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Physicochemical characteristics and consumer perception of artisanal-style soy-based burgers containing pea, cañihua, chickpea, quinoa, or wheat flours

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ABSTRACT

In the search for more sustainable and healthier foods, academic and industrial attention has focused on developing plant-based alternatives to meat products, but the use of synthetic additives and a high degree of processing have led to their classification as ultra-processed foods. In response, this study explores an artisanal processing alternative for obtaining plant-based burgers. The plant-based burgers were made with cooked soybean paste as the main ingredient, combined with 15% (w/w) of pea, cañihua, chickpea, quinoa, or wheat flour. The proximate composition varied with the type of flour. Quinoa increased protein and fat content and decreased carbohydrates, cañihua increased crude fiber, and pea flour increased moisture. Instrumental lightness (L*) in both raw and cooked burgers decreased with the addition of cañihua flour, as well as redness (a*) after cooking. No differences were observed in instrumental hardness, springiness, cohesiveness, or chewiness, nor in cooking losses ($P > 0.05$). Using the free comment method, the sensory attributes that characterized the burgers were identified. Burgers containing chickpea flour were highlighted as being associated with the attributes “tasty” and “tender”, while burgers containing cañihua flour were highlighted with negative attributes such as “bitter”, “burnt”, “brown”, “crispy”, “dry”, and “sandy”. Thus, chickpea flour increased the overall liking and purchase intention of the burgers. It is necessary to evaluate the product's instrumental and sensory stability, and compare it with meat-based burgers, to further explore this artisanal approach as a plant-based alternative available to consumers.

1. Introduction

Currently, consumers are increasingly interested in modifying their eating habits, particularly regarding reducing their consumption of animal products, due to health, climate change, and animal welfare concerns (World Health Organization - WHO, 2021). In this context, plant-based meat analogues have emerged as products that attempt to mimic the characteristics of conventional meat products. However, while projections for the global meat analogue market indicate expansion, technological, nutritional, and sensory challenges remain for these products to gain popularity and consumer preference (Xavier et al., 2025).

Certainly, alternatives have been proposed to improve the characteristics of meat analogues, such as combining soy, pea, and wheat

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proteins with structured oils and polysaccharides, and applying technologies such as high-moisture extrusion and controlled fermentation (Eduardo et al., 2026). Nevertheless, the cost of implementing these technologies is pivotal to ensuring the success of meat analogues. Despite this concern, it has recently been suggested that price, taste, and convenience are not determining factors in matching or surpassing the preference for meat analogues over animal-based products (Peacock, 2026), so finding the best alternative to mimic the characteristics of animal products could be considered an exhausting task. This may be obvious, as these are products with distinct biological categories, for which plant-based industrial efforts have led to the use of additives and unit operations, to the point of being considered "ultra-processed" options (Sultan et al., 2024).

Changing the image of meat analogues as "ultra-processed" foods involves minimal processing or the reduction of additives under a clean-label approach, strategies that have not been addressed in academia for plant-based meat analogues. However, it is not uncommon to find countless alternatives to, for example, "veggie burgers" through a simple Google search for recipes, using homemade, simple, and additive-free methods. These methods, which can be carried out on a small scale and by hand, are often considered artisanal (Nguyen et al., 2023), and specific cases have been reported of artisanal grains, coffee, ice cream, cheeses, and chocolates being perceived as tasting better and being healthier than their industrial counterparts (Cirne et al., 2019). Based on this premise, the commercial availability of artisanal-style meat analogues presents an opportunity to increase their popularity as healthier and sustainable alternatives, especially in contexts where the industrial development of plant-based meat analogues remains limited (Inguglia et al., 2023; Inguglia et al., 2023; Pointke et al., 2022).

Among the protein-rich plant resources currently explored in plant-based formulations, quinoa (*Chenopodium quinoa* Willd.) is recognized as a globally relevant pseudocereal (Bruno, 2014). Within the same category of pseudocereals, cañihua (*Chenopodium pallidicaule* Aellen) also stands out, with protein levels of 15–19%, similar to those of quinoa (Moscoso-Mujica et al., 2024). Due to this nutritional component, the inclusion of both has been suggested in meat analogue formulations, as they can contribute to the product's firmness, cohesiveness, and juiciness, as well as their emulsifying and gelling properties, allowing the formation of a fibrous structure similar to that of meat (Quevedo-Olaya et al., 2025). On the other hand, meat analogue formulations are usually based on more well-known protein sources, with soy being the most popular, mainly due to its availability and low cost (Ishaq et al., 2022; Miller et al., 2024), but a recent bibliometric and systematic review shows that pea and wheat have also been widely used in various studies (Eduardo et al., 2026). Another promising source is chickpea, not only for its suggested use in formulations of plant-based meat analogues (Eduardo et al., 2026; Imran et al., 2026; Mercês et al., 2024), but also for its potential to improve the sensory notes of products such as burgers by acting as a partial meat substitute (Mariod & Abd Elagdir, 2024).

The five flours were selected to cover a representative set of plant ingredients with complementary technological roles. Pea flour was included as a representative legume protein with documented water-holding capacity in burger matrices (Ball et al., 2021; Da Silva et al., 2024). Cañihua flour was selected as the central non-conventional ingredient, given its protein content comparable to quinoa and its underutilized status in plant-based meat formulations (Estalla et al., 2026; Moscoso-Mujica et al., 2024). Chickpea flour was included for its documented capacity to act as a partial meat substitute and to contribute roasted, pleasant flavor notes (Kotsiou et al., 2022; Mariod & Abd Elagdir, 2024). Quinoa flour was added as the most common Andean pseudocereal reported in plant-based burgers (Eduardo et al., 2026). Wheat flour was included as a conventional cereal reference, providing gluten as a binding component.

A latent need in the plant-based meat analogues industry is to conduct sensory tests to evaluate whether investments in product development meet consumer expectations (Peacock, 2026). Within this framework, and using burgers as a case study, this work aimed to evaluate formulations of artisanal-style soy-based burgers containing pea, cañihua, chickpea, quinoa, or wheat flours, and to assess the physicochemical characteristics and consumer perceptions through free comments. The proposal presented here could be an alternative way to develop minimally processed, clean-label, healthy, and sustainable plant-based products.

2. Material and methods

2.1. Materials and burger manufacture

Soybeans, roasted flours of pea, cañihua, chickpea, quinoa (white variety), and wheat, sunflower oil, beetroot, salt, onion powder, garlic powder, and black pepper powder were obtained from a local supermarket in the city of Jaén, Peru.

The main component of the burgers was soybean paste, made by boiling soybeans for 30 min and then grinding them into a homogeneous paste. Beetroot juice was used as a coloring agent in the product, obtained by boiling beets for 30 min, then pressing the cooked beets with a domestic juicer and filtering the juice through cheesecloth to remove any lumps. The roasted flours were sieved through a 60-mesh stainless steel sieve (<250 μm) to ensure uniform particle size. The burgers were manufactured by manually mixing all the components for 3 min. Then, 100 g portions were molded into cylindrical shapes of 10 cm in diameter and 1 cm thick using a plastic mold. The quantities of the formulation components for each treatment are shown in Table 1.

For each treatment, three independent batches were prepared on three different days to obtain block replicates (RCBD). Each batch yielded approximately 2.5 kg of burger mass, which was divided into 25 cylindrical portions of 100 g (10 cm diameter, 1 cm thickness). Across batches, consistency was secured by the following standardized conditions. A single operator carried out all the manufacturing steps, the same domestic equipment was used for boiling, grinding and forming, all components were weighed with the same calibrated balance (± 0.01 g), the mixing time was set at 3 min for every batch, and portions were weighed individually to 100 ± 1 g before forming. This batch-and-block structure is consistent with that adopted in recent peer-reviewed research on burger reformulation (Coaguila Gonza et al., 2026; de Araújo et al., 2025; Peñaranda et al., 2023; Santana et al., 2026). The burgers were stored at –18°C until analysis. Prior to cooking, frozen burgers were thawed under refrigeration at 4 °C for 24 h (Peñaranda et al., 2023). For analyses of cooked samples, the burgers were cooked on an electric hot plate at 150–180 °C until the internal temperature reached 75 °C.

The artisanal-style approach followed in this study is defined by two operational choices. First, the formulation relies on whole-seed flours

Table 1
Artisanal-style soy-based burger formulations containing pea, cañihua, chickpea, quinoa, or wheat flours.

Components (%)	Treatments				
	Pea	Cañihua	Chickpea	Quinoa	Wheat
Soybean paste	65.23	65.23	65.23	65.23	65.23
Pea flour	15	-	-	-	-
Cañihua flour	-	15	-	-	-
Chickpea flour	-	-	15	-	-
Quinoa (white variety) flour	-	-	-	15	-
Wheat flour	-	-	-	-	15
Sunflower oil	10	10	10	10	10
Beetroot juice	7.5	7.5	7.5	7.5	7.5
Salt	1.5	1.5	1.5	1.5	1.5
Onion powder	0.29	0.29	0.29	0.29	0.29
Garlic powder	0.29	0.29	0.29	0.29	0.29
Black pepper powder	0.19	0.19	0.19	0.19	0.19
Total	100%	100%	100%	100%	100%

(pea, cañihua, chickpea, quinoa, wheat) and cooked soybean paste, without the use of textured vegetable protein, isolated protein concentrates, methylcellulose, transglutaminase, hydrocolloids, flavor maskers, or synthetic colorants commonly found in commercial plant-based burgers (Inguglia et al., 2023; Pointke et al., 2022). Second, every unit operation (boiling, grinding, sieving, manual mixing, forming) is performed at small scale and by hand, without industrial unit operations such as extrusion or high-shear mixing. The combination of these choices reflects current clean-label trends in both the meat-product and plant-based product categories.

2.2. Physicochemical characteristics

2.2.1. Proximate composition

Proximate composition was determined according to AOAC official methods (AOAC, 2005) in cooked burgers. Moisture content was determined using the thermogravimetric method 950.46 using a moisture analyzer (Sartorius, MA35, Germany) at 105 °C. Fat content was determined using a Soxhlet system (Fisatom, 22–6, Brazil) with petroleum ether as the solvent (method 960.39). Protein content was calculated using the Kjeldahl method in a digester and distiller (Behrotest, K8-SR3, Germany), considering the total nitrogen content and a protein conversion factor of 6.25 (method 981.10). Ash content was analyzed using a muffle furnace (Thermo Scientific, Furnace 1400, USA) at 550 °C (method 920.153). Crude fiber was determined using the sequential method of acid digestion with 1.25% sulfuric acid and alkaline digestion with 1.25% sodium hydroxide, followed by gravimetric determination (method 962.09). Carbohydrates were calculated by the percentage difference of 100 minus the sum of the percentages of moisture, fat, protein, ash, and crude fiber.

2.2.2. Instrumental color

The color parameters lightness (L*), redness (a*), and yellowness (b*) were determined for raw and cooked burgers using a computer vision system (Saldaña et al., 2014), as described by Arteaga et al. (2021). An Android smartphone (Galaxy S24 Ultra-Samsung) was used to capture images of the samples, which were then evaluated using the IP-WEBCAM-COLOR FOOD PROCESSING algorithm implemented in MatLab® R2016a (MathWorks®, Natick, MA, USA).

2.2.3. Texture profile analysis

The texture parameters of hardness (Newton, N), springiness, cohesiveness, and chewiness (N) were determined in cooked burgers using a texture analyzer (Perkin Elmer, TVT 6700, Australia) coupled to a 3.5 cm diameter cylindrical probe. After cooking (hot plate between 150 and 180 °C, internal burger temperature of 75 °C), the burgers were cooled to room temperature, and then cylindrical samples of 2.5 cm diameter were extracted and subjected to compression in the texture analyzer to 75% of their original height, at a constant probe speed of 20 cm/min, and at speeds of 40 cm/min before and after the test. The analysis conditions matched those of previous studies (Guzmán et al., 2023; Rios-Mera et al., 2020, 2021) to ensure methodological comparability.

2.2.4. Cooking losses

Cooking losses were determined by dividing the weight difference between the raw and cooked burgers by the weight of the raw burger, and then expressing the result as a percentage.

2.3. Sensory analysis

Before the sensory analysis, the burgers were microbiologically analyzed in accordance with the Sanitary Technical Standard of the General Directorate of Environmental Health of the Ministry of Health of Peru (Ministerio de Salud del Perú, 2008), which specifies that for processed foods containing ingredients with and without heat treatment, the microorganisms aerobic mesophilic, coliforms, *Escherichia coli, Staphylococcus aureus*, and *Salmonella* sp. must be analyzed. Furthermore, the sensory analysis procedure was approved by the ethics committee of the Universidad Nacional de Jaén through the Informe N° 006–2025/VPI–UNJ/CE.

2.3.1. Consumers

One hundred consumer panelists participated in the sensory analysis, of whom 50% were women, 49% men, and 1% preferred not to state their gender. The ages ranged from 18 to 34 years. Consumers reported their frequency of burger consumption as follows: 13% reported consuming burgers every 15 days, 9% 1–3 times per week, 31% once a month, and 47% occasionally. The panel consisted of general consumers (omnivores and flexitarians), which is consistent with the addressable consumer base reported for plant-based meat products (Estell et al., 2021; Pointke et al., 2022). Before the sensory analysis, consumers read and signed the informed consent form to participate in the study.

2.3.2. Procedure

The sensory profile, overall liking, and purchase intention of the cooked burgers were evaluated using an A4-size assessment sheet. Approximately 10 g portions of each sample were served monadically on plates coded with three random numbers, following a Williams Latin Square design (Wakeling & MacFie, 1995). Consumers were first asked to rate their overall liking of the sample using a 9-point hedonic scale, ranging from “extremely dislike” to “extremely like” (Peryam & Pilgrim, 1957). Next, a free comment test was conducted using a blank box on the evaluation sheet, allowing participants to write the sensory characteristics or perceptions of the sample, without using hedonic terms. Participants were then asked to rate their purchase intention using a scale from 1 (“definitely would not buy”) to 5 (“definitely would buy”). Participants consumed water and crackers to cleanse their palates between samples.

2.4. Statistical analysis

The experiment was conducted under a randomized complete block design (RCBD), with treatments and blocks (three independent processes) considered as sources of variation. Physicochemical data was analyzed by Analysis of Variance (ANOVA) at a significance level of $\alpha = 0.05$. The significant differences between pair treatments were identified using Tukey's test at the same significance level. Free comment data were organized in an Excel file. Then, according to Rios-Mera et al. (2019), the words were lemmatized and categorized to construct a contingency table containing the frequencies of mention of the identified sensory attributes. In these data, a global χ^2 test was performed to evaluate significant difference between rows (burger treatments) and columns (sensory attributes) at 5% significance, resulting in a $P = 0.024$. Then, a χ^2 test per cell was performed to identify whether each cell differs from the theoretical value, allowing the evaluation of deviations in the selection of sensory terms among treatments (Symoneaux et al., 2012). Finally, a correspondence analysis was performed to obtain the sensory map of treatments and sensory attributes. Statistical analyses were performed using the R Studio software.

3. Results

3.1. Physicochemical characteristics

The results of the physicochemical characteristics are shown in Table 2. Regarding proximate composition, the ranges for all treatments were as follows: 37.77–40.65% moisture; 14.32–17.01% fat; 14.23–15.69% protein; 3.43–3.57% ash; 5.98–14.24% crude fiber; and 15.20–18.35% carbohydrates. There were no differences among treatments in ash, indicating similar mineral content. Moisture content was higher in burgers containing pea flour and lower in the burger with

Table 2
Physicochemical characteristics of artisanal-style soy-based burger formulations containing pea, cañihua, chickpea, quinoa, or wheat flours.

Variables	Treatments				
	Pea	Cañihua	Chickpea	Quinoa	Wheat
Proximate composition					
Moisture (%)	40.65 ± 0.33^{a}	36.49 ± 0.90^{c}	39.20 ± 0.40^{ab}	37.77 ± 0.63^{bc}	38.79 ± 0.90^{b}
Fat (%)	16.11 ± 0.15^{ab}	14.72 ± 0.43^{b}	14.32 ± 1.36^{b}	17.01 ± 0.45^{a}	14.77 ± 0.51^{b}
Protein (%)	15.34 ± 0.26^{ab}	14.60 ± 0.13^{abc}	14.23 ± 0.26^{c}	15.69 ± 0.77^{a}	14.31 ± 0.30^{bc}
Ash (%)	3.57 ± 0.16	3.56 ± 0.02	3.43 ± 0.40	3.46 ± 0.16	3.43 ± 0.05
Crude fiber (%)	5.98 ± 0.16^{c}	14.24 ± 0.52^{a}	10.76 ± 0.26^{b}	10.88 ± 0.13^{b}	10.63 ± 0.13^{b}
Carbohydrates (%)	18.35 ± 0.33^{a}	16.39 ± 1.27^{ab}	18.04 ± 0.85^{a}	15.20 ± 0.65^{b}	18.07 ± 1.43^{a}
Instrumental color					
L* raw	72.21 ± 0.84^{ab}	70.35 ± 0.82^{b}	72.13 ± 1.19^{ab}	73.55 ± 0.67^{a}	72.47 ± 0.87^{ab}
L* cooked	72.40 ± 1.11^{ab}	68.00 ± 1.33^{b}	72.78 ± 0.83^{a}	71.54 ± 1.26^{ab}	72.57 ± 3.20^{ab}
a* raw	45.12 ± 6.70	31.77 ± 7.62	43.77 ± 10.26	40.63 ± 7.58	44.82 ± 8.30
a* cooked	32.93 ± 2.30^{ab}	22.96 ± 3.79^{b}	28.90 ± 5.44^{ab}	37.46 ± 3.31^{a}	34.19 ± 4.80^{a}
b* raw	28.85 ± 4.82	18.94 ± 3.94	19.88 ± 3.74	22.87 ± 3.75	27.18 ± 5.94
b* cooked	45.10 ± 6.06	31.37 ± 4.97	42.21 ± 9.65	43.53 ± 4.57	48.68 ± 6.94
Instrumental texture properties					
Hardness (N)	110.07 ± 21.22	90.66 ± 18.50	100.11 ± 17.30	95.91 ± 32.93	89.12 ± 12.05
Springiness	0.46 ± 0.02	0.45 ± 0.05	0.54 ± 0.03	0.52 ± 0.07	0.49 ± 0.06
Cohesiveness	0.29 ± 0.03	0.29 ± 0.02	0.32 ± 0.03	0.31 ± 0.04	0.29 ± 0.04
Chewiness (N)	14.92 ± 3.28	11.60 ± 0.73	17.40 ± 1.96	15.27 ± 5.39	13.20 ± 4.53
Cooking losses (%)	14.46 ± 2.14	15.16 ± 1.11	14.35 ± 2.61	14.49 ± 1.78	14.36 ± 3.94

Different letters on the same row represent a significant difference ($P < 0.05$) between treatments according to Tukey's test.

cañihua, but this treatment showed the highest crude fiber content among treatments ($P < 0.05$). Quinoa increased the burger's fat and protein content while decreasing its carbohydrate content. The differences in instrumental color were mainly reflected in the lightness (L*) of the burgers, both raw and cooked, with the cañihua burger tending to have darker tones due to the lower values obtained. This same trend was observed for the redness of the cañihua burger, which tended to decrease significantly due to the cooking effect. No differences ($P > 0.05$) were observed in the instrumental texture parameters and cooking losses among treatments.

3.2. Sensory analysis

In the sensory analysis, it was verified that the microorganism counts were within the limits required for human consumption by the Sanitary Technical Standard of the General Directorate of Environmental Health of the Ministry of Health of Peru (Ministerio de Salud del Perú, 2008). Thus, across all treatments, the aerobic mesophilic count ranged from 10^2 to 10^5 CFU/g; coliforms and *E. coli* were <3.0 MPN/g; *S. aureus* was <10 CFU/g; and *Salmonella* was absent. Therefore, all treatments were suitable for consumption.

Table 3 shows the terms obtained from consumers using the free comment method. Ninety-six words were generated in the evaluation of the five treatments. After the lemmatization and categorization, the terms were grouped into 22 attributes to sensorially describe the burgers.

Table 3
Categorization of the terms generated in the free comment evaluation of the burger samples.

Terms	Related terms
Bitter	-
Brown	*Tan brown, light brown, dark brown, reddish brown*
Burnt	*Burnt smell, dark, black, opaque*
Creamy	*Creamy texture, puree, corn dough*
Crispy	*Crunchy*
Dry	-
Firm	*Consistent, thick, dense, uniform, fibrous, hard, compact*
Flour	-
Juicy	*Wet, fresh*
Lumpy	*Granulated, solid particles*
Meat	*Cooked meat, raw meat, ground meat, meat color, pork meat color, meat odor, sausage flavor, sausage, hot dog, bacon, chicken*
Red	*Reddish, pale red, pink*
Salty	-
Sandy	*Refined, fine*
Seasoned	*Seasoning, seasoning smell, seasoned smell, spices, monosodium glutamate*
Smoked	*Smoked odor*
Spicy	*Pepper, chili*
Sweet	*Caramelized, caramel color*
Tasty	*Pleasant, appetizing, attractive, attractive color, umami, intense*
Tender	*Soft, light, spongy, fragile, meltable*
Unpleasant	*Unappealing, annoying, raw*
Vegetable ingredients	*Vegetable smell, legumes, legume smell, carrot, beans, peanuts, garlic, sweet potato, broccoli, cereals, lentils*

The selected attributes were counted for each treatment, yielding a contingency table that shows the frequency of each attribute's mention for each treatment (Table 4). The most frequently mentioned attributes were firm, tasty, and tender, evidenced by mention frequencies greater than 20, meaning more than 20 consumers used these attributes to describe the burgers. Of these, the numerical differences show that tasty was most frequently mentioned for the pea and chickpea burgers, while tender was most frequently mentioned for the chickpea burger. Other frequently mentioned attributes included bitter, brown, burnt, dry, and sandy, primarily attributed to the cañihua burger, with frequencies between 10 and 15. However, in the statistical differences between treatments, the χ^2 test per cell identified that the burger containing cañihua

Table 4
Contingency table of the frequencies of the sensory attributes.

Attribute	Treatments				
	Pea	Cañihua	Chickpea	Quinoa	Wheat
Bitter	3	10(+)**	0(–)*	5	3
Brown	8	15(+)**	5	4	7
Burnt	2	14(+)***	5	3	4
Creamy	1	3	5	2	4
Crispy	1	6(+)*	0	3	2
Dry	11	12	10	9	9
Firm	24	25	24	20	20
Flour	3	4	3	3	1
Juicy	1	0(–)*	7	5	5
Lumpy	7	7	7	8	10
Meat	10	10	13	11	10
Red	3	0	2	4	4
Salty	7	5	8	7	5
Sandy	11	15	6	8	7
Seasoned	2	4	7	3	2
Smoked	2	1	1	1	7(+)***
Spicy	5	4	7	12	11
Sweet	4	2	3	5	4
Tasty	40	30	42	37	32
Tender	28	25	41	34	37
Unpleasant	2	4	3	6	2
Vegetable ingredients	12	10	7	12	10

(+) or (–) indicate that the observed value is higher or lower than the expected theoretical value. *** $P < 0.001$, ** $P < 0.01$, and * $P < 0.05$; effect of the χ^2 test per cell.

flour was significantly superior in the terms bitter, brown, burnt, and crispy, and inferior in the term juicy, as it did not receive a mention for this attribute. Likewise, chickpea flour did not generate the perception of bitterness unlike the other treatments, while wheat flour increased the frequency of the attribute smoked.

Correspondence analysis was applied to the contingency table of attribute mention frequencies (Table 4) to produce a sensory map of treatments and attributes. The first two dimensions retained 81.58% of the total inertia (D1 = 48.01%; D2 = 33.57%), confirming that the bivariate projection captures most of the sensory differentiation among

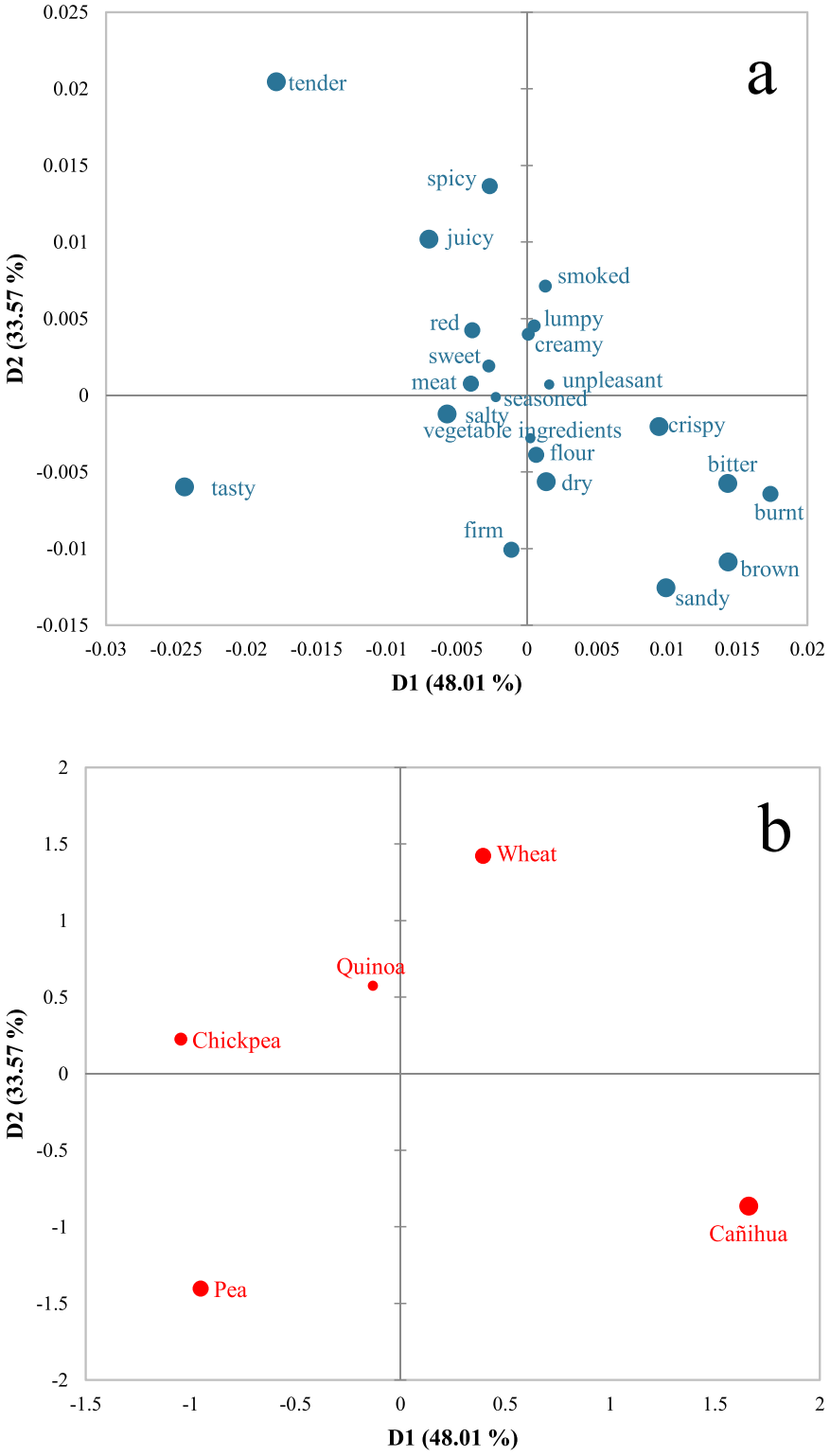


Fig. 1. Correspondence analysis of the sensory attributes (a) and burger treatments (b) from the contingency table of attribute mention frequencies (n = 100 consumers, five treatments, 22 attributes). The first two dimensions retained 81.58% of the total inertia (D1 = 48.01%; D2 = 33.57%). Attributes positioned far from the origin (Fig. 1a) contributed most to the differentiation among treatments. Treatments located in the same quadrant as a given attribute were preferentially associated with that attribute by consumers.

treatments. In Fig. 1a, attributes positioned far from the origin contributed most to the differentiation across treatments, while attributes close to the origin were used by consumers across all treatments and were less discriminant. In Fig. 1b, treatments located in the same quadrant as a given attribute in Fig. 1a were preferentially associated with that attribute by consumers. The chickpea and pea treatments were projected in the negative region of D1, in the same area as "tasty", while the chickpea treatment was additionally associated with "tender" in the upper-left quadrant. The cañihua treatment was projected in the positive region of D1, in the same area as the negative descriptors "bitter", "burnt", "brown", "crispy", "dry" and "sandy". The quinoa and wheat treatments were projected near the origin, indicating a less distinctive sensory profile, with the wheat treatment showing the highest mention frequency for "smoked" (Table 4). This bidimensional pattern is consistent with the univariate χ^2 per cell results reported in Table 4, supporting the robustness of the sensory discrimination.

Overall liking is shown in Fig. 2a. The chickpea burger received the highest score between the treatments (average 6.40), while the cañihua burger had the lowest acceptability (average 5.66), which can be explained by the sensory attributes represented in Fig. 1. The wheat, pea, and quinoa treatments did not show significant differences compared to the cañihua and chickpea burgers. Purchase intention followed a similar pattern to overall liking (Fig. 2b), with the chickpea treatment showing the highest purchase intention among consumers (average 3.89), compared to quinoa and cañihua, which had lower purchase intentions.

4. Discussion

Under the artisanal processing conditions applied uniformly to every

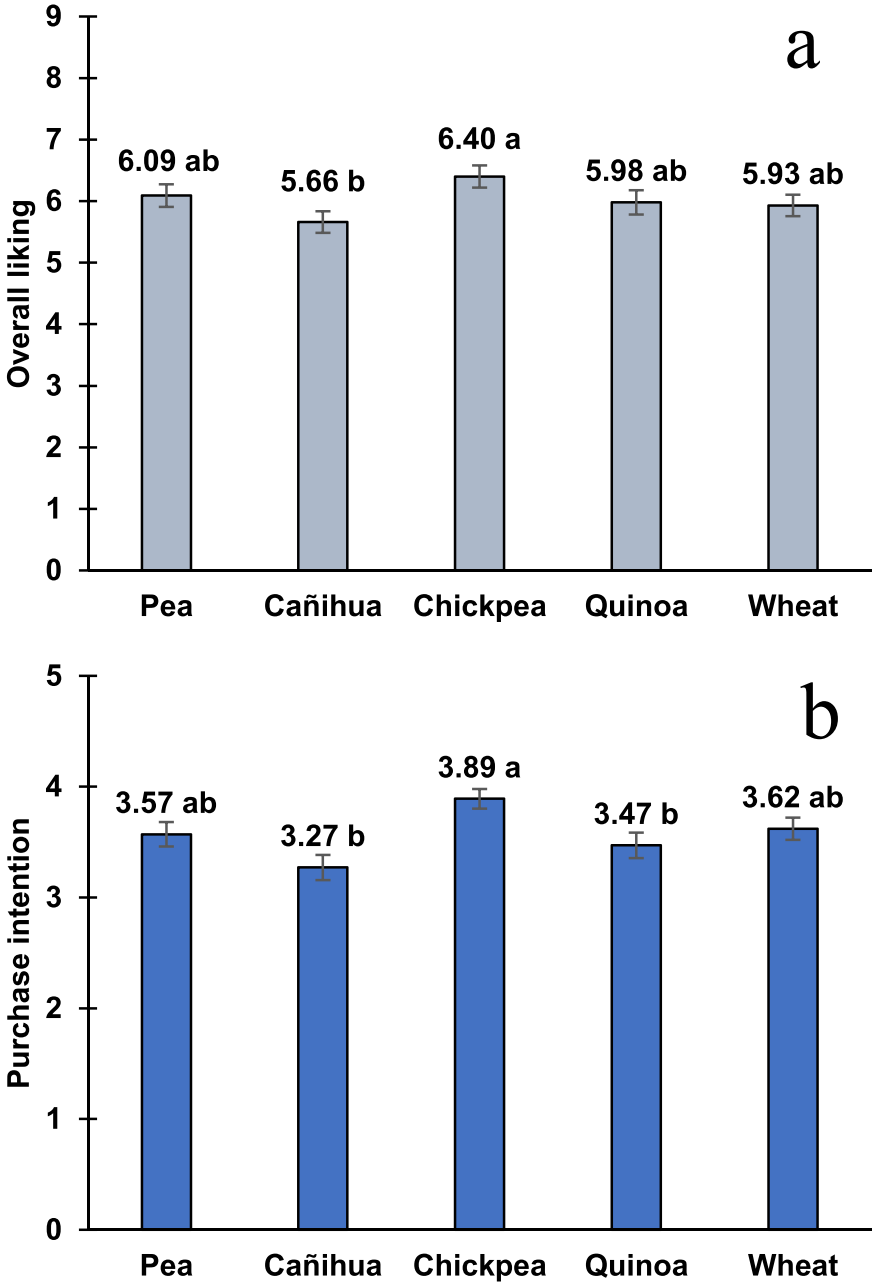


Fig. 2. Overall liking (a, 9-point hedonic scale) and purchase intention (b, 5-point scale) of the burger treatments. Bars represent means ± SE, n = 100 consumers. Different letters above bars indicate significant differences (Tukey, $P < 0.05$).

formulation, the physicochemical and sensory differences observed among burgers can be attributed to the type of flour added at 15% (w/w), namely pea, cañihua, chickpea, quinoa, or wheat.

Because the artisanal processing approach used here differs from the industrial manufacture of most commercial plant-based burgers (Inguglia et al., 2023; Pointke et al., 2022), differences in proximate composition were expected and observed. Compared with the average composition reported by Biazotto et al. (2025) for commercial plant-based burgers (range 54 to 65% moisture, 3 to 12% fat, 5 to 13% protein), the burgers developed in this study showed lower moisture (36.5 to 40.7%), higher fat (14.3 to 17%) and comparable protein (14.2 to 15.7%). The lower moisture and the higher fat are consistent with the absence of water-binding hydrocolloids (e.g., methylcellulose, carrageenan) and texturized vegetable protein in the present formulations. In the treatments, the higher moisture content observed in the formulation with pea flour suggests a greater water-holding capacity, attributed to the proteins of this legume, which are characterized by high solubility and water-retention (da Silva et al., 2024). Conversely, the lower moisture content in the burger made with cañihua flour can be attributed to its high fiber content (Table 2), primarily insoluble, as reported by Quispe et al. (2024). In this context, a higher proportion of this fiber type may be associated with a lower water-holding capacity (Bulgaru et al., 2025), which could explain the perception of "crispy", "dry" (or not "juicy") and "sandy" in the burger (Fig. 1), attributes that have been interrelated in previous studies (Laguna et al., 2021; Nakamoto et al., 2024; Puerta et al., 2020). These characteristics may be associated with lower overall liking and purchase intention for the burger containing cañihua flour (Fig. 2).

The protein content of the quinoa formulation (15.7%, Table 2) did not differ statistically from the pea and cañihua formulations ($P > 0.05$), and was numerically the highest among treatments. This level is consistent with the protein content typically reported for quinoa added to plant-based formulations (Quevedo-Olaya et al., 2025). The numerically higher fat content in the quinoa formulation (17%, Table 2) is consistent with the lipid contribution of quinoa flour, which has a higher total lipid content compared with cereal flours such as wheat (Manzanilla-Valdez et al., 2024). The lower carbohydrate percentage observed in the quinoa formulation aligns with Manzanilla-Valdez et al. (2024), who reported low carbohydrate content in three quinoa varieties.

Instrumental color analysis showed differences primarily in lightness (L*), with the cañihua burger exhibiting the lowest values in both raw and cooked states (Table 2). Redness (a*) also decreased in the burger with cañihua flour after cooking. These effects may be due to pigments that give cañihua its characteristic dark color, the Maillard reaction induced by cooking, and the presence of phenolic compounds that lead to the formation of the melanoidin pigment (Brito et al., 2015). In this context, cañihua is notable for its high content of phenolic compounds, especially flavonoids (Quispe et al., 2024), but these compounds are often associated with bitterness (Soares et al., 2013). Consequently, the cañihua burger was sensorially described as "bitter", "brown" and "burnt".

In the instrumental texture profile, no significant differences were observed among treatments in hardness, springiness, cohesiveness and chewiness, and cooking losses remained between 14 and 15% across treatments (Table 2). Two complementary explanations support these results. First, soybean paste was the largest mass fraction in every formulation, and the soy protein matrix has been shown to dominate the structural and water-binding behavior of plant-based burger systems, buffering minor compositional differences between treatments (Azachi & Wiesman, 2026). Across published plant-based burger formulations, no clear relation has been found between composition and TPA outputs when a protein matrix dominates the structure (Godschalk-Broers et al. 2022). Second, the narrow moisture range observed across treatments (36.5 to 40.7%) was unlikely to drive significant TPA differences under these conditions, since differences of this magnitude do not exceed the variability typically reported for the same formulations across batches in similar plant-based products (Peñaranda et al., 2023).

The lack of TPA differences contrasts with the sensory profile, in which consumers discriminated treatments and assigned descriptors such as "tender", "firm", "sandy", "dry" and "crispy". This pattern is consistent with the literature on meat analogues, where instrumental hardness can correlate with sensory firmness, but cohesiveness, springiness and chewiness frequently fail to correlate with their sensory counterparts (Lee et al., 2024). Sensory texture in particulate, fiber-rich matrices is shaped by oral processing phenomena, such as bolus formation, mastication dynamics, particle release and saliva mixing, that uniaxial compression does not capture (Godschalk-Broers et al. 2022).

In this context, consumers gave favorable descriptors to burgers made with pea and chickpea flours, both of which were associated with "tasty", with chickpea standing out even more due to its association with "tender" (Fig. 1). These attributes are key because they align with consumer needs, which emphasize taste and texture as drivers of liking of meat analogues, even more than the environmental discourse (Curtain & Grafenauer, 2019). These sensory attributes have also been associated with greater overall liking in burgers of animal origin, such as beef (Rios-Mera et al., 2020) and fish (Saavedra et al., 2022), which is a good indicator in the search for meat analogues that do not compromise consumers' sensory expectations. In this regard, the chickpea-flour burger also elicited the greatest overall liking and purchase intention (Figs. 1 and 2). In a previous study, Mariod and Elagdir (2024) reported that replacing camel meat with chickpea flour improved the sensory scores of burgers, with the highest overall acceptability achieved at a 30% meat substitution. The sensory improvement in chickpea-containing formulations can be attributed to the heat treatment the product undergoes. It has been suggested that treatments such as roasting eliminate unpleasant volatile compounds and promote the formation of pyrazines and alkylated pyrazines, which impart a pleasant flavor and mask off-flavors (Ajay et al., 2024). Roasting also softens the texture of kernels (Bagheri et al., 2016). Thus, roasted chickpea flour and cooking burgers on a hot plate may have contributed to the increased perception of "tasty" and "tender". In this regard, chickpea flour can be considered a suitable plant-based option for replacing meat or mimicking meat-based products, such as burgers.

The present study provides a sensory and physicochemical screening of five flours within an artisanal soy-based burger platform. Once chickpea has been identified as the lead candidate, follow-up work should quantify the chemical drivers of the sensory descriptors observed here. Specifically, total saponins, total phenolics, individual phenolic acids and flavonoids by HPLC, Maillard reaction products (5-hydroxymethylfurfural, melanoidins), and the volatile aroma profile by HS-SPME-GC–MS / olfactometry would clarify the molecular basis of the "bitter", "burnt", "brown" notes attributed to cañihua and of the "tasty" and "tender" notes attributed to chickpea (Abderrahim et al., 2012; Guo et al., 2024; Peñarrieta et al., 2008; Repo-Carrasco-Valencia et al., 2010; Xu et al., 2019).

A methodological limitation of the present study concerns the assessment of purchase intention. Consumers evaluated the burgers under blind conditions, without contextual information regarding the artisanal, clean-label, or sustainable positioning of the product. Under such conditions, blind purchase intention is known to track the hedonic score closely and to underestimate the actual market-behavior purchase intention, since contextual cues (price, nutritional labelling, sustainability claims) substantially modify consumer choice for plant-based products (Grasso et al., 2022; Caputo et al., 2023). The purchase intention reported here should therefore be interpreted as a screening metric. A follow-up study including a between-subjects information-disclosure design will be needed to evaluate the actual market potential of the lead formulation under informed conditions.

The consumer panel was composed of general consumers aged 18 to 34, which is consistent with the addressable market for plant-based meat products and aligns with previous sensory studies of plant-based burgers

(Grasso et al., 2022; Caputo et al., 2023). Recent comparative work suggests that dietary identity affects overall liking and motivation more than attribute perception (Pointke et al., 2022), so the sensory discrimination among treatments reported here is expected to be robust across dietary groups. Nevertheless, a follow-up study with a panel segmented by dietary identity (omnivores, flexitarians, vegetarians, vegans) and a between-subjects information-disclosure design will be useful to refine the market-positioning analysis of the lead artisanal formulation.

Still, the overall liking scores are slightly lower than those of beef-based burgers (Llatas et al., 2024; Rios-Mera et al., 2020, 2021), so further comparative studies with animal-based counterparts are needed to improve plant-based formulations resulting in better sensory liking scores, as well as to evaluate physicochemical, nutritional, and sensory stability.

5. Conclusion

The artisanal-style soy-based burgers containing pea, cañihua, chickpea, quinoa, or wheat flours showed differences in physicochemical characteristics and consumer sensory perceptions. Pea flour increased moisture content, cañihua flour increased crude fiber, and quinoa stood out for its increased protein and fat content and decreased carbohydrates. The burger's lightness was reduced by the addition of cañihua flour, as was the redness after cooking. The instrumental texture parameters (hardness, springiness, cohesiveness, and chewiness) and cooking losses of the burgers were similar, but in terms of sensory characteristics, the burgers containing pea and chickpea flour were highlighted as "tasty". Burgers containing chickpea flour were also associated with the sensory attribute "tender", contributing to the increased overall liking and purchase intention compared to the other treatments. To further explore the artisanal approach to plant-based meat analogues, future studies should assess their physicochemical, nutritional, and sensory stability and compare them to animal-based products.

Ethics statement

This research involved human participants and was conducted in accordance with the Declaration of Helsinki. The study received ethical approval from the Ethics Committee of Universidad Nacional de Jaén (Informe N° 006–2025-VPI-UNJ-CE). One hundred consumer panelists (50 women, 49 men, 1 preferred not to state; ages 18–34) voluntarily participated after reading and signing informed consent forms. All participants were informed of their right to withdraw at any time.

All plant-based burger samples underwent rigorous microbiological analysis in accordance with the Sanitary Technical Standard of Peru (Ministerio de Salud del Perú, 2008). Testing confirmed compliance with safety standards: aerobic mesophilic bacteria (10^2–10^3 CFU/g), coliforms ($\leq$3.0 MPN/g), *E. coli* ($\leq$3.0 MPN/g), *S. aureus* ($\leq 10^2$ CFU/g), and *Salmonella* sp. (absent). All samples met the required standards before serving. The study was classified as minimal risk, and no adverse events were reported.

Participant data were collected, stored, and analyzed in accordance with data protection regulations. Personal information remained confidential, and only aggregated, anonymized data is reported. Individual responses cannot be identified in published materials.

Animal studies

This research did not involve any animal subjects, animal testing, or animal-derived materials requiring ethical approval.

CRediT authorship contribution statement

Ander Altamirano: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis. **Gladis A. Perez-Alberca:** Writing – original draft, Methodology, Investigation, Formal analysis. **Hubert Arteaga:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis. **Melina L. M. Cruzado-Bravo:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Fernando Tello:** Writing – review & editing, Writing – original draft, Supervision, Investigation. **Erick Saldaña:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Juan D. Rios-Mera:** Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare no competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

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Data availability

Data will be made available on request.

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