Heliyon 10 (2024) e28363

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Technological and textural properties of gluten-free quinoa-based pasta *(Chenopodium quinoa Wild)*

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ARTICLE INFO

Keywords:
Quinoa
Cooking quality
Texture
Gluten-free

ABSTRACT

Quinoa (*Chenopodium quinoa* Willd.) is an Andean grain with a perfect nutritional composition that, by diversifying its transformation, becomes an attractive alternative for consumers looking for a high-quality, healthy diet with a source of vegetable proteins. The objective of this work was to elaborate and evaluate the technological and textural properties of quinoa paste in its entirety through the Star-Shaped Composite Central Design (CCD) of 5 process variables: Water Temperature (°C), Water Quality (ml), Mixing Time (min), Drying Temperature (°C), and Drying Time (min), with 5 levels each. At the same time, the yield and good cooking quality were studied to optimize the process. In the model of the equation for the cooking time response, a negative and significant influence of drying temperature was shown. On the other hand, for cooking loss, dough gain, a* and b* values, and texture had high values if the drying time was increased. On the contrary, the L-value decreases, which is positively significant. Meanwhile, the swelling index was only significantly positive within the technological properties. In addition, it was found that the optimal conditions for producing quality pasta were 25 °C: 1150 ml: 30 min: 70 °C and 80 min, respectively, with a desirability of 0.883. When the pasta was prepared with quinoa, the cooking time was 7 min, the cooking loss was 2.46 g/g, the mass gain was 23.6 g/g, the cooking yield was 7.99%, the swelling index was 2.9%, water absorption was 135%, and protein was 12.71 g and 0. 21 Pa in texture, these results being consistent with cited research. Likewise, the whiteness was 51.97 for the values a* 2.41 and b* 12.45; all this analysis is reflected in the final yield of the process at 78%. In conclusion, the results indicated that, by optimizing the conditions in the production of gluten-free quinoa pasta, it is possible to obtain a gluten-free product with high added value, excellent cooking quality, adequate technological properties, texture, and color acceptable to the consumer.

1. Introduction

Pasta is a traditional Italian product made mainly from durum wheat and recognized worldwide for its versatility, complex carbohydrate profile, pleasing sensory profile, affordable cost, long shelf life, simplicity in preparation, and adaptability to specific enrichments or fortifications today [1]. Despite these attributes, wheat contains gluten, a protein made up of two main components

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https://doi.org/10.1016/j.heliyon.2024.e28363
Received 13 November 2023; Received in revised form 8 March 2024; Accepted 18 March 2024

(gliadin and glutenin), which are responsible for the technological properties of the dough, as well as in the direct relationship of pasta quality attributes, reflected in terms of texture, cooking quality, and structural development during pasta processing [2]. On the other hand, there has been evidence of an increase in some digestive disordersamong the population, such as gluten intolerance, which has created the need to produce differentiated foods to cover this growing market segment [3]. Among these disorders is celiac disease (CD), characterized by the inflammatory process of the intestine and the inability to digest gluten proteins present in certain cereals such as wheat, barley, rye, and probably oats [4]. It is estimated that 1% of the population suffers from celiac disease, and recently, 6% suffered from gluten-related non-celiac gluten sensitivity [5], being the only cure for celiac disease; a strict gluten-free diet for life, as lower concentrations of gluten are sufficient to provoke an immune response; therefore, they require high-quality gluten-free foods [6].

Gluten-free pasta products are of growing interest, motivated by their functionality, since the level of proteins and bioactive components in conventional flours is shallow. Likewise, it is a great challenge to achieve nutritious and optimal products in the eyes of the consumer with a baking quality similar to traditional pasta. In this sense, studying new ingredients, such as quinoa, and processing conditions that improve gluten-free doughs' technological and functional properties is necessary. Several studies have used alternative flour blends to improve the nutritional value of gluten-free pasta products, such as amaranth, quinoa, and buckwheat flour [7], millet-pomace [8], semolina, defatted soybeans, whole grain quinoa, whole grain rye, whole grain oats, whole grain barley and rice [9], quinoa flour, zein, and other biopolymers [4], soybeans, sorghum, as well as multigrain flour [1]. The search for alternative and nutritious sources will continue.

In short, quinoa, a crop native to South America, can play a fundamental role in functional food applications due to its high protein potential (12.9–16.5%), essential amino acids such as lysine (5.4g/100g), histidine (2.9g/100g), methionine (3.6g/100g) [10], high-quality lipids (linoleate and linoleate), bioactive compounds, vitamins, and minerals (iron, calcium) compared to wheat, which qualifies it as suitable for a healthy diet, according to the FAO.

Therefore, the cooking quality and the final structure of the pasta will depend on the characteristics of the raw material and the conditions adopted during production [11]. Pulp production commonly involves mixing, extruding, drying, and cooling [12], as well as the amount of water added, water temperature, and mixing time, affecting the final quality of the paste and consumer acceptance. Similarly, extrusion technology is a method that promotes moisture migration and improves dough quality by producing pastes with a uniform and tight structure [13]. In this sense, the present study aimed to evaluate gluten-free quinoa-based pasta's technological and textural properties and optimize the process variables using Response Surface methodology to provide industrial use.

2. Materials and methodology

2.1. Raw materials

Naturkost Peru SAC (Puno, Peru) donated quinoa grits from the coarse grinding process. The treated water and salt supplies were purchased in local markets and from national brands.

2.2. Preparation of quinoa pasta

To make the quinoa pasta (Pipe rigate type), the ingredients described in the section raw materials were weighed (quinoa 99.9% and salt 0.1%) for approximately 5.0 kg. Mixing the paste with water and forming it was carried out in a cold extruder (Dominioni, Punto & Pasta SRL, Italy). The amount of water and process conditions were according to Table 1. The drying was carried out on a rotary convection oven (NOVA 2000 MAX, Peru). After cooling for 90 min, the pastes were vacuum sealed in polyethylene packaging for their respective evaluation.

2.3. Experimental design

Central composite design (CCD) based on response surface methodology (RSM) was used to evaluate the influence of parameters on pasta production and its characteristics. The CCD design was five-factor and five-level, each combining two central points. The range of each variable was selected based on initial testing. Table 1 summarizes the levels, units, and symbols of the parameters for pasta production with the CCD design. A total of 28 experiments were carried out in this model.

Levels and factors independent of the process of obtaining quinoa paste.

Table 1
Levels, units, and symbols of the process parameters of elaboration quinoa pasta for the CCD.

Factor	Units	Symbol	Levels				
			+α	1	0	−1	- α
Water temperature	°C	X1	45	35	25	15	5
Water amount	ml	X2	1550	1450	1350	1250	1150
Mixing time	min	X3	50	40	30	20	10
Drying temperature	°C	X4	90	80	70	60	50
Drying time	min	X5	120	100	80	60	40

2.4. Product characterization

The pasta's cooking quality was assessed using four responses following the guidelines of AACC 66-50.01 [14], which defines the cooking conditions and procedure for determining pasta's cooking quality. The samples were evaluated in triplicate for each assessment.

2.4.1. Optimal cooking time (OCT)

In a 500 ml beaker, 300 ml of water was heated to boiling. Then, 25 g ± 0.1 g of paste was added to the boiling water (without adding salt) while maintaining a continuous boil. Every 30 s, a paste sample was removed and pressed between two methacrylate plates. The cooking time (min) was determined when no white core was visible anymore.

2.4.2. Solid loss (SL)

The determination was determined gravimetrically by weighing the residues after evaporating the cooking water. The pasta was cooked according to the Optimal Cooking Time (OCT). The cooking water collected from each sample was evaporated to a constant weight in an oven at 105 °C. The residue was weighed and determined according to equation (A).

$$\boldsymbol{SL}\ (\%) = \frac{\boldsymbol{Driedresidueincookingwater}}{\boldsymbol{Pastaweightbeforecooking}}\boldsymbol{x100} \tag{A}$$

2.4.3. Mass gain (MG)

Mass gain is defined as the weight increase of the pasta during cooking and indicates the amount of water absorbed. Therefore, it is an index of the pasta's swelling capacity. Each quinoa pasta sample was cooked according to the determined cooking time, after which the weight was calculated and expressed as a percentage using formula (B).

$$\boldsymbol{MG}\ (\%) = \frac{\boldsymbol{Weightofcookedpasta}}{\boldsymbol{Weightofrawpasta}}\boldsymbol{x100} \tag{b}$$

2.4.4. Cooking yield (CY)

The determination of cooking yield is an indicator of pasta quality related to the consistency of the pasta in terms of water absorption and stability during cooking. The determination is expressed in (%) using equation (C), according to the method used by Bhatt & Gupta [15].

$$\boldsymbol{CY}\ (\%) = \frac{\boldsymbol{Weightofcookedpasta} - \boldsymbol{Weightofdriedpasta}}{\boldsymbol{Weightofdriedpasta}}\boldsymbol{x100} \tag{C}$$

2.5. Analysis of technological properties

2.5.1. Swelling index (SI)

10 g of pasta were cooked in 100 ml of distilled water. The cooked pasta was then dried to a constant mass at 105 °C and weighed Gull [8]. The swelling index was expressed as 1g of water per g of dry pasta and calculated using equation (D).

$$\boldsymbol{SI} = \frac{\boldsymbol{Weightofcookedpasta} - \boldsymbol{Weightofdriedpasta}\ (\boldsymbol{g})}{\boldsymbol{Weightofdriedpasta}(\boldsymbol{g})} \tag{D}$$

2.5.2. Water absorption capacity (WAC)

10 g of pasta was cooked in 100 ml of boiling distilled water according to their respective cooking times, then dried and weighed. The water absorption of the cooked pasta was expressed in g/100 g and was calculated using equation (E) for cooking.

$$\boldsymbol{WAC}\ (\%) = \frac{\boldsymbol{Weightofcookedpasta} - \boldsymbol{Weightofrawpasta}(\boldsymbol{g})}{\boldsymbol{Weightofrawpasta}(\boldsymbol{g})}\boldsymbol{x100} \tag{E}$$

2.6. Color determination

The products' color values were assessed in both raw and cooked states using a digital colorimeter (Fru-WR10QC, Shanghai, China), measuring L* (black (0) to white (100)), a* (+a = red, -a = green), and b* values (+b = yellow,—b = blue). Three measurements were taken for each sample. The color of each sample was compared to the control sample's, and differences in L*, a*, and b* were compiled into the total color difference (ΔE*). To determine the ΔE, an equation (F) was used.

$$\Delta E* = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{F}$$

2.7. Determination of pasta texture analysis (fracturability)

Fructurability measures the strength at which a food will break under specified conditions. It is a measure of the brittleness or toughness of the paste. This property was evaluated using a dynamometer (PASCO AirLink PS-3200, Australia), a maximum force of 15 N, a sampling rate 20Hz, and a metal rod with a diameter of 5.57 mm. The force data were exported from the dynamometer via Bluetooth SMART technology to a cell phone with SPARKVUE software pre-installed and subsequently analyzed. Samples were compressed with the dynamometer at an initial speed of approximately 2.00 mm/s until the paste fractures or breaks (Fig. 1). Twelve repetitions were performed for each treatment, and the maximum applied force (N) at the moment of fracture or breakage was determined.

2.8. *Statistical analysis*

The data from the experimental design were statistically analyzed using Analysis of Variance (ANOVA) with $p < 0.05$ using the DESIGN EXPERT software (version 19.2.0 Statpoint Technologies, Inc., Warrenton, USA). Quantitative results were expressed as arithmetic mean and standard deviation ($\bar{x}$ and ±).

3. Results and discussions

3.1. *Nutritional composition*

The study of the technological and textural properties (fracturability) of pasta made entirely from quinoa grits was developed and conducted. The nutritional composition of the control and optimal pasta (M12) was 12.2 g/100g and 12.11 g/100g of moisture, respectively. The protein content of the processed quinoa pasta increased from 10.93 g/100g to 12.2 g/100g under conditions of 35 °C, 1250 ml of water, 40 min of mixing, 80 °C drying, and 60 min of drying time. The fat content was 0.53 g/100g for the control pasta and 0.62 g/100g for the optimal pasta. The carbohydrate content was 74.80 g/100g for the control sample and 70.77 g/100g for the optimal pasta. Studies report 8.9% moisture and 11.34% protein in pasta made with quinoa flour, extruded gum, and tara. These results can be altered by conditioning other ingredients in the pasta-making process [16].

3.2. *Cooking profile*

3.2.1. *Optimal cooking time*

Table 2 shows the results of the optimal cooking time of quinoa pasta according to the experimental design. The value for control was found to be 14.7 min and 6.33–7.33 min in 28 experimental groups. Using these results, it was only found that the variable Note that this optimal temperature was 7 min.

Furthermore, as expected, the 28 experimental groups showed cooking times up to half compared to the control pasta (14 min); this is due to the use of quinoa grits, which are pre-cooked. On the other hand, there are factors such as protein content and the processing parameters, mainly the boiling point, which is lower in areas such as the mountains. This is supported by what was reported by Kamali Rousta et al. [9] and Rani et al. [1], who observed that the variation in time results from parameters such as the amount of protein, the quality of gluten, the concentration of the raw material, and the amylose-lipid content that inhibits starch leaching granules and prevent water from entering the granules. Gelatinization, by having greater availability of water, also reduces the time.

The structural attributes of pasta, especially its shape, can modify its cooking quality and physicochemical and nutritional characteristics; a study concludes that the rigatoni shape presented longer cooking times, the inclusion of different flours of chickpea at a level of 50% in gluten-free pasta was successful, and all products with good cooking quality were identified [17].

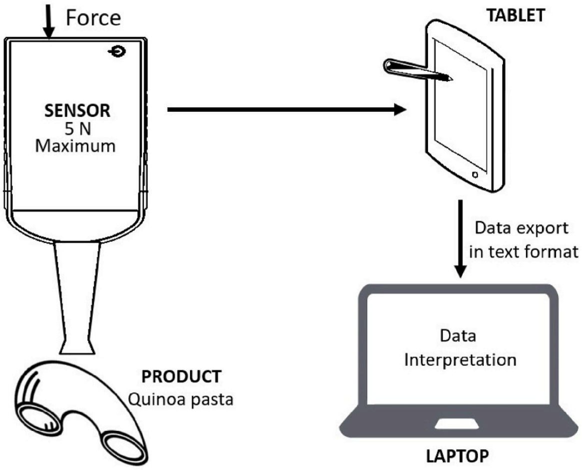

Fig. 1. Schematic representation indicating a process of Determining the Fracturability of Quinoa Pasta.

Table 2
Cooking quality of quinoa pasta.

Treatment	Answers											
	X1	X2	X3	X4	X5	Optimal cooking time (min)	Cooking Loss (%)	**Cooking Weight (%)**	**Cooking Yield %**	Swelling Index (g/g)	Water absorption Index (%)	Process Yield (%)
Control	ND	ND	ND	ND	ND	14.7 ± 0.5	1.64 ± 0.01	20.64 ± 0.85	3.29 ± 0.83	2.22 ± 0.13	109.4 ± 9.00	ND
1	35	1250	20	60	60	7.00 ± 0	8.53 ± 0.7	23.67 ± 2.87	8.59 ± 5.05	2.69 ± 0.45	165 ± 5.00	66.00 ± 1.00
2	35	1450	40	60	60	7.19 ± 0.26	14.03 ± 0.83	22.00 ± 1.41	12.35 ± 7.14	2.59 ± 0.23	125 ± 5.00	37.00 ± 2.65
3	35	1250	40	60	100	7.00 ± 0	4.4 ± 0.08	26.00 ± 2.16	9.86 ± 5.81	2.13 ± 0.26	175 ± 5.00	51.00 ± 1.00
4	15	1250	40	60	60	6.33 ± 0.47	10.77 ± 1.11	24.00 ± 3.56	14.45 ± 8.42	2.18 ± 0.47	165 ± 5.00	57.33 ± 0.58
5	15	1450	40	60	100	7.33 ± 0.47	13.48 ± 0.45	26.00 ± 0	8.33 ± 4.8	1.54 ± 0	160 ± 0.00	30.33 ± 0.58
6	15	1250	20	60	100	7.00 ± 0.82	13.16 ± 0.04	26.00 ± 2.16	10.69 ± 6.63	2.17 ± 0.26	175 ± 5.00	83.00 ± 2.00
7	35	1450	20	60	100	6.67 ± 0.47	14.23 ± 0.45	27.33 ± 0.47	7.95 ± 4.18	2.11 ± 0.05	175 ± 5.00	61.67 ± 0.58
8	15	1450	20	60	60	6.33 ± 0.47	16.64 ± 0.71	25.00 ± 0.82	9.32 ± 5.11	2.16 ± 0.1	145 ± 5.00	44.67 ± 0.58
9	25	1350	30	70	120	7.00 ± 0	18.24 ± 0.58	27.67 ± 1.25	9.2 ± 7.08	2.37 ± 0.15	170 ± 10.00	68.83 ± 1.15
10	25	1350	50	70	80	6.67 ± 0.47	19.36 ± 0.68	23.33 ± 0.94	9.46 ± 4.03	2.64 ± 0.82	130 ± 10.00	70.00 ± 1.00
11	45	1350	30	70	80	6.67 ± 0.47	9.16 ± 0.48	23.67 ± 1.25	12.98 ± 7.93	1.88 ± 0.15	147.5 ± 2.50	76.33 ± 1.15
12	25	1150	30	70	80	7.00 ± 0.82	2.46 ± 0.58	23.67 ± 0.47	7.99 ± 5.37	2.9 ± 0.06	135 ± 5.00	78.00 ± 5.29
13	25	1550	30	70	80	6.33 ± 0.47	12.19 ± 0.46	25.67 ± 1.7	6.56 ± 2.96	2.3 ± 0.22	145 ± 5.00	56.00 ± 1.00
14	25	1350	30	70	80	7.00 ± 0.82	17.78 ± 0.64	24.67 ± 1.7	9.72 ± 5.27	2.16 ± 0.22	135 ± 5.00	41.67 ± 1.53
15	25	1350	30	70	80	7.00 ± 0.82	12.93 ± 0.54	26.67 ± 2.05	9.27 ± 4.68	2.22 ± 0.34	167.5 ± 2.5	41.00 ± 0.00
16	25	1350	10	70	80	6.67 ± 0.47	14.4 ± 0.78	26.00 ± 2.16	9.3 ± 4.7	2.31 ± 0.27	145 ± 5.00	50.67 ± 1.53
17	25	1350	30	70	40	6.33 ± 0.47	6.35 ± 0.37	24.33 ± 0.47	7.83 ± 4.15	2.08 ± 0.06	145 ± 5.00	68.00 ± 1.00
18	35	1250	20	80	100	6 ± 0.82	16.75 ± 0.99	24.97 ± 2.11	11 ± 6.69	2.29 ± 0.28	149.5 ± 9.50	69.67 ± 1.53
19	15	1450	20	80	100	6.67 ± 0.47	14.98 ± 1.08	26.33 ± 1.25	9.01 ± 5.30	2.36 ± 0.16	155 ± 5.00	40.33 ± 4.04
20	15	1250	40	80	100	6.67 ± 0.47	6.7 ± 0.52	24 ± 2.83	8.79 ± 5.21	2 ± 0.35	155 ± 5.00	45.67 ± 0.58
21	35	1450	40	80	100	7 ± 0.82	5.33 ± 0.41	23.97 ± 0.78	8.27 ± 4.55	1.78 ± 0.09	144.5 ± 4.50	41.67 ± 0.58
22	35	1250	40	80	60	7 ± 0.82	6.72 ± 0.29	22 ± 1.62	27.24 ± 3.02	1.52 ± 0.19	110 ± 10.00	80.33 ± 1.15
23	15	1450	40	80	60	6.83 ± 0.62	7.28 ± 0.29	25.33 ± 1.25	15.21 ± 9.65	2.19 ± 0.16	145 ± 5.00	46.33 ± 1.15
24	15	1250	20	80	60	7 ± 0.82	8.21 ± 0.15	24.83 ± 0.62	10.25 ± 5.73	1.92 ± 0.31	152.5 ± 2.50	45.00 ± 0.00
25	35	1450	20	80	60	7 ± 0.82	14.17 ± 0.25	25 ± 0.82	10.87 ± 5.81	2.48 ± 0.35	145 ± 5.00	62.67 ± 2.31
26	25	1350	30	50	80	6.67 ± 0.47	6.99 ± 0.10	26.33 ± 1.25	9.74 ± 5.43	1.98 ± 0.35	170 ± 10.00	61.33 ± 1.15
27	5	1350	30	70	80	6.33 ± 0.47	12.02 ± 0.19	27.56 ± 0.55	10.04 ± 5.41	2.18 ± 0.34	179.5 ± 0.50	66.07 ± 0.58
28	25	1350	30	90	80	6.67 ± 0.47	5.55 ± 0.18	30.67 ± 2.05	14.01 ± 8.16	2.44 ± 0.23	220 ± 10.00	77.00 ± 4.58

Note: X1: Water temperature (°C), X2: Water amount (ml), X3: Mixing time (min), Drying temperature (°C), X5: Mixing time (min). Different letters in the same column indicate statistical differences ($P \leq 0.05$). Data are the means of three independent experiments ± standard deviations ($n = 3$). ND = indefinite.

Table 3
Color characteristics of raw and cooked pasta with their respective study factors.

Treatment	Answers					Cooked				Raw			
	X1	X2	X3	X4	X5	L	a*	b*	ΔE	L	a*	b*	ΔE
Control						53.51 ± 0.98	0.39 ± 0.18	10.91 ± 0.31	ND	35.5 ± 0.15	3.54 ± 0.67	17.04 ± 1.34	ND
1	35	1250	20	60	60	51.05 ± 0.57	3.2 ± 0.31	14.67 ± 0.56	5.30	33.47 ± 1.02	7.78 ± 1.19	26.03 ± 1.28	10.15
2	35	1450	40	60	60	52.07 ± 1.61	3.03 ± 0.32	14.11 ± 0.14	4.39	34.05 ± 1.15	8.21 ± 0.76	23.41 ± 1.07	8.03
3	35	1250	40	60	100	50.2 ± 0.18	3.19 ± 0.23	13.32 ± 1.04	4.96	34.58 ± 1.01	8.66 ± 1.01	25.71 ± 1.34	10.11
4	15	1250	40	60	60	54.16 ± 0.48	1.87 ± 0.45	12.17 ± 1.5	2.05	35.99 ± 1.27	7.72 ± 0.88	20.35 ± 1.2	5.35
5	15	1450	40	60	100	48.74 ± 1.01	3 ± 0.52	14.29 ± 0.78	6.41	41.43 ± 1.41	8.4 ± 0.69	22.17 ± 1.72	9.23
6	15	1250	20	60	100	43.32 ± 0.85	3.62 ± 0.31	14.04 ± 0.6	11.14	45.82 ± 2.2	8.02 ± 0.67	24.26 ± 0.86	13.37
7	35	1450	20	60	100	47.93 ± 0.59	3.12 ± 0.37	13.7 ± 0.27	6.81	35.86 ± 1.74	8.15 ± 0.13	21.99 ± 0.12	6.77
8	15	1450	20	60	60	50.95 ± 0.96	2.96 ± 0.32	13.67 ± 0.41	4.56	37.84 ± 1.03	8.59 ± 0.38	21.85 ± 1.58	7.36
9	25	1350	30	70	120	51.25 ± 0.1	3.05 ± 0.65	14.26 ± 0.97	4.84	39.11 ± 0.77	8.31 ± 0.65	22.05 ± 1.4	7.80
10	25	1350	50	70	80	52.95 ± 0.74	2.22 ± 0.14	11.89 ± 0.51	2.15	40.71 ± 0.31	8.09 ± 0.38	22.29 ± 1.13	8.69
11	45	1350	30	70	80	50.48 ± 0.72	2.53 ± 0.15	11.9 ± 0.51	3.85	39.57 ± 1.66	8.64 ± 0.53	23.32 ± 1.46	9.06
12	25	1150	30	70	80	51.97 ± 0.62	2.41 ± 0.42	12.45 ± 0.83	2.98	43.19 ± 0.97	7.63 ± 0.21	23.72 ± 0.54	10.98
13	25	1550	30	70	80	52.58 ± 0.82	2.55 ± 0.58	14.25 ± 1.36	4.09	46.1 ± 2.38	8.26 ± 0.4	24 ± 0.83	13.53
14	25	1350	30	70	80	53.43 ± 1.01	2.44 ± 0.29	12.95 ± 0.81	2.90	42.59 ± 1.68	7.6 ± 1.01	19.13 ± 0.84	8.43
15	25	1350	30	70	80	44.67 ± 0.28	3.36 ± 0.57	11.86 ± 1.94	9.38	35.49 ± 0.64	8.64 ± 0.28	23.68 ± 1.62	8.38
16	25	1350	10	70	80	50.77 ± 0.48	3.18 ± 0.18	13.8 ± 0.63	4.87	36.86 ± 0.95	8.66 ± 0.15	22.38 ± 0.62	7.52
17	25	1350	30	70	40	51.56 ± 0.49	2.66 ± 0.46	10.94 ± 0.82	2.99	35.06 ± 0.51	8.66 ± 0.68	23.04 ± 1.62	7.90
18	35	1250	20	80	100	51.66 ± 0.44	3.35 ± 0.43	14.72 ± 0.75	5.17	48.09 ± 0.49	8.61 ± 0.92	24.73 ± 0.36	15.60
19	15	1450	20	80	100	48.03 ± 0.58	3.55 ± 0.4	14.86 ± 0.11	7.46	37.33 ± 1.02	9.28 ± 0.55	24.22 ± 1.47	9.38
20	15	1250	40	80	100	43.81 ± 0.15	4.61 ± 0.71	13.53 ± 0.2	10.90	36.56 ± 0.6	9.2 ± 0.33	24.12 ± 0.54	9.13
21	35	1450	40	80	100	50.38 ± 0.77	3.1 ± 0.12	13.7 ± 0.57	4.99	34.58 ± 2.35	8.36 ± 0.99	25.69 ± 1.31	9.95
22	35	1250	40	80	60	46.17 ± 0.67	3.77 ± 0.21	14.06 ±1.23	8.67	34.91 ± 1.06	8.13 ± 0.47	23.12 ± 0.93	7.64
23	15	1450	40	80	60	44.16 ± 0.43	3.28 ± 0.07	11.19 ± 1.06	9.79	38.05 ± 1.59	7.89 ± 0.57	21.51 ± 0.1	6.74
24	15	1250	20	80	60	52.76 ± 0.59	2.94 ± 0.16	14.75 ± 0.47	4.67	38.11 ± 1.69	7.84 ± 0.57	21.36 ± 0.05	6.63
25	35	1450	20	80	60	50.61 ± 0.68	4.46 ± 0.16	16.05 ± 0.37	7.17	36.88 ± 0.65	10.88 ± 0.38	27.49 ± 0.49	12.85
26	25	1350	30	50	80	51.99 ± 0.89	2.82 ± 0.66	14.47 ± 1.16	4.57	34.36 ± 1.3	7.96 ± 0.8	24.74 ± 1.81	8.95
27	5	1350	30	70	80	47.53 ± 0.82	3.18 ± 0.54	14.71 ± 0.68	7.62	36.31 ± 1.08	9.5 ± 0.34	24.31 ± 0.72	9.43
28	25	1350	30	90	80	31.09 ± 1.2	11.55 ± 0.09	30.54 ± 0.78	31.82	19.01 ± 0.76	13.19 ± 2.05	39.67 ± 1.13	29.62

Note: X1: Water temperature (°C), X2: Water amount (ml), X3: Mixing time (min), Drying temperature (°C), X5: Mixing time (min). Different letters in the same column indicate statistical differences ($P \leq 0.05$). Data are the means of three independent experiments ± standard deviations ($n = 3$). ND = indefinite.

Pasta prepared from a mixture of chia seed flour (15%) with quinoa flour (85%) was considered good in terms of overall cooking quality and sensory and texture parameters [5].

3.2.2. *Cooking loss*

The amount of solid residue in cooking water is widely used as an indicator of pasta quality: low amounts of residue (<9%) indicate good pasta quality [14]. As shown in Table 2, solids loss was significantly higher ($p < 0.05$) in the experimental groups compared to the control paste. A significant effect was identified with the variable X5 (positive effect) and interaction with variables X4 and 8.2%, which impairs performance) the determination coefficient was good (R2 = 0.8619). This increase in pasta cooking loss could be attributed to the weak interaction of quinoa proteins (albumins and globulins). At higher fiber content, the extrusion process affected the compact structure of proteins and starches, weakening it and causing the release of solids in the product during cooking, as reported by research by Kamali Rousta et al. [9] and Lorusso et al. [18]. For our control dough, the low value of cooking loss compared to the other treatments is because the ingredients included egg, which favors the density of the protein network, thus preventing solids leakage and ensuring dough cohesion under heating, which is usually present in commercial doughs [19].

The lower weight losses or gains of the cooked pasta could be attributed to the water retention capacity of quinoa protein. Furthermore, the protein in quinoa is characterized by polar amino acids, which favor water absorption and contribute to the increase in the pasta's weight after cooking. In another study, carried out by Sobota & Zarzycki [20], it was observed that increasing the cooking time of the pasta results in a more significant cooking loss due to the hydration of the pasta layers, where the starch granules are gelatinized by removing the soluble components of the dry matter [15]. Fiber also influences the firmness of the dough. The use of corn and orange derivatives was investigated, finding that dietary fiber caused a loosening of the pasta structure by altering the compact matrix of protein and starch. Higher cooking loss, sticky dough, and low cooking time due to pregelatinized starch were also evidenced [21].

3.2.3. *Cooking weight*

Low mass loss, statistically significant and positive, was identified for the control sample during cooking. The fitted model was quadratic ($p < 0.05$) with an R2 of 0.7959. This low variation of the cooked paste could be attributed to the water retention capacity of quinoa protein. In addition, the protein in quinoa is characterized by polar amino acids, which favor water absorption and contribute to the increase in pasta weight after cooking. In another study conducted by Sobota & Zarzycki [20], it was observed that as the pasta cooking time increases, a more significant cooking loss occurs due to the hydration of the pasta layers, where the starch granules gelatinize, eliminating the soluble components of the dry matter [15]. These researchers obtained values close to our research's when substituting quinoa protein isolate.

3.2.4. *Cooking yield*

Cooking yield and swelling index describes the swelling capacity of the noodles. Table 3 shows the cooking performance results. A significant quadratic interaction effect was found (variables The mathematical model has a coefficient of determination (R2 = 0.8457) for the cooking performance response, where the value was 3.29% for the control pasta and the standard and 6.56–27.24% for 28 experimental groups. Mirhosseini et al. [22] reported much lower results, of 3.45%, which confers the important role of the complete presence of quinoa in giving stability to the polymeric carbohydrate trapping network (starch granules), which affects the quality of the pasta during cooking. These values are within the study of Kasunmala et al. [23], where they found high yield values as the dough temperature increased, with the optimum value being recorded at 85 °C extrusion.

3.2.5. *Swelling index and water absorption index*

The swelling Index and water absorption index are used to estimate the functional characteristics of the paste. This characteristic shows the ability of water to bind (limiting factor) with a product. The important process is extrusion gelatinization, which occurs in starch components in foods [18,24]. In this study, the terms IH and AA were found, where water absorption did not receive a significant effect from the study factors. On the other hand, a significant model was found in the HI terms as a linear term (Variables X1, X5, X4), and the model fit had a coefficient of determination of 0.99.

Despite the non-significant effect it had on AA, there are values of 109% for the control and much higher values of 130–175% for the experimental groups M6, M11, M12, and M19 (Table 2). Sobota and Zarzycki [20] and Torres et al. [25] stated that the absorption capacity is also affected by the content of fiber, proteins (polar amino acids), gluten quality, and strength of the protein network, which explains the high values. This increase in water absorption presents the property of hydration and formation of protein gels, where the hydrogen bonds of starch are challenging to break at low gelatinization temperatures, thus reducing the water absorption rate. However, the recipe's precise formulation and humidity control in manufacturing could explain its lack of significance.

On the contrary, Repo-Carrasco et al. [26] attribute the swelling index to the protein's water binding and gelation capacity. It was reported that quinoa protein has a suitable gelation property and forms a gel by aggregating the unfolded protein molecules, followed by chain formation of the aggregates and then joining these chains into the three-dimensional structure, which would explain the result. Torres Vargas et al., [27]. For both cases, the results were within the studies mentioned by the previous authors.

3.3. *Texture analysis (fracturability)*

Due to its macromolecular structure, starch plays a fundamental role in the texture of gluten-free pasta (N). Likewise, it is affected by the raw material and processing conditions. Quinoa contains 60% starch, of which 11% is amylose, compared to 25% in wheat;

therefore, this is reflected in our results, explaining the value [28].

Fig. 2 presents the fracturebility or force (N) required for the dough to break after cooking. The control sample's fracturebility was 4.95 N, corresponding to the force required to break the cooked paste between the teeth. It can be observed that the pastes with quinoa required less force to break except for sample M21, which required more force (5.24 N) than the control. Concerning the experimental groups, M3, M4, M16, M17, M19, M20, M23, M24, M25, and M27 required force values of less than 2.08 N, and the other samples values between 2.47 and 3.5 N. Three groups were observed, the third being the control sample and sample M21. The first can be attributed to the increase in protein concentration; the second to the modification caused in the protein network by proteolysis [18, 25]. These compression characteristics in the texture of the paste still had to be improved with the incorporation of proteins from other sources that can form a network or give stability to the paste by other mechanisms, so it is considered that as the temperature increases of water in the preparation of the paste and the drying temperature, increases the texture or fractureability expressed in units of N..

3.4. *Color*

Color plays a crucial role in the appearance of pasta, affecting the consumer's purchasing decision; the color of the 28 treatments performed showed a pleasing appearance (Fig. 3). Color values (L, a*, b*) were evaluated in the raw and cooked phases (Table 3). The control pasta exhibited a higher L* value (53.51 for cooked and 35.5 for raw), decreasing significantly to values ($L^* > 19$ and $L^* > 31$) for cooked and raw pasta, respectively, in the 28 experimental groups. A main effect of interaction with the drying temperature (X4) will be observed, indicating that, working with higher values, L presents low values, while a* and b* increase with a quadratic model and an R2 (0.75, 0.7578, and 0.69), respectively.

The decrease in L* and the increase in a* and b* in the raw pasta coincides with the conclusions of Torres et al. [25], who attributed these changes to including ingredients such as amaranth, quinoa, and wheat. On the other hand, Baah et al. (twenty-one) and Bhatt & Gupta (twenty) also reported a lightness reduction in the control paste after adding fish powder and pangasius protein isolate, respectively. Despite these observations, additional research, such as those by Mirhosseini et al. [22] and Torres Vargas et al. [27], suggests that the characteristic color of quinoa flour, together with the effect of cold extrusion and drying, contributes to the color profile of the pasta. These changes are linked to increasing starch concentration, drying time, and temperature, supporting the present study's findings as indicated by Sosa et al. [29].

Consequently, statistically significant main effects were evident, positive for L values and negative for a* and b*. The best-fitted model for cooked pasta turned out to be the quadratic one, with an R2 of 0.71, 0.74, and 0.68, respectively.

Calculations of total color differences (ΔE) were carried out for treatments made with quinoa grits compared to the control treatment, where it stood out with an optimal ΔE* and an overall attractive appearance, without bubbles, comparable to a commercial pasta. These color differences in the pasta may be associated with processing conditions, the presence of specific ingredients, and other factors. In this sense, it is concluded that an increase in temperature leads to a decrease in L and an increase in a* and b* values in raw and cooked pasta.

3.5. *Performance optimization*

The samples were analyzed regarding cooking quality and compared with the control sample. The optimization was carried out by minimizing the cooking loss and maximizing the mass gain while maintaining the TOC (Fig. 4). The optimal conditions of X1, X2, X3, X4, and 7.99% cooking yield, 1.9 IH, 135% AA, and 78% in the final process yield, as shown in Figs. 2 and 3.

Table 4 shows the results of the nutritional analysis of the optimized quinoa-based pasta and the control sample. The difference in protein, fat, and fiber content is especially observed. The protein, fat, and fiber contents of the tested quinoa pasta were comparatively higher than those of the control pasta.

Total dietary fiber almost doubled in quinoa pasta, making it significantly ($P < 0.05$) different from the control. These high

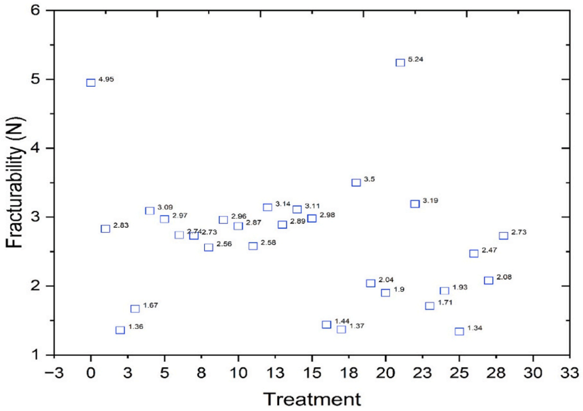

Fig. 2. Fracturability (N) of the 28 treatments of pastes after cooking.

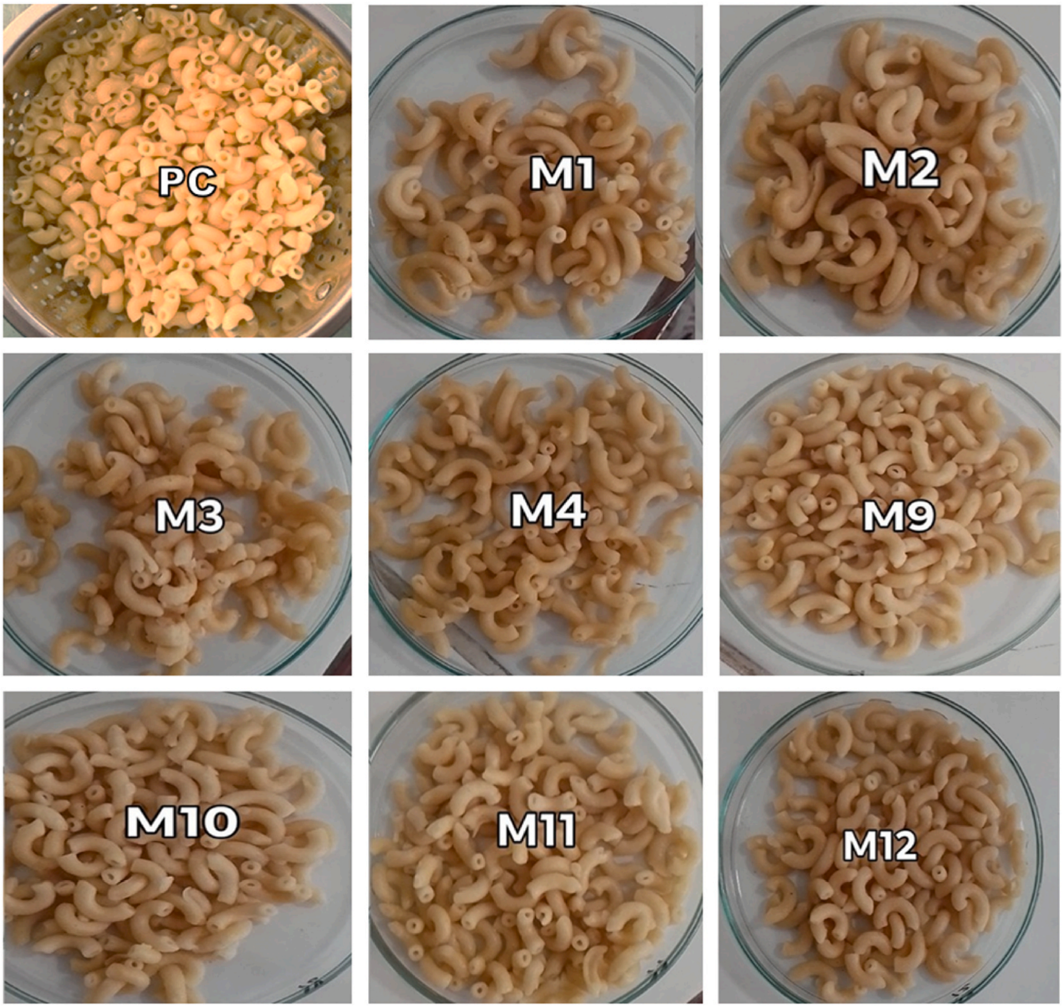

Fig. 3. Pasta control and some pasta resulting from the treatments (cooked).

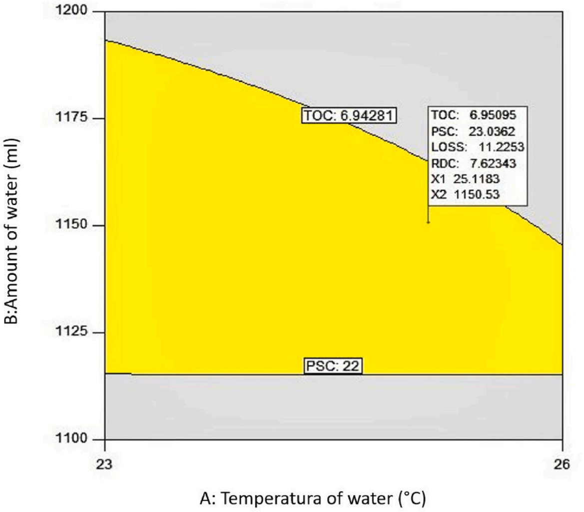

Fig. 4. The optimization graph is the response surface, minimizing cooking loss and maximizing mass gain.

Table 4
Nutritional composition of optimized pasta (per 100 g).

Composition (100g)		
	Quinoa pasta	Pasta control
Energy (Kcal)	392.33 ± 3.79	295 ± 2.65
Moisture content (%)[a]	12.12 ± 0.35	12.17 ± 0.27
Proteins (g)	12.22 ± 0.33	10.93 ± 0.53
Fats (g)	0.62 ± 0.05	0.53 ± 0.09
Carbohydrate (g)	70.77 ± 0.57	74.8 ± 1.87
Fiber (g)	4.32 ± 0.2	1.54 ± 0.45

[a] Only value expressed in percentage.

nutritional values were attributed to the nutrient-rich nature of quinoa, ultimately resulting in a product packed with nutrients and gluten-free, making them a formidable food alternative for celiac and sensitive patients to gluten [30]. Total dietary fiber was approximately 4.3 g/100 g in the optimized pasta compared to 1.54 g/100 in the control sample. This variation is expected, considering quinoa seeds' higher fiber content than durum wheat. Furthermore, due to environmental conditions, there is a notable variation in the dietary fiber content of this pseudocereal (quinoa), with the amount of soluble dietary fiber being less than that of insoluble dietary fiber [26].

4. Conclusions

The pasta made with 100% quinoa stood out for the amount of protein, fiber, fat, mass gain, cooking performance, water absorption, swelling index, and the minimum amount of carbohydrates. The pasta is already better in nutritional properties than traditional pasta. It did not compromise the technological quality during cooking while at the same time showing a good appearance in terms of color. The breakability of the cooked pasta is mostly lower than the reference pasta without compromising its quality. The paste was prepared at process conditions of 25 °C water temperature, 1150 ml amount of water, 30 min of mixing time, 70 °C drying temperature, and 80 min of drying time, which presented adequate results to maximize mass gain and reduce cooking loss. For this reason, quinoa pasta is a promising product on the market with high nutritional and functional quality. More research should be conducted using other raw material characteristics to improve the stability of pasta quality further.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Y.M. Itusaca-Maldonado: Writing – original draft, Resources, Methodology, Investigation, Conceptualization, Data curation, Writing – review & editing. **C.R. Apaza-Humerez:** Writing – review & editing, Data curation, Supervision, Validation. **A. Pumacahua-Ramos:** Visualization, Supervision, Methodology, Data curation, Investigation, Validation, Writing – review & editing. **E. Mayta-Pinto:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors thank Nelida Mayta, a member of Naturkost Perú SAC, for her support in the experiments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28363.

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