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Formulation and Production of Gluten-free Bread Based on Canihua Flour, Quinoa Flour, and Sweet Potato Starch with High Protein and Fiber Value

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Abstract

In recent years, progress has been made in overcoming the technological challenge of gluten-free final quality in gluten-free products using potential ingredients and optimized processing conditions. However, the nutritional profile of these products is often inferior compared to their gluten-containing versions, which can negatively affect those who follow a lifelong gluten-free diet, such as people with celiac disease. This can lead to nutritional deficiencies, weight gain, and digestive health problems. For this reason, the main objective of this research was to formulate and produce a gluten-free bread based on canihua flour (*Chenopodium pallidicaule*), quinoa flour (*Chenopodium quinoa*) and sweet potato starch (*Ipomoea batatas*) as main ingredients, with a high protein and crude fiber content. Seven formulations were developed, varying the percentages of the ingredients using the mix design method. In addition, different methodologies were used to determine the percentage of protein, fiber, sensory evaluation and humidity, in order to identify the optimal formula from the results obtained. As a result, the optimal formulation was the one that combined 66,67% canihua flour, 16,6% quinoa flour and 16,6% sweet potato starch, reaching a protein content of 12,12% and a fiber percentage of 1,32 %. In conclusion, the use of canihua flour, quinoa flour and sweet potato starch in the production of gluten-free bread represents a promising alternative to improve the nutritional profile of these products, while at the same time making it possible to overcome the challenges related to the absence of gluten, which is positively reflected in the final sensory properties of the bread.

Keywords
Gluten-free bread, nutritional deficiency, gluten intolerance, canihua, quinoa, sweet potato starch.

1.Introduction
Celiac disease is an autoimmune disorder in which a person's immune system responds adversely to the gluten present in their diet (De la Calle et al. 2020). That is, the ingestion of gluten, a protein present in wheat, causes an abnormal immune response in the body that damages the mucosa of the small intestine and hinders the absorption

of essential nutrients from foods such as carbohydrates and proteins (Salehi 2019). The prevalence of celiac disease is 1% to 2% worldwide (Arslan et al. 2019; De la Calle et al. 2020). The only treatment or remedy that can currently be chosen if one has a celiac disease is to follow a strict gluten-free diet for life, since it is a chronic condition (Arslan et al. 2019; De la Calle et al. 2020).

Developing gluten-free products has been a very difficult challenge due to the scarcity of alternative ingredients that fulfill the function of gluten in the dough (Ronie et al. 2021). In the bread industry, gluten is the set of proteins that is responsible for the formation of a cohesive, elastic and extensible dough, thus making proper fermentation and baking possible (Belorio M. & Gómez M. 2020). To date, various investigations have been carried out on a better formulation of gluten-free baked goods so that they can have acceptable sensory and physicochemical properties. Among the different gluten-free ingredients that have been used are alternative flours made from gluten-free grains, hydrocolloids, emulsifiers, leavening agents, preservatives and flavorings that improve their quality (Arora et al. 2023).

In the bread-making process, technologies such as high-pressure treatment, sourdough fermentation and extrusion technology have been improved (Ronie et al. 2021), although the nutritional value of these products does not always improve and may even decrease. Mármol et al. (2022) points out that, despite improvements in the formulation of gluten-free products, their macronutrient profile varies considerably, and they are not nutritionally equivalent to gluten-containing products. Furthermore, De la Calle et al. (2020) mention that these products are often low in protein and high in fat, as well as deficient in essential vitamins and minerals such as B12, calcium and iron. The use of refined flours without bran or germ contributes to their low nutritional value. Fiber, scarce in the diet of celiacs, is beneficial for health and improves the texture and durability of gluten-free products (Arslan et al.2019; Ronie et al. 2021). Pseudocereals such as buckwheat and quinoa, which are rich in fiber and have a low glycemic index, are nutritious options. A lack of fiber in the diet of celiac patients can contribute to health problems such as coronary heart disease, hypertension, obesity, and type II diabetes (Arslan et al. 2019; Myhrstad et al. 2020).

1.1 General objective of the project

To formulate and produce a gluten-free artisan bread based on canihua flour, quinoa flour and sweet potato starch with a protein value greater than 10% and a fiber value greater than 4%.

1.2 Specific objectives

a) Develop 7 preliminary bread formulations using different proportions in the mixtures of the main ingredients such as canihua flour, quinoa flour and sweet potato starch applying an experimental mixture design.
b) Develop a detailed production process for gluten-free artisan bread that includes dough preparation, fermentation times and temperatures, and baking. Identify the best formulation by analyzing specific volume, moisture, sensory characteristics, protein and fiber.

2.Methodology

2.1 Ingredients and supplies

Canihua flour: Canihua is a gluten-free Andean cereal with high nutritional content, rich in polyunsaturated fatty acids, minerals and vitamins (Dávalos et al. 2023). Quinoa flour: Quinoa, like canihua, is an Andean cereal with high nutritional content and is considered a possible healthy alternative to gluten-containing cereals according to the FAO (Dávalos et al. 2023). The white variety (*Chenopodium quinoa*) and the product were obtained from the company Mantaro SAC. Sweet potato starch (*Ipomoea batatas*): Bach et al. (2021) mentions that one of the benefits of this product is gelation and water retention, it can improve the texture of gluten-free bread, making it softer and fluffier. It was obtained from the company Mantaro SAC.

The other ingredients are: Kefir, which according to Spizzirri et al. (2022), represents an interesting source of proteins, polysaccharides and minerals, capable of imitating the behavior of the gluten network in gluten-free preparations; Xanthan gum, a hydrocolloid used in gluten-free breads to improve their quality during dough preparation, its ability to confer viscosity and create gels (Gómez Manuel & Belorio Mayara 2020); Mother yeast, a natural ferment that involves the mixture of flour and water, allowing spontaneous fermentation with the presence of lactic bacteria and yeasts, which has been shown to be effective in improving the texture and volume of bread (Dan et al. 2022); Water, which in bread production plays an important role in the gelatinization of starch, denaturation of proteins and in the development of flavor and color (Arslan et al. 2019), obtained from the Jaujina Artisan Bakery; and Vegetable Shortening, Salt and Sugar, all obtained from the company Mantaro SAC.

2.2 Determination of gluten-free bread formulations

The mixture design method was used with the simplex reticular model in the Minitab 18 software, which yielded 7 formulations for the 3 main ingredients such as canihua flour, quinoa flour and sweet potato starch.

Table 1. Gluten-free bread formulations

Formulation	Canihua flour (CF)	Quinoa flour (QF)	Sweet potato starch (SPS)
1	66,67%	16,67%	16,67%
2	100%	0%	0%
3	16,67%	16,67%	66,67%
4	16,67%	66,67%	16,67%
5	0%	0%	100%
6	0%	100%	0%
7	33,33%	33,33%	33,33%

The quantity of the other ingredients in each formulation is also presented, which are in a fixed proportion extracted from the formulations as a guide in the literature. As shown in Table 2, the quantities of the ingredients are for a mixture of 125 g of the 2 flours and the sweet potato starch. That is, a dry mixture of these 3 main ingredients. Each formulation will have the same weight of 125 g of its dry mixture. 2 units or samples of each formulation were made.

Table 2. Proportion of ingredients

Ingredients	**For a mixture of 125 g of (CF + QF + SPS)**
Kefir	30 ml
Xanthan gum	2 g
Vegetable shortening	10 g
Sugar	30 g
Water	70 ml
Sourdough yeast	6,25 g
Salt	5 g

2.3 Description of the gluten-free bread making process

The experimentation and quality tests were carried out in a bakery as a production workshop and the laboratory of the University of Lima respectively. First, the sourdough yeast had to be obtained, where the fermentation process of the canihua flour was used with the water mixture. The quantity of canihua flour used was 5% of the dry mixture, that is 6,25 g. which yielded only 1 formulation. Therefore, for the 7 formulations to be processed, the quantity of canihua flour resulted in 43,75 g. in total. To it 200 ml of water was added. The fermentation lasted 48 hours at room temperature 20 - 25 °C. A hand mixer was used to mix the ingredients, starting with a dry mix at 100 rpm for 2 minutes. Afterwards, the other ingredients were added and mixed at 150 rpm for 5 minutes. The resulting dough was manually kneaded with a rolling pin for 5 minutes to ensure even distribution, controlling the time to prevent the dough from becoming brittle. Each dough resulting from each formulation was weighed again resulting in a weight of approximately 200 g and was divided into 2 portions of 100 g each. The portions were placed in a fermentation chamber at 40 °C for 40 minutes. Then, a craft oven was preheated for 10 minutes before baking the doughs at 300 °C for 20 minutes. Finally, the loaves were removed from the oven and allowed to cool on a worktable for 1 hour. This process was repeated for a total of 7 formulations, resulting in 14 portions or samples.

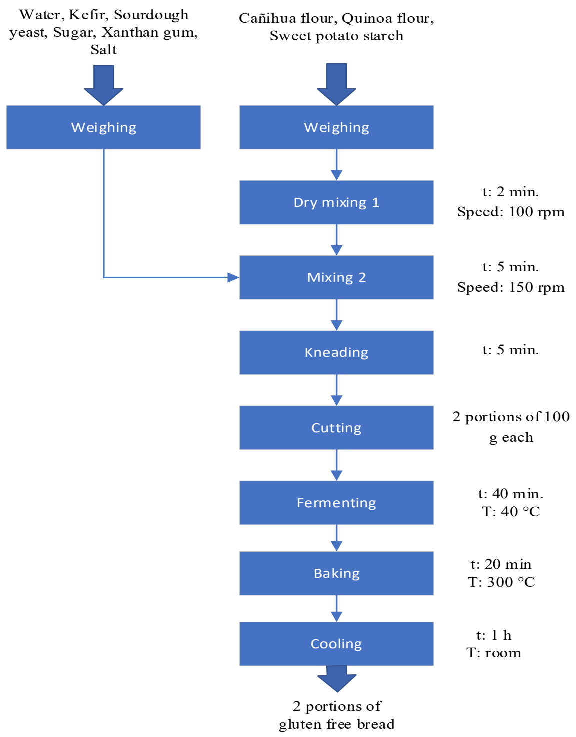

Figure 1. Flow chart of the production process

2.5 Specific volume

The method for determining the specific volume of bread was the rapeseed displacement method taken from the works on gluten-free bread preparations by (Valino et al., 2020; Remilekun et al., 2023). This method is also provided by the AACC (Cereals & Grains Association). in its 11th edition. The calculated volume of the bread sample by the difference in volumes of the displacement of the seed in a container is divided by its weight to calculate the specific volume.

2.6 Determination of moisture

To determine the moisture content of the breads produced, the SARTORIUS MA-30 food moisture balance was used. The measurement procedure followed the gravimetric method of the Peruvian Technical Standard NTP 209.264:2018. This method is based on the weight loss of the sample due to the evaporation of the water present in it.

2.7 Color analysis

Lovibond colour scale was used, which ranges from a lighter shade to a darker shade. This scale is often used to analyse the colour of beers, fats and oils, but can also be used to analyse breads.

2.8 Taste and smell analysis

It was carried out using a 9-point hedonic scale (1 = I don't like it very much to 9 = I like it very much). The method was taken from the work of (Medina et al., 2021). 10 untrained people in the laboratory, including the head of the laboratory, were asked to taste the breads made. The same was true for the smell test.

2.9 Protein determination

It was determined by the Peruvian Technical Standard (NTP 209.262:2013) that establishes the use of the Kjeldahl method . In which the sample is subjected to digestion with sulfuric acid, which converts the nitrogen present into ammonia. Then this released component is neutralized with sodium hydroxide to release ammonia in the form of gas, which occurs in the distillation. The released ammonia is collected with a boric acid solution and then titrated with hydrochloric acid to calculate the amount of acid consumed in the titration that reflects the amount of nitrogen in the sample. Finally, this amount is multiplied by the conversion factor of 6,25 to calculate the percentage of proteins.

2.10 Determination of fiber

The AOAC 991.43 methodology was used, which uses the gravimetric extraction method for the determination of dietary fiber. It consists of degreasing the sample, then subjecting it to acid hydrolysis to dissolve soluble carbohydrates. The mixture is then neutralized and filtered to separate the insoluble fiber. The fiber retained in the filter is dried and weighed, which allows the total dietary fiber content in the sample to be calculated. The dietary fiber analysis was carried out in another laboratory outside the University of Lima, where only the best 2 formulations were considered taking into account the attributes of flavor, color and odor as well as specific volume, humidity and protein content. These formulas were 1 and 2.

3.Results

3.1 Specific volume results

Table 3 shows the results of the specific volume analysis of the 2 samples resulting from each formulation using the seed displacement method. It can be observed that the formula with the highest specific volume is formula 7 with 2,22 ml/g. This implies a greater gas retention capacity during the fermentation and baking of the bread. This may be desirable, as it is associated with a lighter and fluffier texture. On the other hand, the formula with the lowest specific volume was formula 2 with 1,42 ml/g. This can be explained due to the sole presence of canihua flour without the presence of sweet potato starch that gives more texture to the dough.

Table 3. Specific volume results table

Formulation	Specific volume sample 1 (ml / g)	Specific volume sample 2 (ml / g)
1 (CF: 66,67%, QF: 16,67%, SPS: 16,67%)	1,64	1,63
2 (CF: 100%, QF: 0%, SPS: 0%)	1,42	1,44
3 (CF: 16,67%, QF: 16,67%, SPS: 66,67%)	1,53	1,52
4 (CF: 16,67%, QF: 66,67%, SPS: 16,67%)	1,90	1,91
5 (CF: 0%, QF: 0%, SPS: 100%)	1,94	1,92
6 (CF: 0%, QF: 100%, SPS: 0%)	2,19	2,18
7 (CF: 33,33%, QF: 33,33%, SPS: 33,33%)	2,22	2,20

Table 4 shows the ANOVA analysis of variance values for the specific volume of the 7 formulations and 14 samples calculated in Minitab 18.

Table 4. Analysis of variance for specific volume

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	1,15417	0,192362	1683,17	0,000
Error	7	0,00080	0,000114		
Total	13	1,15497			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of specific volume.

3.2 Moisture results

The gravimetric method for measuring moisture shows that a good moisture level in bread contributes to a juicy and pleasant texture, while a lack of moisture makes it dry and crumbly (Arora et al., 2023). Formula 2 had the highest moisture content at 24.76%, and formula 4 the lowest at 13.58%, indicating little liquid retention. According to Delarca et al. (2023), moisture in gluten-free breads is crucial for gas retention during fermentation, which affects volume and fluffiness. Furthermore, excessive moisture levels can encourage mold growth, while very low levels result in stiff breads. Therefore, formulas 1 and 6 could be balanced options in terms of moisture.

Table 5. Moisture results table

Formulation	Moisture sample 1 (%)	Moisture sample 2 (%)
1 (CF: 66,67%, QF: 16,67%, SPS: 16,67%)	21,06	20,01
2 (CF: 100%, QF: 0%, SPS: 0%)	24,76	24,7
3 (CF: 16,67%, QF: 16,67%, SPS: 66,67%)	14,37	14,35
4 (CF: 16,67%, QF: 66,67%, SPS: 16,67%)	13,58	13,6
5 (CF: 0%, QF: 0%, SPS: 100%)	17,28	17,25
6 (CF: 0%, QF: 100%, SPS: 0%)	18,21	18,19
7 (CF: 33,33%, QF: 33,33%, SPS: 33,33%)	14,36	14,3

The ANOVA analysis of variance values for moisture is shown in Table 6.

Table 6. Analysis of variance for moisture

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	194,378	32,3963	407,94	0,000
Error	7	0,55600	0,0794		
Total	13	194,933			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of the moisture value.

3.3 Smell, taste and colour results

A 5-point hedonic scale was used for smell analysis and a 9-point hedonic scale for flavour analysis. The test was conducted with 10 untrained subjects who tasted the formulations and gave their rating according to their preference. The results were averaged and placed in Table 7.

Table 7. Table of results for smell, taste and color

Formulation	Smell (1 - 5) sample 1	Smell (1 - 5) sample 2	Taste (1 - 9) sample 1	Taste (1 - 9) sample 2	Color (1: Very light - 40: Very dark) sample 1	Color (1: Very light - 40: Very dark) sample 2
1 (CF: 66,67%, QF: 16,67%, SPS: 16,67%)	4	4	6	6	22	21
2 (CF: 100%, QF: 0%, SPS: 0%)	5	5	7	7	40	39
3 (CF: 16,67%, QF: 16,67%, SPS: 66,67%)	4	4	6	5	22	22
4 (CF: 16,67%, QF: 66,67%, SPS: 16,67%)	3	2	5	4	21	21
5 (CF: 0%, QF: 0%, SPS: 100%)	2	3	7	7	1	2
6 (CF: 0%, QF: 100%, SPS: 0%)	4	3	7	6	2	2
7 (CF: 33,33%, QF: 33,33%, SPS: 33,33%)	3	4	6	5	26	25

Analyzing the smell of the formulations, the highest score was obtained for formula 2, composed of 100% cañihua flour, which had a more pleasant aroma. The least pleasant formula in terms of aroma was formula 5, composed of 100% sweet potato starch. Analyzing the flavor attribute, the highest scores were obtained for formulas (2, 5 and 6) to be taken into account in identifying the optimal formula from the sensory aspect. The most pleasant flavor of the 3 formulas mentioned above can be explained by the presence of sweet potato starch. The variance analysis of odor and flavor are shown below.

Table 8. Analysis of variance for odor

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	9,429	1,5714	5,50	0,021
Error	7	2,000	0,2857		
Total	13	11,429			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of odor scores.

Table 9. Analysis of variance for flavor.

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	10,000	1,6667	5,83	0,018
Error	7	2,000	0,2857		
Total	13	12			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of taste scores. On the other hand, color is one of the most relevant quality indicators for the acceptability of the product in food, and it is also of great importance when selecting a product for consumers, which is why its analysis is so important. It was analyzed using the Lovibond color scale with a score of 1 to 40 from light to dark. The Lovibond color scale is presented below in Figure 2.

Figure 2. Lovibond color scale

Below is an image of the gluten-free bread formulas made where you can see the color in a better way.

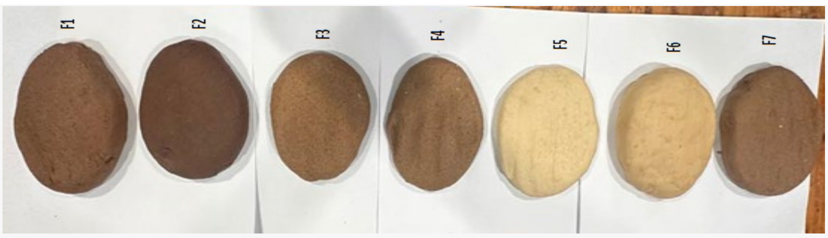

Figure 3. Gluten-free breads made

Analyzing the color score in Table 7, formula 2 was obtained with a dark brown tone, which shows its 100% canihua composition, since this cereal contains this type of pigment. On the other hand, the formula with an opposite lighter tone turned out to be formula 5 due to its composition with 100% sweet potato starch of the yellowish species.

Table 10. Analysis of variance for color

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	2154,00	359,000	1256,50	0,000
Error	7	2,00	0,286		
Total	13	2156,00			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of color scores.

3.3 Protein content results

Table 11. Protein content results table

Formulation	Protein sample 1 (%)	Protein sample 2 (%)
1 (CF: 66,67%, QF: 16,67%, SPS: 16,67%)	12,12	12,1
2 (CF: 100%, QF: 0%, SPS: 0%)	13,96	13,94
3 (CF: 16,67%, QF: 16,67%, SPS: 66,67%)	10,88	10,7
4 (CF: 16,67%, QF: 66,67%, SPS: 16,67%)	13	13,05
5 (CF: 0%, QF: 0%, SPS: 100%)	10,46	10,48
6 (CF: 0%, QF: 100%, SPS: 0%)	12,65	12,54
7 (CF: 33,33%, QF: 33,33%, SPS: 33,33%)	11,35	11,32

Table 11 shows that formula 2 had the highest protein content with a value of 13,96%. On the other hand, the lowest protein content was formula 5 with 10,46%, probably because it is only 100% sweet potato starch, which due to its properties is not so rich in protein. The second best formulation with a good protein content was formula 4 with a higher content of quinoa flour in its composition. All formulations met the objective of passing the 10% protein content.

Table 12. Analysis of variance for protein content

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	6	18,9113	3,15189	898,71	0,000
Error	7	0,0246	0,00351		
Total	13	18,9359			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of protein content.

3.4 Fiber content results

For the evaluation of fiber content, we used the 2 most promising formulations in terms of protein content, volume, moisture and sensory characteristics. These were formulas 1 and 2.

Table 13. Fiber content results table

Formulation	Fiber sample 1 (%)	Fiber sample 2 (%)
1 (CF: 66,67%, QF: 16,67%, SPS: 16,67%)	1,3	1,34
2 (CF: 100%, QF: 0%, SPS: 0%)	0,98	1,05

Table 13 shows that the expected target of exceeding 4% dietary fiber content was not achieved. A maximum of 1,34% was reached, which represents formulation 1. The explanation for the low fiber content will be seen in detail in the discussions.

Table 14. Analysis of variance for fiber content

Analysis of variance					
Source	GL	SC Ajust.	MC Ajust.	F-value	P-value
Formulation	1	0,093025	0,093025	57,25	0,017
Error	2	0,003250	0,001625		
Total	3	0,096275			

The p value is less than the significance level of 0,05, thus confirming that there is a significant difference between the formulations in terms of fiber content.

3.5 Obtaining the optimal gluten-free bread

The optimal formulation was obtained by comparing the results of all the tests performed on each formulation. The criteria collected from the literature were evaluated and the value of the 2 samples in each formulation was averaged. Table 15 below shows the optimal formulation.

Table 15. Optimal formulation table

Components	Optimal value
Canihua flour	66,67%
Quinoa flour	16,67%
Sweet potato starch	16,67%
Properties	
Specific volume (ml/g)	1,64
Moisture (%)	20,53
Color (1 - 40)	22,00
Odor (1 -5)	4,00
Taste (1 - 9)	6,00
Protein content (%)	12,11
Fiber content (%)	1,32

The formula with the optimal recipe was formula 1 due to its desirable values of having a higher specific volume, balanced humidity, high scores in sensory attributes and high protein and fiber content.

Discussion

The key findings of the research are discussed below, highlighting their significance, their relationship to previous work, and the comparison of the final results with the initial expectations of the project. Regarding the use of sweet potato, Valino et al. (2020), reported a specific volume of only 1,02 ml/g using 100% sweet potato flour in one of their formulas. Unlike our result in formula 5 where 100% sweet potato was used in starch presentation. A higher specific volume of 1,94 ml/g was obtained. These results could indicate that the use of sweet potato is much more effective as a starch to improve the texture of gluten-free bread due to its water retention capacity. This is reinforced by the result obtained by Valino et al. (2020), adding 10% sweet potato starch in another formula increasing its specific volume to 1,73 ml/g. In the sensory evaluation, Saby Zegarra & Ramos Escudero (2019) used a 5-point hedonic scale in celiac consumers to evaluate attributes such as taste, smell and color, without finding significant variations between their three gluten-free bread formulations. They used cañihua flour, cassava starch and corn starch, highlighting the formula with the highest acceptability, which contained less cañihua flour and corn starch, and a greater amount of cassava starch, xanthan gum, yeast and egg. In comparison, our formulas with the highest acceptability were 1 and 2, with more cañihua flour than quinoa flour and sweet potato starch. This differs in terms of the proportion of cañihua flour, which in our study was used in greater quantities to achieve sensory acceptability, possibly due to the exotic and novel flavor of cañihua. Regarding moisture, Ronnie et al. (2023) made 4 gluten-free bread formulas with rice flour and potato starch, obtaining a moisture content between 34.90% and 41.22%, within the permissible range of 35% to 45%. However, our results were significantly lower, with a maximum of 24.76% in formula 2, which used 100% cañihua flour. These low moisture values caused the breads to be dry and hard. The cause of these results could be the baking time and high temperatures, since the cañihua breads were baked at 300 °C for 20 minutes, while the rice breads in the study by Ronnie et al. (2023) were baked at more moderate temperatures between 165 °C and 225 °C. To improve moisture, it is suggested to reduce the baking temperature to 180°C or 220°C and increase the baking time to allow for adequate moisture retention.

Miranda et al. (2018) developed 20 gluten-free bread formulations with a protein content between 7.3% and 9.5%, thanks to white lupine and quinoa flour, outperforming breads made with rice flour and corn starch. In our results, the 5 formulations showed a protein content between 10.46% and 13.96%, mainly due to the use of quinoa and cañihua flours. Remilekun et al. (2023) reached a maximum of 8.48% protein with rice sourdough bread, while Ronie et al. (2023) achieved only 10.5% with rice flour and potato starch. In comparison, our formula 2, with 100% cañihua flour, reached 13.96%, showing a clear nutritional difference between traditional cereals such as rice and pseudocereals such as cañihua and quinoa. The maximum crude fibre content in our research was 1.32%, not reaching the target of exceeding 4%. Valino et al. (2020) indicate that starch reduces fibre content by removing fibrous components during its production process. Bugarín et al. (2023) suggest that citrus fibre improves crumb hydration, cohesion and elasticity, which could have helped to increase fibre content in our study. Although 4% was not exceeded, the use of citrus fibre could have brought the target closer. Ronie et al. (2023) obtained between 0.64% and 0.89% fibre in their rice breads, probably by using processed flours without the outer layer of the cereal, where the fibre is concentrated.

5.Conclusions

Seven preliminary gluten-free bread formulations were developed by applying an experimental design of mixtures with different proportions of canihua flour, quinoa flour and sweet potato starch. This allowed exploring various combinations to find the best formulation based on criteria such as maximizing protein and fiber.A detailed manufacturing process was established, including dough preparation, fermentation and baking times and temperatures. This stage is crucial to guarantee the quality of gluten-free bread and a consistent and reproducible procedure was defined.

Through the analysis of various characteristics such as specific volume, moisture, color, smell, taste, protein and fiber content, the best formulation was identified, achieving an improvement in the nutritional profile, surpassing the protein and fiber content compared to gluten-free breads made in previous research. The optimal bread from this research has 12,11% protein and 1,32% fiber. The challenge of making gluten-free bread was also overcome, as shown in the results of sensory and rheological tests. However, the moisture, fiber and specific volume content must be improved to obtain a product with greater acceptability.

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