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Strategic modulation of lime concentration to optimize chemical composition, microbial stability, and sensory quality in quispiño dough formulation

Carmen Gisela Mindani Cáceres[1,2*], Vladimiro Ibañez Quispe[1], Edwin O. Baldeón [2], José Luis Cahuana Jorge[3,4], Fredy Grimaldo Calizaya Llatasi[1], Franklin Ore Areche[5], Danitza Corina Paricanaza Ticona[6], José Manuel Barrera Condori[6], Daphne Heela Castro Arata[6], Olivia Magaly Luque Vilca[7], Tania Jakeline Choque Rivera[7], Denis Dante Corilla Flores[5] and Maxgabriel Alexis Calla Huayapa[7]

*Correspondence:
Carmen Gisela Mindani Cáceres
cmindani@epg.unap.edu.pe
[1]National University of the Altiplano, Puno, Peru
[2]La Molina National Agrarian University, Lima, Peru
[3]Center for Advanced Research and Higher Training in Education, Health and Environment Amtawi, Ica, Peru
[4]National Agrarian Health Service - SENASA, Lima, Peru
[5]National University of Huancavelica, Huancavelica, Peru
[6]CITE Agroindustrial Moquegua, Technological Institute of Production, Moquegua, Peru
[7]National University of Juliaca, Juliaca, Peru

Abstract

This study investigates the impact of varying lime concentrations (0.1–0.9%) on the chemical composition, microbial stability, color, texture, and sensory properties of quispiño dough. Lime concentrations ranging from 0.1 to 0.9% were analyzed. The results demonstrated that higher lime concentrations significantly reduced moisture, protein, pH, total phenols, fat, and fiber content, while increasing ash content. Microbial stability improved with higher lime concentrations, leading to substantial reductions in total viable count (TVC), yeast, mold, and the complete absence of *E. coli* at concentrations of 0.5% and above. Color analysis revealed a decrease in lightness (L) and increases in redness (a) and yellowness (b), especially after cooking. Texture profile analysis (TPA) indicated that higher lime levels led to softer dough, characterized by reduced hardness, elasticity, and cohesiveness. Sensory evaluation confirmed that the overall acceptability of the dough decreased as lime concentration increased, with significant declines in flavor, texture, and appearance at concentrations above 0.5%. Results revealed lime enhances microbial stability and alters the chemical composition of quispiño dough, it can also negatively impact its sensory qualities at higher concentrations above 0.5%. A balance between functional benefits and consumer acceptability is therefore critical when using lime in dough formulations. This study provides valuable insights for both traditional and industrial food applications where lime is used as a natural preservative and processing aid. Striking a balance between functional benefits and consumer acceptability is critical when incorporating lime in quispiño dough. Optimizing lime concentration is essential to balance functional benefits and consumer acceptability in quispiño dough production.

Keywords Lime optimization, Microbial safety, Textural modification, Color analysis, Sensory acceptability

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1 Introduction

The global food industry has increasingly recognized the importance of traditional and indigenous foods, particularly those with potential health benefits and cultural significance. One such product is *quispiño*, a traditional dish made from quinoa flour (*Chenopodium quinoa* Willd), a crop that has been a staple in Andean diets for thousands of years. Quinoa, frequently referred to as a "superfood," has gained international attention due to its high nutritional value, offering essential amino acids, dietary fiber, and important micronutrients, including magnesium, iron, and zinc [1]. In recent years, quinoa's role in global food security has been highlighted due to its ability to grow in diverse environmental conditions and its resistance to drought and poor soil quality [2]. Despite quinoa's popularity, *quispiño* has remained largely unknown outside of the Andean regions, likely due to the artisanal and traditional methods required for its preparation, which affect its sensory attributes such as texture, flavor, and appearance [3].

A key element in the preparation of *quispiño* is the use of lime (calcium hydroxide), which plays a significant role in altering the physicochemical properties of the dough. Lime has been traditionally used in food processes such as nixtamalization, where it is employed to treat corn in the production of tortillas. This process enhances the bioavailability of certain nutrients, improves dough texture, and stabilizes color. The role of lime in *quispiño* preparation, though similar, has not been extensively studied. Lime alters the pH of the dough, affecting its gelatinization, which can have significant implications for the texture and appearance of the final product [4]. Furthermore, lime can impact the microbial stability of the dough, which is critical for extending the shelf life of the product. As the use of lime influences multiple aspects of food quality, understanding the effects of different concentrations of lime on *quispiño* could provide valuable insights into optimizing its preparation for wider consumer acceptance and commercial production [5].

Quinoa's nutritional profile is exceptional, particularly due to its high-quality protein content, which contains all nine essential amino acids, making it a complete protein source [6]. Additionally, quinoa is rich in dietary fiber and bioactive compounds such as flavonoids and phenolic acids, which contribute to its antioxidant properties [7]. These characteristics have made quinoa an increasingly popular choice for consumers seeking functional foods with health benefits, including the management of chronic conditions like cardiovascular diseases, obesity, and diabetes [8]. However, quinoa also contains saponins, bitter-tasting compounds that need to be removed during processing to improve palatability. The use of lime in *quispiño* preparation helps to neutralize these saponins, making the product more acceptable to consumers by reducing its bitterness [9].

While *quispiño* has deep cultural roots in the Andean region, its nutritional potential and health benefits have drawn attention from researchers interested in promoting traditional foods as part of modern diets. Lime's role in this process extends beyond taste and texture modifications. It also contributes to the preservation of *quispiño*, making it suitable for long-term storage without refrigeration, a key characteristic that has made it a popular food for long journeys and festivals [10]. The lime-induced alkalinity of the dough inhibits the growth of spoilage microorganisms, thereby enhancing its microbial stability. Studies have shown that increasing the pH of food products through the

addition of lime or other alkaline substances can significantly reduce microbial growth, which is essential for ensuring food safety and extending shelf life [11].

Sensory evaluation is critical for determining consumer acceptance of traditional foods like *quispiño*. The sensory attributes, including flavor, texture, and appearance, play a pivotal role in the market success of any food product. The use of lime directly impacts these attributes, with higher lime concentrations potentially introducing an alkaline taste, which might not be well received by all consumers [11]. Moreover, lime can influence the dough's color, which is another important sensory characteristic. Lighter or more uniform color may be perceived as more appealing, especially in modern food markets where visual appearance strongly influences purchasing decisions [5]. Previous studies have demonstrated that sensory attributes can be optimized by modifying the ingredient composition, particularly by adjusting lime concentrations to balance the benefits of improved texture and shelf life with the need for consumer-acceptable taste and appearance [10].

The chemical composition of *quispiño* is also an area of interest for researchers looking to optimize its nutritional and functional properties. Lime, in combination with the quinoa flour, influences the final chemical composition of the product, particularly its moisture, protein, and carbohydrate content. The interaction of lime with the protein structures in quinoa may alter the dough's elasticity and cohesiveness, two important factors that contribute to the texture profile of the final product [8]. Additionally, lime has been shown to affect the retention of certain nutrients during cooking, which is critical for maintaining the nutritional value of traditional foods during modern food processing [4]. The pH adjustment caused by lime can also improve the availability of minerals such as calcium and magnesium, which are important for bone health and metabolic functions [7].

Microbial stability is another key factor that has been investigated in relation to quinoa-based products. Given quinoa's high moisture content and nutrient density, products made from quinoa are particularly susceptible to microbial spoilage. However, the alkaline conditions created by lime can inhibit the growth of spoilage organisms, thereby extending the shelf life of *quispiño*. This characteristic is especially important in rural and mountainous regions where refrigeration is limited [9]. Studies have indicated that the lime concentration directly correlates with microbial stability, with higher concentrations of lime leading to longer preservation periods due to the reduced microbial activity [10].

In light of these findings, it is clear that optimizing the use of lime in *quispiño* preparation is critical for enhancing its nutritional value, microbial stability, and sensory attributes. Understanding the interactions between lime and the various components of quinoa dough can help standardize the preparation of *quispiño*, making it more accessible to a global market. This research aims to fill the gap in knowledge regarding the impact of lime concentration on the chemical, microbial, sensory, and textural properties of *quispiño*, thereby contributing to the development of traditional foods for modern consumption.

2 Materials and methods

2.1 Study design

The study was designed to evaluate the effects of varying lime concentrations on the chemical composition, microbial stability, sensory attributes, and texture profile of *quispiño*, a traditional Andean food made from quinoa flour. The 2 × 5 Factorial Randomized Complete Design (RCD) was used to assess two main factors: lime concentration (0.1%, 0.3%, 0.5%, 0.7%, and 0.9%) and dough state (raw vs. cooked was specifically evaluated for color parameters). The lime concentrations refer to the total mass of the dough and are expressed as weight/weight (w/w). Each treatment group was randomly assigned, and the experimental procedures were repeated in triplicates to ensure the reliability of results. A factorial design is particularly suited for evaluating the interaction effects of multiple factors and allows for a detailed statistical analysis of both independent variables and their interaction on the dependent variables [12].

2.2 Materials used

2.2.1 Quinoa flour

The primary ingredient used was quinoa flour (100 g) made from the Salcedo variety of quinoa, which was sourced from the INIA Agraria Experimental Station, Puno, Peru. Quinoa (*Chenopodium quinoa* Willd) [13].

2.2.2 Lime (Calcium hydroxide)

Lime (calcium hydroxide) was purchased from the Laykakota Market in Puno and was used at five concentrations (0.1%, 0.3%, 0.5%, 0.7%, 0.9%) [14].

2.2.3 Sample preparation

The preparation of *quispiño* involved several key steps to ensure consistency across batches. Each batch was prepared with a specific lime concentration, and the following process was followed.

The formulation for the quispiño dough was standardized as follows:

Ingredient name	Quantity
Quinoa Flour	100 g
Lime	Variable (0.1%, 0.3%, 0.5%, 0.7%, and 0.9% of total flour weight)
Salt	2 g
Anise	1 gram
Water	60 milliliters, adjusted based on dough consistency
Vegetable Oil	1 milliliter, added to prevent sticking during kneading

Quinoa flour was mixed with lime and other dry ingredients, including salt and anise, ensuring homogeneous distribution. Water was gradually added to form a cohesive dough. The dough was prepared and kneaded using a KitchenAid Professional 600 Series mixer (Model KP26M1X, USA). This mixer, equipped with a spiral dough hook, ensured consistent and homogeneous mixing across all batches, allowing for even distribution of lime and other ingredients such as salt and anise. The mixer was operated at a medium speed setting for 10 min for each batch to achieve the desired dough consistency. The dough was kneaded until smooth, with a minimal amount of vegetable oil used to prevent sticking. The dough was manually shaped into small rolls or cookies, traditionally sized for *quispiño*. The dough was manually shaped into small rolls or

cookies, traditionally sized for quispiño, with each piece weighing approximately 20 g (or measuring about 3 cm in diameter). The dough was steamed in a traditional clay pot at 100 °C for 45 min, ensuring full gelatinization and achieving the characteristic texture [15]. Each batch (Specific amount of quispiño dough prepared with a particular lime concentration) was closely observed to make sure the lime concentrations were correct and the dough was formed consistently.

2.3 Color analysis method

2.3.1 Color analysis

In this study, the color of both raw and cooked quispiño dough was measured using a CIELAB color space system, which quantifies color based on three parameters: L (lightness), a (green-red spectrum), and b (blue-yellow spectrum). The analysis of color was carried out to assess the influence of different lime concentrations on the visual properties of the dough. The color measurements were taken using a portable spectrophotometer (Model NS800, China) equipped with a D65 illuminant and a 2° observer angle. The spectrophotometer was calibrated using a white reference tile before each measurement. This device measures the reflected light from the sample and expresses the color values in the CIELAB system.

The following color parameters were recorded for each sample:

L: Represents lightness, where L = 0 indicates black and L = 100 represents white.

a: Measures color along the green (-a) to red (+ a) axis.

b: Measures color along the blue (-b) to yellow (+ b) axis.

Chroma (C): The chroma or purity of the color was calculated using the Eq. 1:

$$\mathrm{C} = \sqrt{\left(\mathrm{a}^2 + \mathrm{b}^2\right)} \tag{1}$$

Hue angle (H): The hue or actual color of the sample was calculated as:

$$\mathrm{H} = \arctan\ (\mathrm{b}/\mathrm{a})$$

Samples of both raw and cooked dough were allowed to cool to room temperature before being placed in the spectrophotometer for color measurement. Each sample was measured in triplicate to ensure accuracy, with readings taken from different locations on the surface of the dough to account for possible color variation across the sample. The total color difference (ΔE) between the raw and cooked dough samples was calculated to determine the extent of color change during cooking. The ΔE was computed using the following equation:

$$\Delta\mathrm{E} = \sqrt{\ (\mathrm{L}_2 - \mathrm{L}_1)^2 + \ (\mathrm{a}_2 - \mathrm{a}_1)^2 + \ (\mathrm{b}_2 - \ \mathrm{b}_1)^2}$$

Where:

L_1, a_1, b_1 are the color parameters of the raw dough.

L_2, a_2, b_2 are the color parameters of the cooked dough.

This method is widely used to quantify the extent of color change and is particularly helpful in comparing color differences across different treatments [16].

2.4 Texture profile analysis

The Texture Profile Analysis (TPA) was conducted using a Texture Analyzer. Key parameters measured included: Hardness: The force required to compress the sample. Elasticity: The ability of the sample to return to its original shape after compression. Cohesiveness: The degree to which the sample sticks together during chewing. These parameters were evaluated in both raw and cooked states, providing a comprehensive understanding of how lime concentration impacts the texture of *quispiño* [14].

The TPA of the dough samples was conducted using a TA.XT Plus Texture Analyzer (Stable Micro Systems, Model TA.XT Plus, UK), which was equipped with a 2.5 kg load cell to measure the forces during compression. The P/75 compression probe (diameter: 75 mm) was used for the analysis, as it is suitable for evaluating the texture of dough and other semi-solid food products. The test speed was set to 1 mm/**s**, and the samples were compressed to 40% of their original height during each compression cycle. Two compression cycles were performed, with each cycle involving an upward and downward motion of the probe to simulate the mechanical actions during chewing. The data collected from these tests was used to calculate various TPA parameters, including hardness, cohesiveness, elasticity, and adhesiveness, based on the force-time curves recorded by the device. This comprehensive analysis provided insights into the textural properties of the quispiño dough under different lime concentrations.

2.5 Sensory evaluation

A sensory evaluation was conducted with 40 untrained panelists, who were asked to score the flavor, texture, appearance, and overall acceptability of the product using a 5-point hedonic scale (1 = dislike a lot, 5 = like a lot). The panelists evaluated three coded samples prepared with 0.5%, 0.7%, and 0.9% lime concentrations. Each attribute was statistically analyzed to identify significant differences between lime levels using the Friedman test and Wilcoxon post-hoc test [17].

2.6 Chemical composition

The moisture content was determined using the oven drying method (AOAC Method 934.01), which involves drying the sample at 105 °C for 24 h until a constant weight is achieved [18]. Protein content was measured using the Kjeldahl method (AOAC Method 978.04), which quantifies nitrogen content [18]. A conversion factor of 6.25 was used to calculate protein from nitrogen. This method is widely recognized for its accuracy in measuring total protein content [19]. Fat content was determined using the Soxhlet extraction method (AOAC Method 963.15) with hexane as the solvent [20]. This method involves continuous solvent extraction, where fat is dissolved and measured as a percentage of total sample weight. Fiber content was measured using the Acid-Detergent Fiber (ADF) method (AOAC Method 973.18), which removes non-fibrous components and calculates the remaining insoluble fiber [20]. Ash content was determined by igniting the sample at 550 °C in a muffle furnace (Model F48010-33, USA) AOAC Method 942.05) until all organic material was combusted. The remaining inorganic material represents the mineral content of the product. Carbohydrate content was calculated by subtracting the sum of the moisture, protein, fat, and ash contents from 100%. This method provides an estimate of the non-fiber carbohydrates present in the product [15]. The pH level of the dough was measured using a digital pH meter (Model HI5221, Romania, ISO

10523) [21], with the sample dissolved in a distilled water solution (1:10 w/v) at room temperature.

2.7 Microbial stability analysis

To assess the microbial stability of the product, three key microbial parameters were measured. Total viable counts (TVC) were measured using the pour plate method on Plate Count Agar (PCA). This method provides an estimate of the total number of viable microorganisms in the sample. Yeast and mold counts were performed on Potato Dextrose Agar (PDA), a medium optimized for fungal growth [22]. The presence of *E. coli* was determined using MacConkey agar [23]. The absence of *E. coli* is important for ensuring food safety and hygiene. All samples were incubated at 37 °C for 24–48 h to allow for microbial growth before counting colonies.

2.8 Phenolic compounds

The phenolic substance analysis was performed on the extracted samples rather than directly on the dough. The phenolic substances were analyzed from extracted samples rather than directly from the dough. The extraction was carried out using ethanolic solvent. Briefly, 5 g of the sample was homogenized with 50 mL of ethanol (70%, v/v) using a magnetic stirrer for 1 h at room temperature. The mixture was then centrifuged at 4,000 × g for 10 min, and the supernatant was collected. This process was repeated twice to ensure maximum extraction of phenolic compounds. The combined extracts were filtered through Whatman No. 1 filter paper and stored at -20 °C until analysis. The total phenolic content was measured using the Folin-Ciocalteu method [24], with results expressed as mg of gallic acid equivalents (GAE) per gram of sample. The Folin-Ciocalteu reagent (Sigma-Aldrich, ≥98% purity, USA) and gallic acid standard (analytical grade, Merck, Germany) were used in the analysis. Methanol (HPLC grade, Fisher Scientific, USA) was employed as the solvent for extraction. All reagents and solvents were stored under controlled conditions to preserve their integrity and ensure accurate results. The absorbance for total phenolic content was measured using a UV-Vis spectrophotometer (Shimadzu, Model UV-1800, Japan). This spectrophotometer was calibrated before each use, and measurements were taken at 765 nm using the Folin-Ciocalteu method. The protein content was determined using a Kjeldahl digestion and distillation unit (VELP Scientifica, Model DK 20, Italy) in combination with a nitrogen analyzer to calculate protein based on nitrogen content, using a conversion factor of 6.25. The fat content was measured with a Soxhlet extractor (Buchi, Model E-812, Switzerland), using hexane as the extraction solvent. This continuous solvent extraction method was selected for its precision in quantifying total fat content in food samples.

The antioxidant capacity of the samples was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay, a method widely used for determining the free radical-scavenging activity of extracts [25]. A solution of DPPH (0.1 mM) in methanol was prepared, and a certain volume of the extract was mixed with the DPPH solution. The decrease in absorbance was measured at 517 nm using the Shimadzu UV-1800 spectrophotometer [26]. The antioxidant capacity was expressed as the percentage inhibition of DPPH radicals, calculated using the formula:

$$\%\text{Inhibition} = \ \text{A}_{\text{control}} - \text{A}_{\text{sample}}/\text{A}_{\text{control}}$$

Where $A_{control}$ is is the absorbance of the DPPH solution without the extract, and A_{sample} is the absorbance of the solution containing the extract.

2.9 Statistical analysis for color

Statistical analysis was performed using two-way ANOVA to assess the effects of lime concentration and dough state (raw vs. cooked) on chemical, microbial, sensory, and texture properties. Tukey's post-hoc test was applied to identify significant differences between lime concentrations, with a significance level set at $p < 0.05$. Effect sizes (η^2) were calculated to measure the magnitude of the observed differences. For color analysis, the impact of lime concentration on color parameters (*L*, *a*, *b*, chroma, and hue) was evaluated, and ΔE values were compared using one-way ANOVA to assess total color differences between raw and cooked dough. Sensory data were analyzed using the Friedman test, with pairwise comparisons conducted using the Wilcoxon post-hoc test.

3 Results

3.1 Color analysis

3.1.1 Lightness of raw and cooked dough

The lightness (*L*) values of the quispiño dough exhibited a significant decrease as the concentration of lime increased, with raw dough consistently showing higher L values compared to the cooked dough across all treatments. This indicates a marked reduction in brightness following the cooking process. For example, at the lowest lime concentration (0.1%), the raw dough had a lightness value of 72.32 ± 0.50, while the cooked dough dropped to 46.32 ± 0.40. As the lime concentration increased to 0.9%, the raw dough showed a lightness of 67.78 ± 0.50, and the cooked dough decreased to 39.44 ± 0.37. Statistically significant differences ($p < 0.05$) were observed between raw and cooked dough across all lime concentrations. Additionally, the effect size (Cohen's d) ranged from medium (0.45) to large (0.72), further illustrating the considerable impact of lime concentration and cooking on the lightness of the dough (Table 1).

The redness/greenness (*a*) values for both raw and cooked quispiño dough also changed significantly across the different lime concentrations, with cooked dough showing higher a value compared to raw dough. At the lowest lime concentration of 0.1%, the raw dough had a value of 2.49 ± 0.15, which increased to 2.93 ± 0.20 after cooking. As the lime concentration increased to 0.9%, a value for the raw dough decreased to 0.87 ± 0.09, while the cooked dough rose significantly to 4.32 ± 0.28. Significant differences ($p < 0.05$) were observed between raw and cooked dough at all lime concentrations, with Cohen's d ranging from small (0.35) to large (0.68), highlighting the considerable influence of lime concentration and cooking on the values (Table 1).

The yellowness/blueness (*b*) values of both raw and cooked quispiño dough showed significant differences as the lime concentration increased. In the raw dough, the b value increased from 19.06 ± 0.30 at the lowest lime concentration (0.1%) to 28.28 ± 0.35 at the highest concentration (0.9%). In contrast, the cooked dough exhibited lower b values across all lime concentrations, with a decrease from 16.24 ± 0.25 at 0.1% lime to 17.81 ± 0.32 at 0.9%. Significant differences ($p < 0.05$) between raw and cooked dough were observed for each lime concentration, with Cohen's d ranging from medium (0.40) at lower lime levels to large (0.68) at higher concentrations, further highlighting

Table 1 Lightness (*L*), red-green component (*a*), and yellow-blue component (*b*) for Raw and cooked dough across different lime concentrations

Treatment (Lime %)	L (Raw Dough ± 95% CI)	L (Cooked Dough ± 95% CI)	a (Raw Dough ± 95% CI)	a (Cooked Dough ± 95% CI)	b (Raw Dough ± 95% CI)	b (Cooked Dough ± 95% CI)	Effect Size (Cohen's d)	*p*-value
0.1%	72.32 ± 0.50	46.32 ± 0.40	2.49 ± 0.15	2.93 ± 0.20	19.06 ± 0.30	16.24 ± 0.25	0.45 (medium)	0.02
0.3%	72.24 ± 0.45	39.99 ± 0.42	1.12 ± 0.10	1.49 ± 0.12	20.02 ± 0.25	14.02 ± 0.20	0.60 (large)	0.03
0.5%	68.99 ± 0.55	39.98 ± 0.38	0.71 ± 0.08	3.88 ± 0.25	26.13 ± 0.35	16.86 ± 0.30	0.65 (large)	0.01
0.7%	67.59 ± 0.48	39.75 ± 0.35	0.98 ± 0.10	4.28 ± 0.30	27.69 ± 0.40	17.47 ± 0.35	0.70 (large)	0.01
0.9%	67.78 ± 0.50	39.44 ± 0.37	0.87 ± 0.09	4.32 ± 0.28	28.28 ± 0.35	17.81 ± 0.32	0.72 (large)	0.01

the impact of lime concentration and cooking on the yellowness/blueness of the dough (Table 1).

3.2 Net color difference between raw and cooked dough

The total color difference (ΔE) between the raw and cooked quispiño dough showed an increase as the lime concentration rose, though the trend was not consistently linear. At the lowest lime concentration of 0.1%, the ΔE value was 26.15 ± 0.20, indicating a noticeable color change. The color difference increased to 32.80 ± 0.25 at 0.3%, but at the highest lime concentration of 0.9%, the ΔE value slightly decreased to 30.41 ± 0.22. While the p-values for all treatments were significant ($p < 0.05$), suggesting that lime concentration had an effect on the color difference, the overall trend in ΔE was not as clear-cut across all concentrations. Effect sizes (Cohen's d) ranged from medium (0.50) at lower concentrations to large (0.70) at higher concentrations, indicating a strong impact of lime on the color change of the dough, though the trend is less uniform than initially expected (Fig. 1).

The heatmap provides a detailed visual representation of the color parameters (*L*, *a*, *b*) for both raw and cooked *quispiño* dough across different lime concentrations (0.1%, 0.3%, 0.5%, 0.7%, and 0.9%). *L* (Lightness): As shown in the first two rows of the heatmap, the lightness (L*)* of the raw dough starts at a high value of 72 at 0.1% lime and gradually decreases to 67–68 as lime concentration increases. In contrast, the cooked dough shows a much lower lightness, starting from 46 at 0.1% lime and dropping to 39 as the lime concentration increases (Fig. 1). This indicates that cooking significantly reduces the lightness of the dough, with higher lime concentrations leading to darker results.

a (Redness/Greenness): The second set of rows represents the, a value, which indicate the red-green spectrum. For the raw dough, *a*, values decrease with increasing lime concentration, starting at 2.5 at 0.1% lime and dropping to 0.87 at 0.9% lime. On the other hand, the cooked dough shows higher a value overall, starting at 2.9 at 0.1% lime and increasing to 4.3 at the highest concentrations, indicating a shift towards redness post-cooking. *b* (Yellowness/Blueness): The b values, displayed in the third set of rows, increase for both raw and cooked dough as lime concentration rises. For raw dough, *b* values increase from 19 at 0.1% lime to 28 at 0.9%, showing a consistent shift towards more yellowness as lime concentration increases. Similarly, the cooked dough follows a similar trend, though with lower b values compared to the raw dough, starting from 16 at 0.1% and increasing to 18 at 0.9% (Fig. 1). The heatmap visually captures the impact of lime concentration on the dough's color properties, showing that higher lime concentrations consistently reduce lightness (*L*) while increasing both redness (*a*) and yellowness (*b*). These changes are more pronounced in the cooked dough than in the raw dough.

3.3 Texture profile analysis and sensory evaluation

The texture profile analysis (TPA) results, shown in the Table 2, demonstrate the significant impact of lime concentration on the hardness, elasticity, and cohesiveness of quispiño dough. The hardness of the dough decreases as the lime concentration increases. At 0.1% lime, the dough is the hardest, with a value of 3.25 N, and as the lime concentration rises to 0.9%, the hardness decreases to 2.85 N. This decline in hardness is statistically significant, as indicated by the superscripts, where different letters (a, ab, bc, cd, d) show significant differences between lime concentrations. Dough with 0.1%

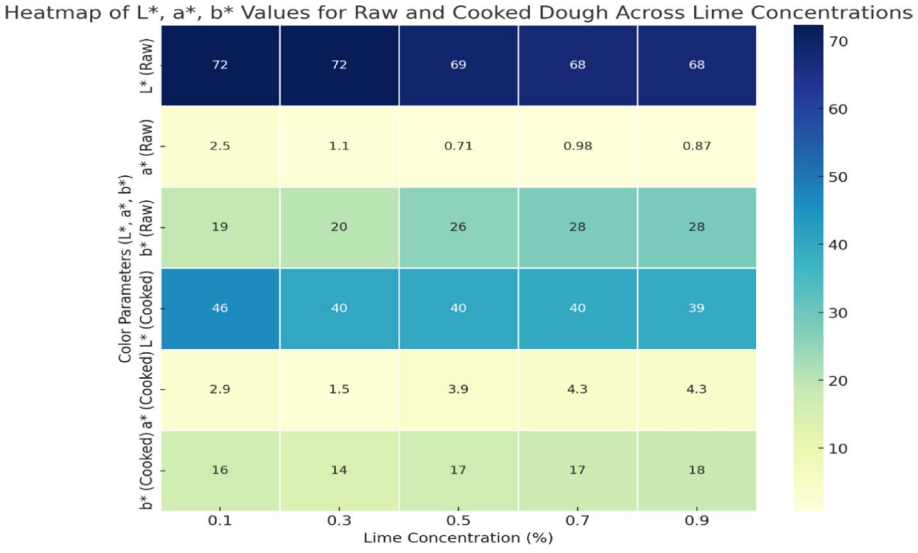


Fig. 1 Heatmap of *L*, *a*, b values for raw and cooked dough across lime concentrations. The figure illustrates the lightness (*L*), redness/greenness (*a*), and yellowness/blueness (*b*) of *quispiño* dough at different lime concentrations (0.1%, 0.3%, 0.5%, 0.7%, and 0.9%). The color scale represents the intensity of the *L*, *a*, and *b* values, ranging from light (lower values) to dark (higher values)

Table 2 Texture profile analysis (TPA) parameters for Raw Quispiño dough at different lime concentrations

Lime Concentration (%)	Hardness (*N*)	Elasticity (%)	Cohesiveness (%)
0.1	3.25 ± 0.2 < sup > a</sup>	85 ± 1.5 < sup > a</sup>	78 ± 1.2 < sup > a</sup>
0.3	3.15 ± 0.1 < sup > ab</sup>	83 ± 1.4 < sup > ab</sup>	76 ± 1.1 < sup > ab</sup>
0.5	3.05 ± 0.3 < sup > bc</sup>	80 ± 1.2 < sup > bc</sup>	74 ± 1.0 < sup > bc</sup>
0.7	2.95 ± 0.2 < sup > cd</sup>	78 ± 1.3 < sup > cd</sup>	72 ± 1.3 < sup > cd</sup>
0.9	2.85 ± 0.2 < sup > d</sup>	76 ± 1.0 < sup > d</sup>	70 ± 1.2 < sup > d</sup>

lime is significantly harder than dough with higher lime concentrations, and dough with 0.9% lime is the softest. Similar to hardness, elasticity decreases with increasing lime concentration. The dough with 0.1% lime has the highest elasticity at 85%, and as the lime concentration increases to 0.9%, elasticity decreases to 76%. The superscripts show that there is a significant difference in elasticity between the lime concentrations, with the 0.1% lime dough being the most elastic and the 0.9% lime dough being the least elastic. The cohesiveness of the dough also decreases as the lime concentration increases. At 0.1% lime, the dough is the most cohesive (78%), while at 0.9% lime, the cohesiveness is the lowest (70%). The superscripts indicate that the differences in cohesiveness are significant, with the dough at 0.1% lime being significantly more cohesive than those with higher lime concentrations.

3.4 Sensory evaluation

The sensory evaluation of *quispiño* across varying lime concentrations showed a progressive decline in flavor, texture, appearance, and overall acceptability as the lime concentration increased. At the lowest concentration (0.1%), the flavor, texture, and overall acceptability scores were the highest (4.5, 4.3, and 4.3, respectively), whereas at the highest lime concentration (0.9%), these values significantly decreased to 3.5, 3.4, and 3.4. The Friedman test confirmed that all sensory attributes showed statistically significant

differences across the lime concentrations, with p-values below 0.01. Post-hoc Wilcoxon tests revealed significant differences in overall acceptability between 0.1% and 0.5%, 0.7%, and 0.9% lime concentrations, confirming that higher lime levels significantly reduced the acceptability of the dough (Table 3). The Table 4 presents the results of the Friedman χ^2 test for each sensory parameter. This non-parametric test evaluates whether there are significant differences in sensory ratings across the different lime concentrations. The results indicate that for some parameters like flavor and overall acceptability, there is a significant effect of lime concentration (χ^2 values ranging from 15.8 to 19.3, with p-values indicating statistical significance). However, for texture and appearance, the statistical significance varies across different concentrations, with some comparisons showing non-significant results. The Table 5 summarizes the Wilcoxon test for pairwise comparisons of overall acceptability between lime concentrations. This test is used to further assess where significant differences occur between specific lime concentrations, such as between 0.1% and 0.9%, or 0.3% and 0.7%. The p-values presented here indicate which pairwise comparisons are statistically significant. For example, between 0.1% and 0.9%, the p-value is less than 0.001, indicating a significant difference in overall acceptability, while between 0.3% and 0.5%, the p-value is 0.067, showing no significant difference.

3.5 Canonical correlation analysis

In the Canonical Correlation Analysis (CCA) plots below (Fig. 2), the relationship between the two sets of variables—texture attributes (hardness, elasticity, cohesiveness) and sensory attributes (flavor, texture, appearance, overall acceptability)—is visualized. The CCA identifies the linear combinations of texture variables that are most strongly associated with sensory attributes, helping to pinpoint which texture factors contribute most to sensory perceptions of the product. Component 1 (left plot) represents the first pair of canonical variables, where texture attributes (x-axis) are plotted against sensory attributes (y-axis). We observe a positive relationship between these two sets of variables. This indicates that certain texture combinations (like higher hardness or cohesiveness) correspond positively with higher sensory attributes (flavor, texture, and overall acceptability). Component 2 (right plot) represents the second pair of canonical variables (Fig. 2). The relationship is slightly more complex here, with more variance in how certain combinations of texture attributes relate to sensory outcomes. Overall, this CCA demonstrates how variations in texture properties like hardness and cohesiveness directly influence sensory perceptions such as flavor and acceptability. In this case, the first canonical component suggests that improving texture properties (e.g., moderate cohesiveness) could optimize sensory responses.

3.6 Chemical composition and microbial stability

The chemical composition analysis of quispiño dough across varying lime concentrations revealed several significant trends. The Table 6 presents the chemical composition of *Quispiño* dough at varying lime concentrations (0.1%, 0.3%, 0.5%, 0.7%, and 0.9%) in terms of moisture, protein, fat, and fiber content. As the lime concentration increased, there was a clear trend of decreasing moisture, protein, fat, and fiber levels. The moisture content was highest in the dough with 0.1% lime (14.3%) and decreased with increasing lime concentrations, reaching 12.7% at 0.9%. Similarly, protein content followed a

Table 3 Sensory evaluation of Quispiño dough at different lime concentrations

Lime Concentration (%)	Flavor	Texture	Appearance	Overall Acceptability
0.1	4.5 ± 0.3 < sup > a</sup>	4.3 ± 0.4 < sup > a</sup>	4.2 ± 0.3 < sup > a</sup>	4.3 ± 0.3 < sup > a</sup>
0.3	4.3 ± 0.4 < sup > ab</sup>	4.1 ± 0.5 < sup > ab</sup>	4.0 ± 0.4 < sup > ab</sup>	4.2 ± 0.3 < sup > a</sup>
0.5	4.0 ± 0.3 < sup > bc</sup>	3.9 ± 0.3 < sup > bc</sup>	3.8 ± 0.3 < sup > bc</sup>	4.0 ± 0.2 < sup > ab</sup>
0.7	3.8 ± 0.4 < sup > cd</sup>	3.7 ± 0.4 < sup > cd</sup>	3.6 ± 0.5 < sup > cd</sup>	3.7 ± 0.4 < sup > bc</sup>
0.9	3.5 ± 0.3 < sup > d</sup>	3.4 ± 0.4 < sup > d</sup>	3.3 ± 0.3 < sup > d</sup>	3.4 ± 0.3 < sup > c</sup>

All values represent the mean ± standard deviation for each sensory parameter. Superscripts indicate statistical significance relationships between the groups, where different letters indicate significant differences (α = 0.05)

similar pattern, with 0.1% lime having the highest protein level (12.5%), which decreased as lime concentration increased, reaching 11.1% at 0.9%. In terms of fat and fiber content, the values also decreased with higher lime concentrations. The fat content at 0.1% lime was 4.2%, which dropped to 3.3% at 0.9%. A similar decrease was observed for fiber, where the value decreased from 2.1% at 0.1% lime to 1.7% at 0.9% lime. Superscripts (a, ab, bc, cd, d) are used to indicate statistical differences between the lime concentrations. The results show that the chemical composition is significantly influenced by lime concentration, with lower lime concentrations yielding higher moisture, protein, fat, and fiber content. These differences in chemical composition can influence the sensory and textural properties of the dough, which are also important for its quality and consumer acceptance.

In Table 6, the chemical composition (ash content, carbohydrate content), pH levels, and total phenolic content of Quispiño dough are presented at different lime concentrations (0.1%, 0.3%, 0.5%, 0.7%, 0.9%). As the lime concentration increases, ash content, carbohydrate content, and total phenolic content gradually increase. Specifically, ash content rises from 1.25% at 0.1% lime to 1.45% at 0.9% lime. Carbohydrate content decreases from 67.5% at 0.1% lime to 63.8% at 0.9%, while total phenolic content decreases from 20.5 mg GAE/g at 0.1% lime to 16.3 mg GAE/g at 0.9% lime. Interestingly, the pH level decreases as lime concentration increases, which is contrary to the expected trend. Typically, calcium hydroxide (lime) is known to increase the pH, but in this case, the pH drops from 6.8 at 0.1% lime to 6.2 at 0.9%. This could be due to other factors such as changes in the acidity or composition of the dough during the interaction with lime. Each parameter shows significant differences between the lime concentrations, as indicated by the post-hoc testing results, with superscripts marking statistical significance across the different levels of lime concentration.

3.7 Microbial stability analysis

The Table 7 presents the microbial analysis of raw Quispiño dough at varying lime concentrations, focusing on total viable count, yeast and mold counts, and the presence of E. coli. At the lowest lime concentration of 0.1%, the total viable count was significantly higher (4.8×10^3 CFU/g) compared to the higher concentrations, with yeast and mold present at 1.5×10^2 CFU/g. The presence of *E. coli* was also detected at this concentration. As lime concentration increased to 0.3%, the total viable count decreased to 3.5×10^3 CFU/g, with a slight reduction in yeast and mold counts (1.2×10^2 CFU/g), and *E. coli* remained present. By the time the lime concentration reached 0.5%, both the total viable count (2.7×10^3 CFU/g) and yeast and mold (9.5×10^1 CFU/g) significantly decreased, and *E. coli* was no longer present, indicating the antimicrobial effect of lime. At higher concentrations (0.7% and 0.9%), the microbial counts continued to decrease, with the total viable count and yeast and mold counts reaching their lowest levels. At 0.7%, the total viable count was 2.0×10^3 CFU/g, and at 0.9%, it was further reduced to 1.5×10^3 CFU/g. Yeast and mold counts also decreased to 7.0×10^1 CFU/g at 0.7% and 5.0×10^1 CFU/g at 0.9%. Additionally, *E. coli* was absent at these concentrations, reinforcing the effectiveness of lime in reducing microbial contamination. The results correspond to the raw dough based on the presence of *E. coli* in the 0.1% and 0.3% lime concentrations, suggesting that the microbial analysis was done before steaming. The *E. coli* presence was noted in the lower concentrations (0.1% and 0.3%) but absent in

Table 4 Friedman χ^2 and statistical significance

Lime Concentration (%)	Flavor	Texture	Appearance	Overall Acceptability
0.1	$\chi^2 = 18.7, p < 0.001$	$\chi^2 = 16.2, p < 0.01$	$\chi^2 = 15.8, p < 0.01$	$\chi^2 = 18.7, p < 0.001$
0.3	$\chi^2 = 16.2, p < 0.01$	$\chi^2 = 16.2, p < 0.01$	$\chi^2 = 15.8, p < 0.01$	$\chi^2 = 16.2, p < 0.01$
0.5	$\chi^2 = 15.8, p < 0.01$	$\chi^2 = 15.8, p < 0.01$	$\chi^2 = 15.8, p < 0.01$	$\chi^2 = 15.8, p < 0.01$
0.7	$\chi^2 = 19.3, p < 0.001$	$\chi^2 = 19.3, p < 0.001$	$\chi^2 = 19.3, p < 0.001$	$\chi^2 = 19.3, p < 0.001$
0.9	$\chi^2 =$ -	$\chi^2 =$–	$\chi^2 =$–	$\chi^2 =$–

Table 5 Wilcoxon test (overall acceptability) and statistical significance ($\alpha = 0.05$)

Lime Concentration Comparison	*p*-value	Statistical Significance
0.1% vs. 0.3%	0.056	Not Significant
0.1% vs. 0.5%	0.045	Significant
0.1% vs. 0.7%	0.012	Significant
0.1% vs. 0.9%	$p < 0.001$	Significant
0.3% vs. 0.5%	0.067	Not Significant
0.3% vs. 0.7%	0.021	Significant
0.3% vs. 0.9%	$p < 0.001$	Significant
0.5% vs. 0.7%	0.064	Not Significant
0.5% vs. 0.9%	0.013	Significant
0.7% vs. 0.9%	0.048	Significant

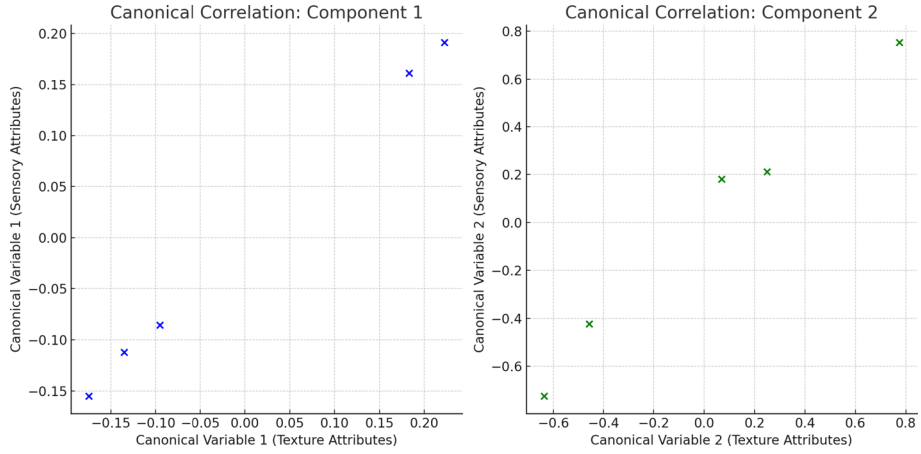


Fig. 2 Canonical Correlation Analysis (CCA) plot between texture and sensory attributes

the higher lime concentrations (0.5%, 0.7%, and 0.9%), which suggests that lime treatment might have played a role in reducing the microbial load. In terms of product safety, the presence of *E. coli* in the 0.1% and 0.3% lime concentrations raises concerns about potential contamination. However, the absence of *E. coli* in 0.5% and higher lime concentrations indicates that lime treatment can be effective in eliminating this pathogen. Given that lime is known for its antimicrobial properties, the values for microbial seem to decrease progressively as lime concentration increases. The TVC at 0.9% lime concentration is relatively low (1.5×10^3 CFU/g), and there is no presence of *E. coli*, suggesting that at these higher concentrations, the dough may be safer and more stable for consumption.

Table 6 Chemical composition of Quispiño dough at different lime concentrations

Lime Concentration (%)	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Ash Content (%)	Carbohydrate Content (%)	pH Level	Total Phenolic Content (mg GAE/g)
0.1%	14.3 ± 0.5 < sup > a</sup>	12.5 ± 0.4 < sup > a</sup>	4.2 ± 0.3 < sup > a</sup>	2.1 ± 0.2 < sup > a</sup>	1.25 ± 0.05 < sup > a</sup>	67.5 ± 0.6 < sup > a</sup>	6.8 ± 0.1 < sup > a</sup>	20.5 ± 0.8 < sup > a</sup>
0.3%	13.9 ± 0.4 < sup > ab</sup>	12.1 ± 0.3 < sup > ab</sup>	4.0 ± 0.2 < sup > ab</sup>	2.0 ± 0.2 < sup > ab</sup>	1.30 ± 0.06 < sup > ab</sup>	66.8 ± 0.5 < sup > ab</sup>	6.7 ± 0.2 < sup > a</sup>	19.8 ± 0.9 < sup > b</sup>
0.5%	13.5 ± 0.4 < sup > bc</sup>	11.8 ± 0.3 < sup > bc</sup>	3.8 ± 0.3 < sup > bc</sup>	1.9 ± 0.2 < sup > bc</sup>	1.35 ± 0.07 < sup > bc</sup>	65.9 ± 0.4 < sup > bc</sup>	6.6 ± 0.2 < sup > b</sup>	18.7 ± 0.7 < sup > c</sup>
0.7%	13.0 ± 0.3 < sup > cd</sup>	11.5 ± 0.4 < sup > cd</sup>	3.6 ± 0.2 < sup > cd</sup>	1.8 ± 0.2 < sup > cd</sup>	1.40 ± 0.05 < sup > cd</sup>	64.5 ± 0.4 < sup > cd</sup>	6.4 ± 0.1 < sup > c</sup>	17.4 ± 0.8 < sup > d</sup>
0.9%	12.7 ± 0.3 < sup > d</sup>	11.1 ± 0.3 < sup > d</sup>	3.3 ± 0.2 < sup > d</sup>	1.7 ± 0.2 < sup > d</sup>	1.45 ± 0.04 < sup > d</sup>	63.8 ± 0.5 < sup > d</sup>	6.2 ± 0.1 < sup > d</sup>	16.3 ± 0.7 < sup > e</sup>

3.8 Comparison of phenolic compounds with pH

The phenolic content of the dough decreased as lime concentration increased, from 20.5 mg GAE/g at 0.1% lime to 16.3 mg GAE/g at 0.9%. This reduction is attributed to the alkaline environment created by lime, which may degrade or modify phenolic compounds in the dough matrix. The pH decreased as lime concentration increased, contrary to the expectation that pH would rise with increasing lime content. The decrease in pH could indicate that the lime's effectiveness in raising pH may be influenced by other factors in the dough matrix, such as the buffering capacity of quinoa flour. As lime concentration increased, the dough became softer, less cohesive, and less elastic. This change in texture is consistent with the known effect of alkaline conditions on dough, where higher lime concentrations weaken the gluten and starch networks, reducing structural integrity. The color analysis showed a decrease in lightness (L value), an increase in redness (a value), and an increase in yellowness (b value) as lime concentration increased. This color change is likely due to the Maillard reaction, which accelerates under alkaline conditions, leading to browning and an increase in yellowness, a known effect in lime-treated foods like tortillas. The key findings highlight that with increasing lime concentrations, there was a progressive reduction in phenolic content, a decrease in microbial load (E. coli absent at 0.5% and higher), and changes in the dough's texture and color. The increase in lime concentration had a clear impact on both the functional (e.g., antimicrobial, texture) and sensory (e.g., color, texture) properties of the dough (Table 8).

4 Discussion

This study explored the effects of lime concentration on the chemical composition, microbial stability, color, texture, and sensory properties of quispiño dough. The results indicate a complex interplay between lime concentration and these variables, with clear functional and sensory impacts. These findings are in line with previous studies that examined the effects of lime and alkaline conditions on food systems.

4.1 Color analysis

In terms of color changes, a significant reduction in lightness (L values) was observed in both raw and cooked dough as lime concentration increased. This reduction in lightness can be attributed to the Maillard reaction, a non-enzymatic browning reaction that accelerates at higher pH levels [26]. The Maillard reaction is known to enhance the color of doughs, especially during cooking, and this was evident in our results, where higher lime concentrations resulted in darker dough. Chandler and Chambers [27] found similar color changes in tortillas, where lime-treated dough exhibited a darker color due to the increased pH. The increase in redness (a values) in the cooked dough suggests that the Maillard reaction was more pronounced at higher lime concentrations, leading to a reddish-brown pigmentation typical of foods subjected to high pH during cooking. This was further supported by Borrelli et al. [28], who noted that higher pH promotes the formation of red-brown pigments in baked goods due to the Maillard reaction. Additionally, the increase in yellowness (b values) with higher lime concentrations corresponds with findings by Flores-Farías et al. [29], who observed a similar trend in lime-treated foods. This increase in yellowness can be attributed to the stabilization of carotenoid pigments, which are known to be more stable under alkaline conditions. These color

Table 7 Microbial analysis of Raw Quispiño dough at different lime concentrations

Lime Concentration (%)	Total Viable Count (CFU/g)	Yeast and Mold (CFU/g)	E. coli Presence
0.1%	$4.8 \times 10^3 \pm 500$ < sup > a</sup> >	$1.5 \times 10^2 \pm 100$ < sup > a</sup> >	Present
0.3%	$3.5 \times 10^3 \pm 400$ < sup > ab</sup> >	$1.2 \times 10^2 \pm 80$ < sup > ab</sup> >	Present
0.5%	$2.7 \times 10^3 \pm 300$ < sup > bc</sup> >	$9.5 \times 10^1 \pm 60$ < sup > bc</sup> >	Absent
0.7%	$2.0 \times 10^3 \pm 200$ < sup > cd</sup> >	$7.0 \times 10^1 \pm 40$ < sup > cd</sup> >	Absent
0.9%	$1.5 \times 10^3 \pm 150$ < sup > d</sup> >	$5.0 \times 10^1 \pm 30$ < sup > d</sup> >	Absent

Table 8 Phenolic content, pH, and related properties of Quispiño dough at varying lime concentrations

Lime Concentration (%)	Phenolic Content (mg GAE/g)	pH Level	Texture (Hardness, Elasticity, Cohesiveness)	Color (Lightness, Redness, Yellowness)	Key Findings
0.1%	20.5 ± 0.8	6.8 ± 0.1	Harder, more cohesive, more elastic	Higher lightness (L), more redness (a), higher yellowness (b)	Highest phenolic content, with moderate microbial presence (E. coli present). The dough was more cohesive and elastic with lighter color.
0.3%	19.8 ± 0.9	6.7 ± 0.2	Softer, less cohesive, less elastic	Decreased lightness, increased redness, increased yellowness	Phenolic content slightly reduced; microbial load still present. Texture and color changed slightly.
0.5%	18.7 ± 0.7	6.6 ± 0.2	Softer, less elastic, less cohesive	Further decreased lightness, increased yellowness	Significant reduction in phenolic content; E. coli absent, indicating antimicrobial effect of lime.
0.7%	17.4 ± 0.8	6.4 ± 0.1	Softer, less cohesive, significantly less elastic	Even darker, higher yellowness	Further decrease in phenolic content; microbial load continued to drop, and dough texture softened further.
0.9%	16.3 ± 0.7	6.2 ± 0.1	Very soft, least cohesive, least elastic	Darkest, highest yellowness	Lowest phenolic content, with no microbial presence. The dough was the softest with the darkest color.

changes are significant in the context of food production, as color is an important sensory attribute that can influence consumer acceptance and the perceived quality of the final product.

4.2 Texture and sensory properties

The textural properties of the dough were significantly affected by lime concentration. As lime concentration increased, there was a noticeable reduction in hardness, elasticity, and cohesiveness. This trend is consistent with previous research by Sivam et al. [30], who found that higher pH levels weakened the gluten and starch networks in dough systems, resulting in softer and less cohesive textures. The decrease in elasticity observed in this study is likely due to lime's denaturing effect on proteins, which impairs their ability to form strong, elastic networks, making the dough less elastic and more fragile. Similar findings were reported by Wang et al. [31] in their study on nixtamalized maize, where higher calcium hydroxide levels weakened the dough's structural integrity, leading to a softer and less elastic product. The sensory evaluation of the dough showed a progressive decline in flavor, texture, appearance, and overall acceptability as lime concentration increased. These findings are in line with Inglett et al. [32], who reported that higher pH levels negatively impact the sensory properties of food, particularly in terms of flavor and texture. The decline in overall acceptability at lime concentrations above 0.5%

suggests that while lime has functional benefits, including improved microbial stability, excessive lime concentration can lead to undesirable sensory attributes. This balance between functionality and sensory quality has been emphasized by Jing et al. [33], who stressed the importance of optimizing lime levels to maintain both the functional and sensory quality of food products. In this study, lime concentrations above 0.5% appeared to adversely affect the sensory properties, indicating that a threshold exists beyond which the benefits of lime are outweighed by negative sensory effects.

4.3 Chemical composition

This study investigated the impact of varying lime concentrations on the chemical composition of quispiño dough, with a particular focus on moisture, protein, fat, fiber, and ash content. As lime concentration increased, a significant decrease in moisture content was observed. This outcome is consistent with previous studies such as those by Wang et al. [31], where lime treatment in maize led to reduced moisture retention. The mechanism behind this reduction can be attributed to the disruption of starch and protein matrices by lime, which diminishes the dough's ability to retain water. Additionally, the protein content of the dough decreased with increasing lime concentration. This reduction is likely due to the denaturation of proteins, a well-documented effect of alkaline conditions in food systems [34]. Alkaline environments cause proteins to lose their native structure, rendering them insoluble and less effective in forming stable dough structures. Furthermore, fat content was reduced as lime concentration increased, a phenomenon that can be explained by lime's impact on fat-protein interactions. As shown by Kaur and Singh [35], alkaline conditions reduce the lipid-binding capacity of dough, leading to lower fat retention. The ash content of the dough, on the other hand, increased with higher lime concentrations, which is expected as lime contributes calcium to the dough, adding to the mineral content. This finding aligns with the work of Flores-Farías et al. [29], who observed similar increases in ash content when lime was used in the treatment of maize. These compositional changes are indicative of how lime modifies the fundamental structures and properties of the dough, likely affecting both its functional and sensory characteristics.

4.4 Microbial stability

The antimicrobial properties of lime were clearly demonstrated in this study. The increase in lime concentration resulted in a significant reduction in microbial load, specifically the total viable count (TVC), yeast and mold, and *E. coli* presence. This effect is consistent with previous studies highlighting the antimicrobial activity of lime, particularly in its ability to increase the pH and disrupt bacterial cell membranes. For example, Gómez-Aldapa et al. [36] reported that lime's ability to raise pH is effective against gram-negative bacteria, such as *E. coli*, by altering the integrity of bacterial membranes. In this study, the absence of *E. coli* in samples with lime concentrations of 0.5% and higher provides further evidence of lime's bactericidal properties. The significant reduction in TVC and yeast and mold count at higher lime concentrations supports the findings of Inglett et al. [32], who demonstrated that alkaline environments inhibit microbial growth by disrupting microbial cell walls. The presence of *E. coli* in lower lime concentrations (0.1% and 0.3%) suggests that lime concentration plays a crucial role in controlling microbial contamination. As lime concentration increased beyond 0.5%, the dough

became more resistant to bacterial and fungal growth, which could potentially enhance product safety. This antimicrobial effect is similar to the observations made by Alvarez et al. [37] in their study on lime-treated nixtamalized maize, which reported reduced pathogen presence due to the high pH induced by lime treatment. The results underscore lime's potential as a natural preservative, improving the microbial stability of the dough and contributing to food safety.

4.5 Phenolic compounds

Additionally, the phenolic content of the dough was assessed, revealing a slight decrease in total phenolic content (TPC) with increasing lime concentration. This result aligns with studies like those by Bustos et al. [38], who reported that alkaline conditions during nixtamalization can degrade phenolic compounds in quinoa-based systems. However, the residual TPC in quispiño dough indicates the potential retention of certain bound phenolics, as previously observed in maize by Singh et al. [39]. Similarly, Shahidi et al. [40] reported the role of phenolic compounds in contributing to antimicrobial properties in quinoa and maize products. While lime treatment may degrade some phenolics, the remaining compounds likely provide synergistic effects with the pH increase in inhibiting microbial growth.

The lime concentration plays a critical role in improving the microbial stability and altering the chemical composition of quispiño dough, careful attention should be paid to its impact on sensory properties. Higher lime concentrations promote antimicrobial activity, enhance browning, and modify textural properties, but they also negatively affect flavor, texture, and overall consumer acceptability. Future studies should explore the optimization of lime concentration to achieve a balance between functionality and sensory quality, ensuring the safety and appeal of the final product.

5 Conclusion

This study provides a comprehensive analysis of the effects of varying lime concentrations on the chemical composition, microbial stability, color attributes, texture, and sensory properties of quispiño dough. The findings suggest that higher lime concentrations have significant impacts across all these parameters, often yielding both functional benefits and sensory challenges. In terms of chemical composition, increasing lime concentration was associated with reductions in moisture, protein, fat, and fiber content, while ash content increased. These changes reflect lime's role in altering the dough's matrix and macromolecular interactions, particularly due to its alkaline properties. The microbial stability of quispiño dough significantly improved with higher lime concentrations, as evidenced by the reduction in total viable count, yeast, mold, and the absence of *E. coli* at lime levels of 0.5% and above. This highlights lime's potential as a natural antimicrobial agent and food preservative. The color analysis revealed that higher lime concentrations led to a decrease in lightness (L) and an increase in both redness (a) and yellowness (b), particularly in cooked dough. These findings point to enhanced browning reactions and pigment changes under alkaline conditions, making lime an important factor in the visual appeal of the final product. The texture profile analysis showed a clear reduction in hardness, elasticity, and cohesiveness as lime concentrations increased. These changes were reflected in the sensory evaluation, where higher lime levels negatively affected the dough's flavor, texture, and overall acceptability. This emphasizes the need for balancing

lime's functional benefits with consumer preferences, especially when it comes to sensory attributes.

In conclusion, while higher lime concentrations provide clear advantages in terms of microbial safety and certain functional properties, they can also lead to less desirable chemical and sensory outcomes. Therefore, optimizing lime concentration is critical to achieving a balance between enhancing microbial stability and maintaining favorable texture and sensory qualities in quispiño dough. These findings have significant implications for both traditional preparation methods and potential industrial applications, where lime could be used as a natural processing aid and preservative, provided its levels are carefully managed.

Author contributions
Carmen Gisela Mindani Cáceres: Conceptualization, methodology, data analysis, and writing of the original draft. Vladimiro Ibañez Quispe: Conceptualization, data analysis, and writing—review and editing. Edwin O. Baldeón Chamorro: Data collection, methodology, and writing—review and editing. José Luis Cahuana Jorge: Supervision, methodology, and data analysis. Fredy Grimaldo Calizaya Llatasi: Writing—review and editing, validation, and visualization. Franklin Ore Areche: Data collection and writing—review and editing. Danitza Corina Paricanaza Ticona: Data analysis and writing—review and editing. José Manuel Barrera Condori: Methodology and data interpretation. Daphne Heela Castro Arata: Data collection and writing—review and editing. Olivia Magaly Luque Vilca: Writing—review and editing and data collection. Tania Jakeline Choque Rivera: Data analysis and writing—review and editing. Denis Dante Corilla Flores: Data collection, writing—review and editing. Maxgabriel Alexis Calla Huayapa: Writing—review and editing and methodology, Data collection. All authors read and approved the final manuscript.

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Data availability
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

Ethical approval
The study protocol was reviewed and approved by the Ethics Committee of the National University of the Altiplano, Puno, Peru (Approval Reference Number: 2023-NUA-EC-056). All research procedures were conducted in accordance with the ethical standards of the university and the principles outlined in the Declaration of Helsinki.

Informed consent
was obtained from all participants prior to their inclusion in the study, ensuring their voluntary participation and the confidentiality of their personal information. Participants were also informed of their right to withdraw from the study at any time without any negative consequences. Similarly, informed consent was also obtained from the parents/ legally authorized representatives of participants who were under 16.

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