste (Lingiardi et al., 2023). The brittle attribute is linked to the structure of quinoa, where its protein (14.45%) and fiber (9.5%) promote rigidity and easy disintegration (Demir & Kilinç, 2017).

### Sensory consumers'perception

Figure 4 shows consumer acceptance of the cookie samples. The control sample (6.46), and Q15S10 (6.33) obtained the highest acceptance score. This behavior is consistent with previous studies showing higher acceptance of the control sample (Chopra et al., 2018; Demir & Kilinç, 2017; Watanabe et al., 2014). While treatments Q15S20 (5.98), Q15S30 (5.97), and Q30S10 (5.92) formed a group with intermediate acceptance, this behavior aligns with previous studies, such as Jan et al., (2018a, 2018b), which suggest that adding up to 30% quinoa flour without significantly affecting sensory acceptance is suitable. In this context, Everitt (2009) noted that scores between 6 and 9 on a 9-point hedonic scale are good indicators of sensory quality in the marketplace.

However, the greater incorporation of quinoa flour and the reduction of sugar in treatments [Q30S20 (5.55) and Q30S30 (5.26)] negatively impacted consumer perceptions, obtaining significantly lower acceptance scores. This behavior could be explained by the impact of the reformulation on the sensory characteristics of the product, such as flavor, texture, and color, which may have been perceived less favorably, thus affecting consumer liking (Azizi et al., 2020; Chopra et al., 2018; Demir & Kilinç, 2017; Lingiardi et al., 2023).

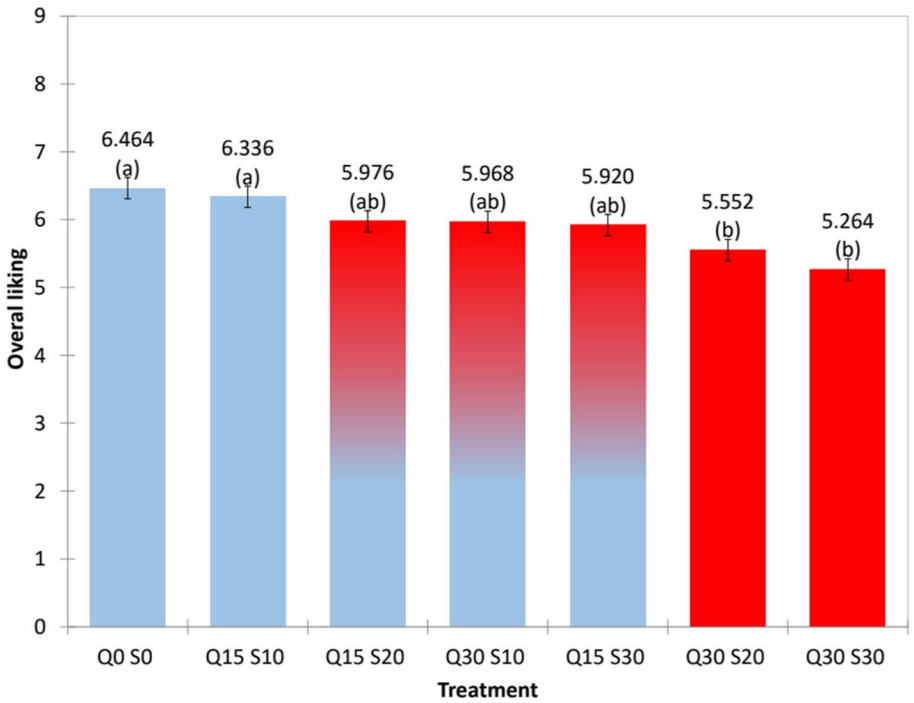



**Fig. 4** Barplot representing the overall liking of cookie treatments. Error bars are the standard error of the mean. Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

Figure 5 (a) displays the CA that illustrates the sensory attributes characterizing the cookie samples based on the consumer sensory profile. The first two dimensions (Dim 1: 71.17% and Dim 2: 14.95%) account for 86.12% of the total variance. The red vectors represent sensory attributes, while the blue and green labels indicate different treatments. The control sample (Q0S0) was located far from the other formulations, suggesting a unique sensory profile, perceived as harder. This same pattern was noted in the sensory profile with experts using DA, aligning with the instrumental results and with the conclusions of previous studies (Brito et al., 2015; Jan et al., 2018a, 2018b; Nadian et al., 2021; Singla et al., 2024). Treatments with higher sucrose reduction (S30) and greater quinoa flour incorporation (Q30) cluster separately, indicating significant changes in consumer sensory perception. Higher sucrose reduction (S30) was associated with salty and crumbly attributes, whereas formulations with higher quinoa flour addition (Q30) tended to align with salty, dark, crumbly, and greasy attributes. These findings align with sensory profiling using DA and instrumental results, consistent with studies by Wagoner et al. (2018) and McKenzie et al. (2022), who point out that reducing sugar affects texture and sweetness, while quinoa flour darkens the color (Demir & Kilinç, 2017; Wang et al., 2015; Watanabe et al., 2014).

On the other hand, the treatments incorporating quinoa (Q15) and reducing sucrose (S10, S20) tend to be associated with attributes such as crunchy, buttery, sweet, and honey. These results align with previous studies, such as those by Azizi et al. (2020) and Chopra et al. (2018), which suggest that quinoa flour provides a crunchy and buttery texture and that sucrose can be reduced by up to 20% without altering the flavor, since the treatments maintain their sweetness, coinciding with the reports by Lingiardi et al. (2023), who reduced the sugar content in cookies aimed at school children by 23.5% without compromising sensory profile.

According to the drivers of liking Fig. 5 (b) and the consumer's sensory profile Fig. 5 (a), positive drivers of liking, such as crunchy, sweet, honey, and butter, are primarily associated with the Q15S10 and Q15S20 treatments. This finding aligns with previous studies, such as those by Azizi et al. (2020), who identified crunchiness as key to the acceptance of quinoa-enriched products, and Chopra et al. (2018), who highlighted that the buttery sensation improves acceptance due to the essential fatty acids in quinoa.

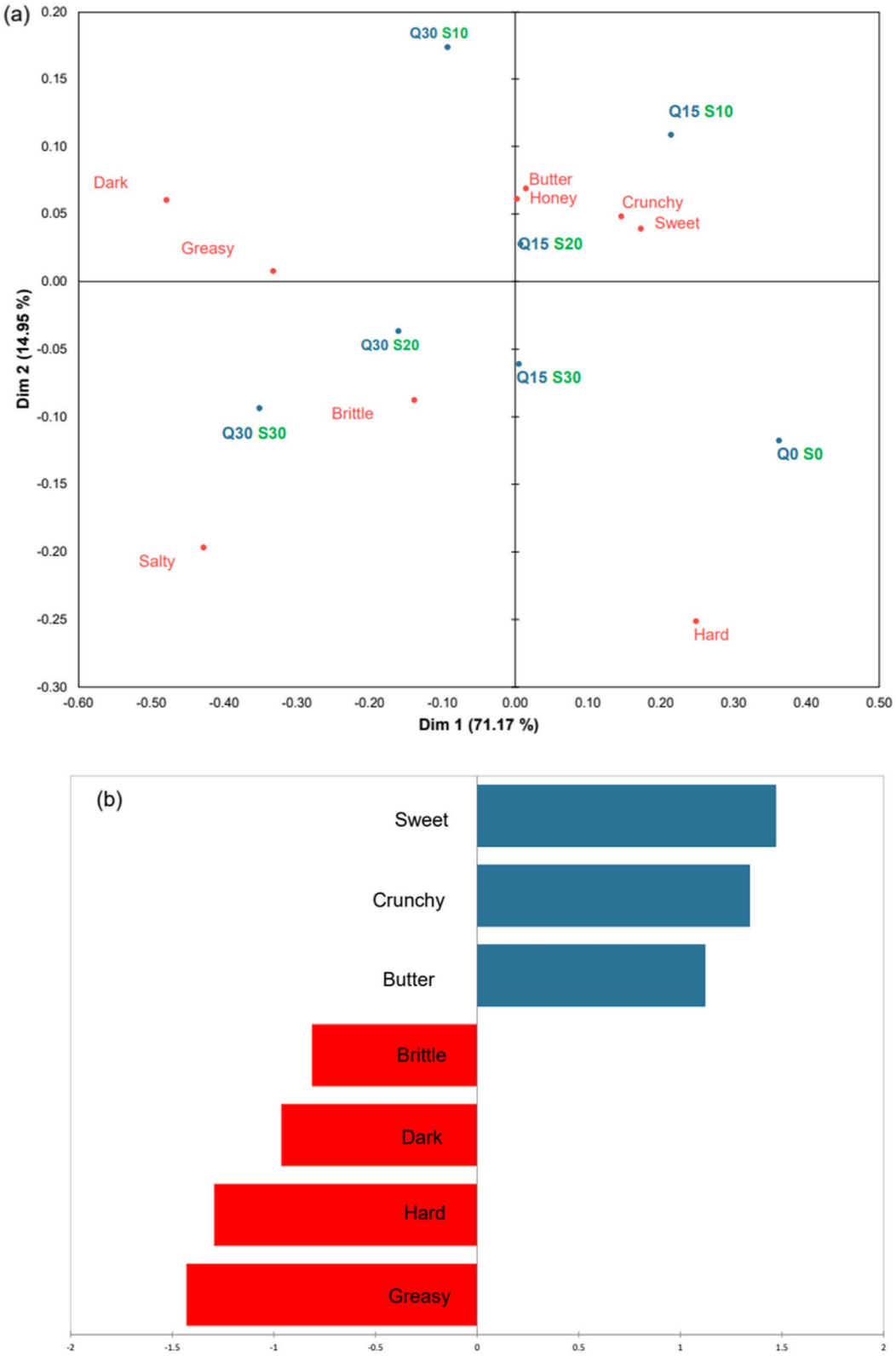



**Fig. 5** Correspondence analysis of CATA results about cookie samples (**a**); and drivers of liking of cookie samples (**b**). Control: 0% incorporation of quinoa flour, 0% sugar reduction; T15Q.10S: 15% incorporation of quinoa flour, 10% sugar reduction; T15Q.20S: 15% incorporation of quinoa flour, 20% sugar reduction; T15Q.30 S: 15% incorporation of quinoa flour, 30% sugar reduction; T30Q.10S: 30% incorporation of quinoa flour, 10% sugar reduction; T30Q.20S: 30% incorporation of quinoa flour, 20% sugar reduction; T30Q.30S: 30% incorporation of quinoa flour, 30% sugar reduction

Additionally, sweetness and the honey flavor have been identified as positive factors in sugar-reduced products, as observed in the study by Lingiardi et al. (2023). On the other hand, negative drivers of liking, such as greasiness, hardness, brittleness, and darkness, are more closely linked to the Q30S20 and Q30S30 treatments, which exhibit a higher presence of these less favorable characteristics. This behavior aligns with the findings of studies like those by Rosell et al. (2010) and Jan et al. (2018b) who pointed out that hardness and greasiness are attributes that negatively affect the acceptance of food products. The control treatment (Q0S0) and Q15S30 occupy an intermediate position, indicating a balance between positive and negative attributes.

The reduction of sucrose and incorporation of quinoa flour in the cookie formulation significantly impact the product's bioactive, sensory, and physical properties. Reducing sugar while enhancing the nutritional profile by lowering calorie content affects the sweetness and texture of the cookies, leading to lower sensory acceptance when the reductions are more pronounced. On the other hand, incorporating quinoa flour improves the cookies'nutritional profile by increasing the content of bioactive compounds, such as antioxidants, and providing functional benefits. However, it also changes physical characteristics, such as hardness and color, which can influence consumer liking. While cookies with 15% quinoa flour and a moderate reduction of sugar achieve a good balance between flavor, texture, and nutritional benefits, those with higher proportions of quinoa or a more significant reduction of sugar exhibit greater brittleness, darker color, and decreased sweetness, which diminishes their sensory acceptance.

## Conclusion

This study demonstrated the feasibility of developing quinoa-based cookies with reduced sugar content, aligning with global nutritional goals to reduce added sugars and promote healthier eating patterns. By replacing wheat flour with 15% quinoa flour and reducing sugar by up to 10%, the cookies achieved an improved nutritional profile, highlighting bioactive compounds, while maintaining favorable sensory attributes and consumer acceptance. However, higher substitution levels (30% quinoa) and greater sugar reductions (20%, 30%) negatively impacted consumer acceptance, primarily due to undesirable sensory attributes such as increased brittleness, darker color, and reduced sweetness. These findings emphasize the critical balance between nutritional enhancement and sensory quality to ensure consumer satisfaction and market success.

## Limitations of the work

One limitation of this study was using pre-processed quinoa flour rather than milling it under controlled conditions. This choice restricted our ability to control particle size and other processing variables, which could have affected the technological and nutritional properties of the final product. For future studies, it is advisable to mill quinoa under standardized and monitored conditions to ensure greater consistency and accuracy in the results.

**Acknowledgements**
We thank the Universidad Nacional de Moquegua for funding this research through the "scientific research seedbed Andean Golden Seeds" and for the support provided through thesis financing.

**Authors' contribution**
The authors made the following contributions. Jennifer Alvarez: Physicochemical analysis, sensory evaluation, drafting the original manuscript. Karina Eduardo: Physicochemical analysis, sensory evaluation. Milagros Maribel Coaguila Gonza: Physicochemical analysis, sensory evaluation. Chimenes Darlan Leal de Araújo: Physicochemical analysis, sensory evaluation. Carmen J. Contreras-Castillo: Supervision, review, and editing. Erick Saldaña: Supervision, review, and editing.

**Funding**
This research was funded by the Universidad Nacional de Moquegua through the scientific research seedbed *Andean Golden Seeds* (Resolución de Comisión Organizadora N° 865-2023-UNAM and N° 778-2024-UNAM) and supported by the thesis grant program from the same institution (Code: PT-2024-002; Resolución de Comisión Organizadora N° 778-2024-UNAM).

**Data availability**
No datasets were generated or analysed during the current study.

**Declarations**
All procedures performed in studies with human participation were approved by the Ethics Committee of the Universidad Nacional de Moquegua written informed consent was obtained from the panelists who participated in the sensory evaluation of cookies with quinoa flour incorporation and sugar reduction. They were informed that their participation was completely voluntary and that they could withdraw from the study at any time without having to justify their decision.

**Consent for publication**
Not applicable.

**Competing interests**
Dr. Carmen J. Contreras Castillo is a member of Editorial Board of *Food Production, Processing and Nutrition* and she was not involved in the journal's review of, or decisions related to this manuscript.

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Received: 5 March 2025 Accepted: 29 June 2025
Published online: 29 December 2025

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