RESEARCH PAPER

Impact Of Replacing With Quinoa, Oat, And Chia Flours On The Nutritional And Technological Quality Of Whole-Grain Lasagna-Type Pasta

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Abstract
This study evaluated the impact of partially substituting whole wheat flour with quinoa, oat, and 2% chia in the production of lasagna-type pasta. A mixture design and response surface methodology were applied to optimize the formulation considering nutritional, technological, and sensory parameters. The optimal formulation identified was W80Q15O5 (80% whole wheat, 15% quinoa, and 5% oat), which showed a significant increase in protein (15.9%), dietary fiber (10.8 g/100 g), iron (4.5 mg/100 g), and calcium (72 mg/100 g), as well as higher levels of essential fatty acids such as α-linolenic and linoleic acids. The energy value was lower compared to the control pasta (196 vs. 279 kcal/100 g), representing an advantage for calorie-controlled diets. Technologically, the enriched pasta maintained stability during lamination and cooking, without excessive stickiness. Sensory evaluation revealed that overall acceptability was comparable to the whole wheat control pasta, confirming that substitution did not negatively affect consumer perception. In conclusion, the incorporation of pseudocereals and Andean seeds is a viable strategy to improve the nutritional and functional profile of traditional pasta products, contributing to food sovereignty and healthier diets.
Keywords: Salvia hispanica; Chenopodium quinua, Avena sativa, Nutritional value. Pasta
How to cite this article: Ramírez CL, Ramos KCM, Bazurto JRE, Zavala AAA. Impact Of Replacing With Quinoa, Oat, And Chia Flours On The Nutritional And Technological Quality Of Whole-Grain Lasagna-Type Pasta. Int J Drug Deliv Technol. 2026;16(69s):125-134. DOI: 10.25258/ijddt.16.69s.14

Introduction

Pasta is recommended for its ease of preparation, palatability, and nutritional quality due to the interactions between its main components, which are starches and proteins.1 This product is mainly made from wheat or durum wheat semolina.2 The Western formulation inherited from Italy includes ingredients such as water, salt, among others, to obtain an edible pasta. It must comply with the parameters established in the NTE INEN 616, 2015-01 3, with a moisture content of 14% and a maximum ash content of 1.5%. In this case, the protein values include other protein sources such as quinoa, oats, and chia, which allow achieve values equal to or greater than 15%, with a maximum acidity of 0.45. 2 Replacing refined wheat flour with whole wheat flour allows the bran and germ to be preserved the bran and germ.

Since 1964, it has been recognized by the Food and Agriculture Organization of the United Nations as a necessity for many countries, including Ecuador, to find ways to return to ancestral foods, mainly because we are not wheat producers.

In addition, previous nutritional studies have found that the central Andean community has up to a 52% nutritional deficit.4 Hence, the aim is to develop mass-market foods that contribute to nutritional quality and enable achieve food sovereignty for disadvantaged populations. In several studies, have replaced up to 40% of wheat flour with other sources of protein and fiber. The replacement of white wheat flour with whole wheat flour and its mixture with quinoa and oat flours and the use of 2% chia seeds causes technological difficulties when industrializing lasagna-type pasta, so finding the right combination of ingredients becomes crucial to obtaining a final product with good technological, nutritional, and functional characteristics.

By partially replacing wheat with Andean products such as quinoa, we not only diversify its its use, but we also promote the production of this pseudocereal, which is currently in Ecuador.

It is produced in the Sierra region, where the following varieties stand out: Tunkahuan, Ingapirca, Cochasqui, Imbaya, Chaucha, Tanlahua, Piartal, Porotoc, Amarga del Chimborazo, Amarga de Imbabura, and Morada.5,6 The INIAP Tunkahuan variety (which has a low saponin content) is currently in use and is the most widely planted in the Ecuadorian highlands. Furthermore, in 2004, INIAP developed The INIAP Pata de Venado or Taruka chaki variety, which is also sweet and low in saponin7, which has already been tested for pasta development. 8 Another ingredient used in this research is oats, which are mainly

produced throughout the inter-Andean sector, at altitudes ranging from 2500 to 3300 m, constitutes. A cereal contains mainly carbohydrates, with a high content of soluble dietary fiber soluble fiber, including beta-glucan (β-glucans), which constitute 60% of the dry matter. Its consumption has beneficial effects on health, one of the most important being the lowering blood cholesterol, preventing coronary heart disease by reducing serum cholesterol, reducing glucose intake, and decreasing the response to plasma insulin and weight control through prolonged satiety.9-11 The use of 2% chia seeds, as with products made with pseudocereals, allows for the inclusion of more minerals, lipids, dietary fiber, and proteins, all with higher biological value. It also reduces the glycemic index, glycemic index (GI), improves the ratio of saturated fatty acids (SFA) to polyunsaturated fatty acids (PUFA) ratios12, the use of quinoa flour contributes to the daily dietary fiber intake and Fe and Zn requirements, it also improves the omega-3 and 6 ratio and protein quality13,14. For this reason, it is growing consumer interest in these whole grain products, although one of the limitations they present is sensory acceptance. Research on the subject shows that consumers are increasingly interested in whole grain products, although one of the limitations they present is sensory acceptance. Research on the subject shows that consumers are increasingly interested in
whole grain products, although one of the limitations they present is sensory acceptance. Research on the is their sensory acceptance. Research on the subject allows develop attractive products that meet nutritional, technological, and sensory quality requirements including adjuvants/additives, among which we have enzymes, chemical compounds chemicals, enhancers, etc.

The main objective of this work is to develop a lasagna-type pasta by replacing the Refined wheat with whole wheat and a blend of flours (quinoa, oats, and 2% chia) to enhance its physicochemical, technological, nutritional, and sensory properties using an optimal mixture design optimal mixture design following the response surface methodology (RSM), considering the formulation with the highest protein value and the best sensory acceptance.

Materials and methods

Raw materials

Quinoa flour (Chenopodium quinoa) variety INIAP Tunkahuan, oat flour (Avena sativa) variety INIAP 82 from the Colta canton, commercial whole wheat (Triticum aestivum L.) brand Cillera. These flours were ground in a cyclone hammer mill with a standard 0.8 mm sieve (Lab Mill 3100, Perten Instruments, Hudddinge) and stored at 14 °C. Chia seeds (Salvia hispanica L.), salt, and water were used.

Procedure for making whole wheat pasta sheets with chia seeds

The pasta production process complied with Ecuadorian technical standard NTE INEN 1375.2014,2 which includes weighing, mixing, and kneading after adding the specified amount
of water according to the formulation, including 2% chia at the end, and was mixed for 12 minutes.

Subsequently, the dough was rolled out, drawn through a die where the sheet is cut, and dried until it reached the 12 to 13% at a temperature of 40 °C, this process is carried out by alternating drying and cooling in to prevent the dough from becoming brittle for 15 hours.15,16 Once the dough was dry, it was cooled, weighed, and packaged.

According to Sandoval15, he mentions the following formula used in his research project where he replaced 30% with quinoa flour and described the following formulation: 100 g of flour (70% whole wheat and 30% mixed flours), 30 g water, 12 g salt, and 0.02 g chia.

Composition of flours and pasta formulations

Proximate analyses of raw materials and pastas were performed in terms of moisture AOAC 925.09, protein was analyzed using the Kjeldahl method NTE INEN 1670, 1988, and a nitrogen conversion factor conversion factor of 5.7/wheat flour; 6.25/oats, 5.53/quinoa, 5.83/whole wheat; the lipid content NTE INEN 523, 1980, ash by ignition at 550 + 15 °C NTE INEN 520,
2013. The measurements were taken in triplicate. Whole wheat flour was replaced by up to 20% with a mixture of quinoa, oat, and chia seed flours.

The dough's ability to absorb water was also evaluated using the index of water absorption index (WAI) and water solubility index (WSI) were determined using the method of Anderson et al. 1969, with modification. The modification consisted of using distilled water at room temperature (25°C). One gram of sample was added to a 50 mL centrifuge tube 1 g of sample was added to a 50 mL centrifuge tube, then 15 mL of distilled water at room temperature was added. The suspension was shaken for 30 min, followed by centrifugation at 5000 rpm for half an hour, the weight of the sediment was recorded and the supernatant was placed in a previously weighed aluminum dish and evaporated in a convection oven until a constant weight was achieved. Both
parameters were calculated using the following equations (1) □ (2):

$$WAI\left(\frac{g}{g}\right) = \frac{\text{Sediment weight}}{\text{Sample weight}} \quad (1)$$

$$WSI\left(\frac{g}{g}\right) = \frac{\text{Dry weight of solids in the supernatant}}{\text{Sample weight}} x\, 100 \quad (2)$$

Technological characteristics of pulp formulations

According to Sandoval15, it is recommended that during the rolling stage, the fabric should be smooth and uniform, without any irregularities on the surface, as the final product will depend on the quality of the sheet.

Tests were carried out using Mixolab equipment on whole wheat flour paste and Three best formulations selected by experimental design (whole wheat flour 90%, quinoa flour 5%, oat flour 5%), (whole wheat flour 80%, quinoa flour 15%, oat flour 5%) and (whole wheat flour 90%, quinoa flour 5%, oat flour 15%), the parameters analyzed were kneading resistance, verifying its maximum consistency during kneading at 30°C; the drop in consistency due to thermal and enzymatic action on proteins (gluten degradation); increased consistency due to starch gelatinization (swelling capacity); consistency at the end of the heating period (thermal stability) and final consistency after cooling (starch retrogradation).

Fatty acid profile
Ours were transesterified to convert triglycerides into fatty acid methyl esters (FAME), following the methodology of the American Oil Chemists Society. 17 The composition of omega-3 and omega-6 fatty acids was quantified by gas chromatography with a capillary column (SP 2330 at 100/120 WAW) and a flame ionization detector flame ionization according to method 2.302 of the International Union of Pure and Applied Chemistry. Measurements were made in triplicate.

Mineral composition
The total concentrations of Ca, Fe, and Zn were determined in an absorption spectrophotometer. Each 0.5 g sample was placed in a Teflon perfluoroalkyl container and digested with HNO_3 (4 mL, 14 M) and H_2O_2 (1 mL, 30% v/v) attack. The samples were irradiated at 800 W for 15 minutes at 180 °C. The digested sample was placed in a polypropylene tube and made up to the final volume with distilled water. Measurements were performed in triplicate.

Sensory evaluation of pasta formulations
The parameters measured in the control pasta formulas and the proposed formulations were evaluated for texture, flavor, and overall acceptability by a panel of 30 untrained tasters
who regularly consume lasagna-type pasta. For this purpose, the pasta was cooked and evaluated using a 9-point hedonic scale of overall acceptance: 9 "I like it extremely," 8 "I like it a lot," 7 "I like it moderately"; 6 "I like it somewhat," 5 "I neither like nor dislike it,"dislike it," 4 "I dislike it slightly," 3 "I dislike it moderately," 2 "Very unpleasant," 1 " extremely unpleasant."

Quadratic mixture design
To study the effect of replacing whole wheat flour with quinoa flour, oats, and 2% chia seeds on the physical, chemical, nutritional, technological, and sensory properties. Three factors were studied: the percentage of whole wheat flour replaced (levels: 70% to 90%), with quinoa flour (levels: 5% to 25%) and oat flour (levels: 5% to 25%), adding 2% chia seed to the final product in the dough.

Table 1. Experimental design

Trial	Name	% Substitution in Flour Basis		
		Whole wheat Flour	Quinoa Flour	Oat Flour
0	WWL	100	0	0
1	W70Q25O5	70	25	5
2	W76Q12O12	76	12	12
3	W80Q5O15	80	5	15
4	W70Q5O25	70	5	25
5	W90Q5O5	90	5	5
6	W80Q15O5	80	15	5
7	W84Q8O8	84	8	8
8	W74Q8O18	74	8	18

9	W74Q18O8	74	18	8
10	W70Q15O15	70	15	15

WWL: Whole wheat lasagna; W: Whole wheat flour; Q: Whole quinoa flour; O: Whole oat flour.
The design allows for an experimental approximation of (Yobs) with a surface response model expressed with coded values according to the following equation (3):

$$Y_{obs} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \quad (3)$$

Y_{obs}= respuesta (por ejemplo: volumen, textura, aceptabilidad, dureza, etc.)

Where

X_1, is the factor Whole wheat flour; X_2, is the Whole Quinoa flour and X_3: is the Whole oat flour

$\beta_1, \beta_2, \beta_3$= linear effects of each flour whereas the mixed coefficients $(\beta_{12}), (\beta_{13})$, and (β_{23}), represent interactions between factors.

The response variables were content of protein, lipids, ash, moisture, Water Solubility Index (WSI), Water Absorption Index (WAI) (nutritional and funtional characteristics) and overall consumer acceptability.

Statistical analysis
One-way ANOVA and surface response analysis were applied to establish significant differences between samples ($p < 0.05$). The homogeneity of the samples was verified using Levene's test.

Results and discussion
Physicochemical composition of the flours
Table 2 shows the chemical composition of the flours used in this study. It was observed Quinoa flour, oat flour, and the mixture with 2% chia seed showed a significantly higher protein content significantly higher protein content than whole wheat flour. The protein levels found in quinoa and oats are consistent with the ranges previously reported by other authors, ranging from 13.5 to 21.5% for quinoa and from 8.0 to 14.0% for oats. 18 These variations in protein content and amino acid profile are attributed to factors such as genotype and growing conditions. 19 The whole-grain flours used in this study, sourced from Andean crops, could meet the protein requirements established by the FAO and the World Health Organization. (WHO). In terms of amino acid profile, quinoa, oats, and chia seeds are notable for their high lysine content, unlike wheat flour, which is deficient in this amino acid, oats, and chia seeds, unlike wheat flour, which is deficient in this amino acid. In particular, in quinoa grains, approximately 65% of the proteins have a high lysine content, concentrated in the germ20, which highlights. The importance of consuming this type of pseudocereal, which unlike others contains lysine, leucine, valine, isoleucine, and threonine, among others, giving it high biological value and good digestibility, among other positive aspects.

Table 2. Chemical composition of raw material

Parametersa	Units	Whole Wheat Flour	Wheat Flour	Whole Quinoa Flour	Whole Oat Flour	Chía Seed
Moisture	%	13.20 ± 0.01 [e]	11.30 ± 0.02 [b]	11.50 ± 0.04 [c]	12.00 ± 0.04 [d]	8.00 ± 0.01 [a]
Protein	% d.m.	11.80 ± 0.3 [a]	12.50 ± 0.3 [b]	18.10 ± 0.5 [d]	12.50 ± 0.10[b]	18.70 ± 0.3 [e]
Lipids	% d.m.	1.40 ± 0.04 [b]	0.98 ± 0.3 [a]	6.40 ± 0.02 [c]	7.10 ± 0.02 [d]	34.30 ± 0.4 [e]
Starch	% d.m.	65.37 ± 0,1 [d]	71.64 ± 0.1 [e]	50.18 ± 0.2 [b]	55.90 ± 0.10 [c]	ND

Ash	% d.m.	1.43 ± 0.03 [b]	0.58 ± 0.01 [a]	2.82 ± 0.05 [c]	5.60 ± 0.01 [d]	12.10 ± 0.02 [e]
Total Fibre	% d.m.	6.80 ± 0.05 [b]	3.00 ± 0.4 [a]	9.10 ± 2.7 [c]	6.90 ± 0.80 [b]	13.20 ± 0.6 [d]

Mean ± SD n=3. Values followed by the same letter in the same column are not statistically different at 95% confidence level; d.m., dry mater; ND, not detected.

The lipid content in chia flour was significantly higher than the lipid content in refined wheat, quinoa, and oat flours. In wheat during the refining process the germ and outer layers of the bran, which contain the highest amount of fat and fiber, are removed fat and fiber. 21 The lipid content of Andean chia seeds can vary between 30.7% and 41.5%.12 During this research, the percentage was 34%. This may be due to the biological composition of the grain, the distribution Of the lipids, in wheat and oats the lipids are in the germ, while in chía, as it is in whole grain form, which retains all of its lipid fraction. These results coincide with other authors, ranging from 2% to 11% in quinoa and from 5.6% to 13% in oats, 25% chia and the lipid content in whole wheat flour (1-2.5%).22,23 The quality of the lipids present in the flours used here is characterized by its high PUFA (polyunsaturated fatty acid) content in chia, quinoa, and oats, as well as their adequate linoleic acid (LA)/alpha-linolenic acid (ALA) ratios, since chia has a high ALA content, around 60% of total fatty acids. Quinoa provides a balanced way, values that have a positive impact on health. The dietary fiber content of chia, quinoa, and oats is higher than that of processed wheat and whole wheat flours, as shown in Table 2. Chia flour is rich in insoluble fiber, while oat fiber is rich in soluble fiber beta-glucans that reduce cholesterol and blood glucose. And quinoa flour has less fiber than chia and oats, but it is still higher than wheat flour. The moisture content is between 8% and 13%, making them stable raw materials for processing due to their low water content.

Evaluation of the behavior of the formulations in terms of nutritional Functional, and Sensory Characteristics.

According to the results shown in Table 3, the formulations with the highest proportion of oats (e.g., W80 Q15 O5 and W74 Q8 O18) had higher moisture content (≈13%), while the control (WWL) had the lowest (8.21%). This is due to the water absorption capacity of the β-glucans present in oats, which increase moisture retention. Studies on pastes Enriched with oats, they confirm that the addition of this flour modifies absorption and cooking quality.

On the other hand, the ash content increased in formulations with a higher proportion of quinoa (e.g., W90Q5O5 with 1.81%), reflecting the higher mineral density of this pseudocereal.

Research on quinoa-enriched pastas reports similar increases in minerals such as iron and magnesium. Additionally, ash contents are within the limits established by the regulations for flours3, which set out the maximum permitted values for flours around 0.3% and 2%, respectively. When analyzing the protein content of the proposed mixtures using the Design-Expert program, expert program, it can be observed that there is a significant difference between the mixtures with a probability of 95%, the behavior of the data presented a linear model, with R2 = 0.8296 (data not shown) Replacing wheat with quinoa significantly increased the protein content (e.g., W70Q25O5 with 16.36%). This is consistent with the findings of Hormozi et al.24, who observed that the adding quinoa to noodles increased the protein value and improved the amino acid profile. Likewise, Gałkowska et al.25 reported that the combination of wheat and quinoa improves the nutritional quality of pasta. The lipid content in all formulations is higher compared to refined and whole wheat flours to refined and whole wheat flours. This is because the refining process removes the germ and outer layers of the bran, where most of the lipids and fiber are concentrated.

These findings are consistent with what has been reported in the literature for products such as quinoa, oats and chia.19,23,22 The formulations with higher oat content showed lower lipid content (≈2.3–2.9%) compared to the control (3.12%). This is related to the composition of oats, which are rich in soluble fiber and lower in fat than whole wheat.

The WAI (water absorption index) and WSI (water solubility index) values are functional properties of starches and proteins in flours, whole wheat flour has a slightly higher IAA than refined wheat due to the fiber content of the bran, which retains more water, the mixtures had values higher than the ISA value of refined wheat.

In terms of IAA, the control (WWL) had the highest value (1.55), while the mixtures with Quinoa and oats reduced absorption. This indicates that substitution weakens the gluten network, decreasing water retention capacity. In this regard, the ISA shows an increase in formulations with higher oat content (e.g. W70Q5O25 and W74Q18O8) reaching very high values (≈22.5%), reflecting greater solubilization of components such as β-glucans and non-gluten proteins.26

They also observed that the addition of oats increases solubility and modifies the texture of the paste the initial sensory evaluation of acceptability using Design Expert software showed that there are significant differences with a p (< 0.05), and it is observed that the sensory attributes are affected, since the more quinoa and oats are added, the lower the acceptability lower. The data presented a cubic mathematical model with a coefficient of determination R2 = 0.9607. (data not shown).

Table 3: Physicochemical, functional, and sensory characteristics of the dough formulations

Parameters	**Units**						**Formulations**					
		WWL	W70Q25O5	W76Q12O12	W80Q5O15	W70Q5O25	W90Q5O5	W80Q15O5	W84Q8O8	W74Q8O18	W74Q18O8	W70Q15O15
Physicochemical Characteristics a												
Moisture	% d.m.	8,21 ± 0,04 a	12,16 ± 0,05b	12,34 ± 0,04b	12,34 ± 0,05b	11,63 ± 0,09ab	13,34 ± 0,10 c	12,91 ± 0,03 bc	13,01 ± 0,04 bc	12,25 ± 0,03b	12,59 ± 0,04 b	11,94 ± 0,06 ab
Ashes	% d.m.	1,38 ± 0,04 ab	1,64 ± 0,04bc	1,42 ± 0,05ab	1,36 ± 0,04 a	1,53 ± 0,10 ab	1,81 ± 0,05 c	1,19 ± 0,01 a	1,54 ± 0,04 ab	1,53 ± 0,03 ab	1,61 ± 0,06 bc	1,44 ± 0,04ab
Proteins	% d.m.	13,60 ± 0,50 ab	16,36 ± 0,01c	13,66 ± 0,01ab	13,79 ± 0,01ab	12,05 ± 0,01a	12,53 ±0,01a	15,92 ± 0,01bc	14,66 ± 0,01b	13,92 ± 0,01ab	14,14 ± 0,01 ab	14,3 8 ± 0,01ab
Lipids	% d.m.	3,12 ±0,02 c	3,10 ±0,02 c	2,93 ± 0,02bc	2,51 ± 0,01a	2,81 ± 0,01ab	2,32 ± 0,01a	2,92 ± 0,01bc	2,89 ± 0,01bc	2,71 ± 0,01an	2,97 ± 0,01bc	2,91 ± 0,012bc
Functional Features b												
WAI	g/g	1,55 ± 0,05 c	0,94 ± 0,03ab	0,87 ± 0,07a	0,93 ± 0,05ab	0,87 ± 0,04a	0,94 ±0,02ab	0,96 ±0,02ab	0,85 ± 0,01a	0,97 ± 0,06ab	0,87 ± 0,04 a	0,94 ± 0,05ab
WSI	%	4,48 ± 0,21 a	8,79 ±0,47b	12,2 ± 0,80bc	5,72 ± 0,30a	22,5 ± 1,73d	4,89 ± 0,32a	8,47 ± 0,73b	4,79 ± 0,33a	8,21 ± 0,64b	22,5 ± 1,18d	5,18 ± 0,33a
Sensory evaluation												
Global Acceptability	n/a	9	5	4	7	6	5	9	6	4	4	4

Codes: WWL, whole wheat lasagna, W70Q25O5 /70% Whole Wheat Flour, 25% Whole Quinoa Flour, 5% Whole Oat Flour; W76Q12O12 /76% Whole Wheat Flour, 12% Whole Quinoa Flour, 12% Whole Oat Flour; W80Q5O15 / 80% Whole Wheat Flour, 5% Whole Quinoa Flour, 15% Whole Oat Flour; W70Q5O25 / 70% Whole Wheat Flour, 5% Whole Quinoa Flour, 25% Whole Oat Flour, W90Q5O5 /90% Whole Wheat Flour, 5% Whole Quinoa Flour, 5% Whole Oat Flour; W80Q15O5 /80% Whole Wheat Flour, 15% Whole Quinoa Flour, 5% Whole Oat Flour; W84Q8O8 / 84% Whole Wheat Flour, 8% Whole Quinoa Flour, 8% Whole Oat Flour; W74Q8O18 / 74% Whole Wheat Flour, 8% Whole Quinoa Flour, 18% Whole Oat Flour, W74Q18O8 /74% Whole Wheat Flour, 18% Whole Quinoa Flour, 8% Whole Oat Flour; W70Q15O15 /70% Whole Wheat Flour, 15% Whole Quinoa Flour, 15% Whole Oat Flour; d.m., dry matter.

Mean ±SD, abn=3.Values followed by the same letter in the same column are not statistically different at 95% confidence level.

The process was optimized using Desing – Expert software, taking into account the highest protein percentages proteins, good acceptability, and the lowest ISA, the selected formulations are as follows:

Tabla 4. Formulas seleccionadas por Design Expert

Trial	**Formulations**	**Global Acceptabilitya**	**Proteinsb %**	**WSIc %**
0	WWL	9.01±0.12	13,60 ± 0,50 ab	4,48 ± 0,21 a
3	W80Q5O15	7.02±0.14	13,79 ± 0,01 ab	5,72 ± 0,30 a
5	W90Q5O5	5.03±0.22	12,53 ±0,01 a	4,89 ± 0,32 a
6	W80Q15O5	9.03±0.12	15,92 ± 0,01 bc	8,47 ± 0,73 b

Codes: WWL, Whole Wheat Flour; W80Q5O15, 80% Whole Wheat Flour, 5% Whole Quinoa Flour, 15% Whole Oat Flour; W90Q5O5, 90% Whole Wheat Flour, 5% Whole Quinoa Flour, 5% Whole Oat Flour; W80Q15O5, 80% Whole Wheat Flour,
15% Whole Quinoa Flour, 5% Whole Oat Flour. Means ± SD, an=3. bn=3. cn=3. Values followed by the same letter in different column are not statistically different at 95% confidence level.
As can be seen when introducing a gluten-free ingredient with different nutritional and functional profiles, the properties of the rolled dough for lasagna, which must withstand cooking without breaking.

Effect of the formulation on technological characteristics
The Mixolab evaluated the behavior of the flours and doughs during mixing and heating, providing information on protein (gluten), starch, and enzymatic activity, which are closely related to tenacity in products such as pasta. In Table 5 shows the results from Mixolab

Table 5. Technological Parameters

Parametersa	Units		Formulations		
		WWL	W80Q5O15	W90Q5O5	W80Q15O5
Kneading resistance	Nm	1.139 ± 0.05 a	1.065 ± 0.04 b	1.114 ± 0.03 ab	1.065 ± 0.04 b
Gluten degradation	Nm	0.597 ± 0.02 a	0.455 ± 0.01 b	0.501 ± 0.02 b	0.422 ± 0.01 b
Swelling capacity	Nm	1.719 ± 0.06 a	1.440 ± 0.05 b	1.528 ± 0.04 ab	1.450 ± 0.05 b
Thermal stability	Nm	1.252 ± 0.04 a	0.950 ± 0.03 b	1.056 ± 0.03 ab	0.944 ± 0.03 b
Starch retrogradation	Nm	1.982 ± 0.07 a	1.520 ± 0.05 b	1.663 ± 0.06 ab	1.516 ± 0.05 b

Codes: WWL, Whole Wheat Flour; W80Q5O15, 80% Whole Wheat Flour, 5% Whole Quinoa Flour, 15% Whole Oat Flour; W90Q5O5, 90% Whole Wheat Flour, 5% Whole Quinoa Flour, 5% Whole Oat Flour; W80Q15O5, 80% Whole Wheat Flour, 15% Whole Quinoa Flour, 5% Whole Oat Flour. Means ± SD, an=3. Values followed by the same letter in the same column are not statistically different at 95% confidence level.
Kneading resistance decreased in the quinoa and oat formulations compared to the control (WWL). This suggests a lower capacity for gluten network formation, attributed to the dilution of wheat proteins and the interference of fibers and phenolic compounds present in pseudocereals. Zheng et al.27 observed that the incorporation of alternative flours reduces gluten network cohesion, affecting dough elasticity and extensibility.
The lower values for gluten degradation in formulations with quinoa and oats indicate A less stable protein network reduces gluten integrity, resulting in greater structural fragility, but with nutritional advantages.25,28 The swelling capacity decreased in the substitution formulations, reflecting lower water absorption and lower matrix expansion. This trend was also observed in studies using germinated quinoa grains, where the swelling capacity was reduced. Swelling, although it improves the protein and antioxidant content. In terms of the presence of oat flour in the formulations, soluble fiber stands out, which limits the expansion of the matrix.29,30

Thermal stability was lower in formulations with substitution, which is related to proteins called gliadins, which are less resistant to denaturation and affect stability of the dough during processing. According to the findings of Gałkowska et al.25, they showed that quinoa reduces the thermal stability of pasta, although it provides important bioactive compounds for health. It should be noted that high values suggest good gelatinization capacity, the pastas are firmer and more elastic, but low values can result in soft or sticky pasta, the Formulations with substitution obtained lower values than whole wheat flour, which causes difficulties in baking, so it is important to adjust the baking time, because very sticky dough causes the sheets to stick together or break when handling. The thermal resistance of gelatinized starch is crucial to prevent the pasta from falling apart during prolonged cooking. The substituted formulations show a higher presence of starches or fibers which do not withstand prolonged heat well, the starch in oats and quinoa gelatinize differently differently, it is important to consider this parameter, especially in laminated doughs where structural firmness is crucial. Starch retrogradation is related to the final firmness and stickiness when cooled; high values indicate that the pasta does not stick and has good texture after cooking, because it reflects the ability of starch to reorganize (crystallize) when the temperature drops, it influences the texture of the pasta after cooling or reheating. Low values were observed in the substituted formulations due to the presence soluble fiber and fat in oats and quinoa. It also has a lower proportion of free amylose and higher protein content but low elasticity, because the proteins in quinoa do not replace the function of gluten.

Technological process in the rolling mill
This operation consists of reducing the thickness of the dough using a series of rollers until achieving the desired thickness for the sheets. In the rolling machine, which has two smooth rollers, it was passed several times to form the sheet according to the graduation corresponding to lasagna, 1.5 mm. With The formulations W80Q5O(15),W90Q5O5did not form the fabric,and in order to laminate the dough,it was necessary to change the thickness of the rolled dough to 2.5 mm, because if it was rolled to a lesser thickness, the dough lost flexibility and therefore broke. In contrast, the formulation W80 Q15 O5 was the one that It showed better characteristics in laminates with a thickness of 1.5 mm. For this reason, the other mixtures were technologically discarded.

Nutritional evaluation of the optimal lasagna-type pasta formulation
The formulation W80Q15O5, with partial substitution of whole wheat flour with 15% quinoa, 5% oats, and 2% chia significantly improves the nutritional profile of the pasta with the highest percentage protein, low WSI values, and better technological performance compared to 1.5 mm thick laminate. It should be noted that this was the formulation most accepted by consumers, similar to whole wheat flour pasta.

Table 6: Nutritional composition of the optimal formulation and the control

Parametersa	**Units**	**WWL**	**W80Q15O5**
Proteins	%.m	12.3±1.6 a	15.92±0.91 b
Lípids	% d.m	3.3±0.61a	3.45±0.06 a
Total dietary fiber	g/100g d.m	7.0±0.62 a	10.8±0.04 b
Fe	mg 100g dm-1	3.6±0.01a	4.5±0.02 b
Ca	mg 100g dm-1	30±0.2 a	72±0.5 b
α-Linolenic acid	g/100g d.m	0.05±0.0 a	0.75±0.0 b
Linoleic acid	g/100g d.m	0.87±0.0 a	1.38±0.0 b
Caloric value	Kcal/100 g	279±1.2 a	196.4± 2.1a

Codes: WWL, Whole Wheat Flour; W80Q15O5, 80% Whole Wheat Flour, 15% Whole Quinoa Flour, 5% Whole Oat Flour.
Means ± SD, an=3. Values followed by the same letter in the different column are not statistically different at 95% confidence level.
The pasta enriched with quinoa and oats had a higher protein content (15.9% vs. 12.3%), which is consistent with studies that highlight quinoa as a pseudocereal rich in high-quality proteins, with a more balanced amino acid profile than wheat. This contribution is relevant because the combination of whole wheat and quinoa improves the bioavailability of lysine, a limiting amino acid in cereals. The W80Q15O5 formulation showed a notable increase in total fiber (10.8 g/100 g vs. 7.0 g/100 g). Oats provide β-glucans, soluble fibers with
hypocholesterolemic and glycemic response modulating effects. Studies on oat-enriched pasta oats confirm that the incorporation of β-glucans improves the functional profile without negatively affecting acceptability. The Fe (4.5 mg/100 g) and Ca (72 mg/100 g) content in the enriched formulation was significantly higher than in the control pasta. This is explained by the contribution of quinoa, recognized for its mineral density and its potential to combat nutritional deficiencies in vulnerable populations. The presence of α-linolenic (0.75 g/100 g) and linoleic acid (1.38 g/100 g) in the enriched formulation reflects the incorporation of oats and quinoa, both sources of polyunsaturated fatty acids. These compounds are relevant for cardiovascular health cardiovascular health and neurological development. The enriched pasta showed a lower caloric value (196 kcal/100 g vs. 279 kcal/100 g), which may be advantageous in energy-controlled diets. This finding coincides with current trends in pasta reformulation to improve its nutritional and functional profile and functional profile.
Pasta enriched with whole wheat, quinoa, and oats shows substantial improvements in protein, fiber, minerals, and

essential fatty acids, aligning with trends in food reformulation to increase their functional and nutritional value. These results support the incorporation of pseudocereals and alternative grains into traditional products such as pasta, contributing to healthier and more sustainable diets.

Conclusions

The W80Q15O5 blend (80% whole wheat, 15% quinoa, 5% oats; plus 2% chia in the process) optimized by blend design and RSM showed the best balance between nutritional performance, technological, and sensory performance, with stable lamination at 1.5 mm and overall acceptability comparable to whole wheat control.

Compared to the whole wheat pasta control (WWL), the optimal formulation significantly increased significantly increased the content of protein, total dietary fiber, iron (Fe), and calcium (Ca), in addition to increasing essential fatty acids (ALA and LA), maintaining similar lipid levels and reducing the energy value per 100 g. The changes in WAI and ISA demonstrate the contribution of oat β-glucans and non-protein gluten, increasing solubility and modifying absorption; this requires process adjustments, but provides nutritional functionality.

Mixolab measurements confirmed a reduction in tenacity and thermal stability associated with gluten dilution and the presence of fibers, without compromising the integrity of the sheet in the optimal formulation. Formulations that did not achieve stable lamination at conventional thicknesses were discarded. The overall acceptability of W80Q15O5 was high and comparable to the integral control, while formulations with higher substitution levels showed decreases in texture and stickiness partial substitution with quinoa, oat, and chia flours in rolled pasta is feasible and beneficial for improving the nutritional profile without losing technological performance, provided that substitution levels and process parameters (rolling, drying, cooking) are optimized.

Evaluate additives (enzymes, gluten improvers), adjust baking times/temperatures and delve deeper into sensory studies with a trained panel to consolidate market acceptance market, as well as validating nutritional stability after storage and cooking.

Acknowledgement

We gratefully acknowledge the Faculty of Chemical Engineering of the University of Guayaquil for providing the institutional support and facilities that made this work possible.

Conflict of Interest

The authors do not have any conflict of interest.

Funding Source

The authors did not receive any financial support for the research, writing, and/or publication of this article.

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