Optimization study of pasta extruded with quinoa flour (Chenopodium quinoa Willd)

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ABSTRACT
This study focused on obtaining an optimal spaghetti-type paste from quinoa flour (60–75%), cassava starch (1.5–5.0%) and water (25–40%) as variable factors and as a fixed egg-white factor (9%). In order to obtain a paste with the highest percentage of protein, the response surface methodology (MSR) with Box–Behnken was used. In addition, the effect of the composition on textural, rheological, and sensory properties was evaluated. Among the most outstanding results, the R² value indicates that the predictive model explains the 76.33% protein variability. The optimal conditions for quinoa flour, cassava flour, and water were 60%, 1.5%, and 35.28%, respectively. It was shown that the quinoa flour content indicates the rheological properties, storage modulus, G', is greater than the loss modulus, G”, in agreement with the maximum breaking force obtained in pasta, indicating behavior more elastic than viscous with good bonding characteristics and dense internal structure. Finally, the application of the experimental design permitted finding the pasta's optimal composition and analyzing the sensory profile by verifying all its attributes; the results obtained indicated that it is possible to prepare a gluten-free pasta with acceptable texture, flavor, and color for the consumer.

Resumo
Este estudio se centró en la obtención de una pasta óptima tipo espagueti a partir de harina de quinua (60–75%), almidón de yuca (1.5-5.0%) y agua (25–40%) como factores variables y como factor fijo clara de huevo (9%). Con el fin de obtener una pasta con el mayor porcentaje de proteína se utilizó la metodología de superficie de respuesta (MSR) con Box–Behnken. Se evaluó, además, el efecto de la composición sobre las properties texturales, reológicas y sensoriales. Entre los resultados más destacados, el valor R² indica que el modelo predictivo explica el 76.33% la variabilidad de la proteína. Las condiciones óptimas para la harina de quinoa, almidón de yuca y agua fueron de 60%, 1.5% y 35.28% respectivamente. Se demostró que el contenido de harina de quinoa afecta las propiedades reológicas, módulo de almacenamiento, G', es mayor que el módulo de pérdida, G”, de acuerdo con la fuerza máxima de rotura obtenida en la pasta, indicando un comportamiento más elástico que viscoso con buenas características de unión y estructura interna densa. Finalmente, la aplicación del diseño experimental permitió encontrar la composición óptima de la pasta y analizar el perfil sensorial verificando todos sus atributos; los resultados obtenidos indicaron que es posible preparar una pasta sin gluten con textura, sabor y color aceptables para el consumidor.

1. Introduction
Poverty, inequality, and food insecurity are among the principal challenges of our time (Calicioğlu et al., 2019). Effectively, levels of overweight and obesity have increased in recent decades, affecting men and women of all ages. This increase is due to the consumption of foods high in calories and their combination with sedentary lifestyles (FAO, 2017). Currently, the demand for gluten-free products is on the rise, evidencing interest by consumers in knowing the origin of raw materials, links between quality and the nutritional value of processed foods obtained through different methods (Wójtowicz et al., 2020).

Pasta is a popular food recognized for its high content of complex carbohydrates, but low in dietary fiber, protein, minerals, vitamins, and bioactive compounds (Aranibar et al., 2018). Thereby, the growing demand for gluten-free products is an important technological challenge, with gluten being the essential protein for construction of the structure (Larrosa et al., 2013), therein – currently – studies focus on improving the pasta’s nutritional value by incorporating other plant seed sources. In this sense, global interest for grains of Andean origin, like quinoa (Chenopodium quinoa Willd), can be explained due to its rheological functional properties, sensory characteristics, and nutritional profile (Burgos et al., 2019) that although not as extended as wheat or rye, its consumption has grown progressively due to its attractive nutritional composition, with high levels of protein (12.9–16.5%), vitamins, minerals, and dietary fibers, as well as bioactive and phenolic compounds (Ayseli et al., 2020). Diverse studies have found that due to its rich nutritional composition it intervenes

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Palabras claves
Diseño experimental; pasta; proteína; reología; sensorial

KEYWORDS
Experimental design; pasta; protein; rheology; sensory
beneficially in preventing cardiovascular disease or as protectors against different diseases, particularly cancer, diabetes, obesity, and inflammatory disease; considering quinoa seeds as a functional food (Pereira et al., 2019).

The cooking quality of the pasta is strongly influenced by the wheat content, where the absence of gluten in the pasta can cause technological and quality problems in the final product, this problem can be minimized by using an adequate proportion of protein, (Ungureanu-Iuga et al., 2020) as well as include in hydrocolloid formulations such as starch used in the food industry for their very important viscoelastic properties, which could also be used to mimic the properties of gluten and form an elastic and firm texture of the paste (Larrosa et al., 2013). In this sense, studying the technological functions of raw materials and technological processes are a necessity for pulp production at an industrial level. The response surface methodology (RSM) is a statistical and mathematical approach used for the development, improvement, and optimization of processes, besides describing interrelations between processing and response variables (Mudgil et al., 2016).

Hence, this research aimed to obtain an optimal spaghetti-type pasta by applying the response surface methodology (RSM) and evaluating the effect of quinoa flour on its protein, rheological, and sensory properties.

2. Materials and methods

2.1. Raw material

Quinoa flour (Chenopodium quinoa W), previously saponified, was obtained from a local market in the city of Armenia, Quindío (Colombia). The egg whites and commercial yucca starch were acquired from a local supermarket in the city of Armenia, Quindío (Colombia).

2.2. Experimental design

To establish the optimal formula for the spaghetti-type pasta (STP) formulated with quinoa flour, an experimental design was created by applying the response surface methodology (RSM) (Ferreira et al., 2019). To establish the minimum and maximum formulation percentages, the Statgraphics Centurion XVIII program was used (Table 2), created with three independent factors: quinoa flour percentage, yucca starch percentage, and water percentage. Protein percentage was taken as a response variable. Upon identifying the variables and factors, the Box-Behnken response surface design was selected, obtaining 15 formulations. The regression analysis was resolved with a second-order polynomial model, according to Equation (1):

$$ Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \sum_{j=1}^{k-1} \beta_{ij} X_i X_j $$

Where: βi is fit constants of the statistical model, Xi model statistical factors; A = % of quinoa flour, B = % of yucca starch; C = % of water, and k number of factors of the model.

To optimize the experimental design, the STP obtained were analyzed regarding the content of raw protein by applying the method by Kjeldahl, ISO 5983 (International Organization for Standardization, 1997) using nitrogen to protein conversion factor of 6.25. The pasta formulation that obtained the highest protein content was selected as optimal spaghetti-type pasta (OSTP).

2.3. Pasta preparation

The development of milling products such as gluten-free pasta, produced by the total replacement of wheat flour by quinoa flour, is therefore at risk in its quality, in order to determine the levels of water, quinoa flour, and cassava starch, preliminary experiments were carried out and the base formulation proposed by Larrosa et al. (2015) was followed, which suggest a percentage of water (25–40%) and starch (0.5–3%). A percentage of quinoa flour (60–75%) and 9% of egg white for the 15 formulations. The ingredients were mixed in the proportions established by the experimental design. First, the dry ingredients (quinoa flour and cassava starch) were pre-mixed for 20 minutes in a food processor, after this time, were transferred to a container in which water and egg white were added and mixed for 5 more minutes. This process was performed for the 15 formulations, each mixture was extruded into a locally manufactured extruder, equipped with un solid helical screw 80 cm long and 3 inches in diameter, powered by 2 Hp 220 V single-phase gear motor and speed variation between 0 and 60 rpm, operated by a PID electronic temperature control with a temperature range from 0°C to 200°C. The homogenizing and cooking process for each formulation was conducted at a mean temperature of 60 ± 4.5°C at 60 rpm. In the final section of product output, the STP was formed in a formation matrix with 12 openings of 0.8 mm in diameter and a depth of 20 mm each. The cooking process by means of extrusion as indicated (Bouasla et al., 2017) it allows texturing and homogenizing pasta masses providing the necessary conditions for the pre-gelatinization of starch, during this process the components interact with each other producing pastes with desirable textural and sensory properties.

After the extrusion cooking process, the preformed pass mass was taken and stored in an airtight container to prevent moisture loss and perform rheological analysis. Drying of the samples was carried out in an air furnace at 70°C for 4 h and stored in tightly sealed polyethylene bags for their later analysis of texture, color, and sensory assessment.

2.4. Rheological properties

The dynamic rheological measurements of the 15 STP formulations, storage modulus (G’), and loss modulus (G”) in a frequency range from 0.1 to 100 Hz were conducted in a controlled stress rheometer (Anton Paar, series MCR 301). For this test, 10 g of sample was taken from each formulation and the methodology proposed by Larrosa et al. (2015) was followed with some modifications. The measurements were conducted at 25°C in a gap of 1 mm. Amplitude Sweep was performed to determine the linear viscoelastic region at a constant frequency of 10 rad/s and to apply a deformation between 0.01 and 1000%. Mechanical spectra were plotted over a frequency (ω) range of 0.1–100 rad/s at 0.5 Pa.

2.5. Texture and color

Once the extrusion and drying process was completed the characterization of the mechanical properties of the STP
obtained, by means of a fracture test the firmness of the paste was measured, with the purpose of measuring the maximum breaking force (N) in the pasta. The study used a universal press TA-XT2 (Stable Micro Systems, Godalming, surrey, UK) spaghetti samples had a length of 10 cm and were placed on the device (HDP/3PB – Three Point Bend), which had a length of 64 mm and was broken with a blade, moving at a speed of 10 mm/s (Mariotti et al., 2011). The color reading was analyzed in a Hunter lab Spectrocolorimeter (ColorQuest XE) with D65 illuminant and a 10° observer as a reference in the CIEL*a*b* space (International Organization for Standardization/International Commission on Illumination, 2008) as L* (lightness; 0 = black, 100 = white), a* (+a = redness, −a = greenness) and b* (+b = yellowness, −b = blueness) values, as reported by (Desai et al., 2018).

### 2.6. Sensory assessment

The sensory analysis was performed by evaluating qualitative characteristics of the OSTP by a semi-trained panel consists of 15 tasters or judges between 20 and 30 years of age from both genders, who evaluated the cooked pasta through a 5-point hedonic test, where −2: I dislike it a lot and 2: I like it a lot. The sensory assessment focused on evaluating the appearance, color, odor, flavor, and general texture of the product. The samples were served on a plate and were presented to the sensory panel immediately after cooking, following the methodology described by Hager et al. (2013).

### 2.7. Statistical analysis

Data from the experimental design were analyzed statistically by applying an analysis of variance (ANOVA) with p < .05 in the Statgraphics Centurion XVIII program. The results obtained were carried out in triplicate and the medians ± standard deviations were reported. Data were analyzed statistically through a simple experimental design (ANOVA) to determine the interaction between factors and variables, using the Statgraphics Centurion XVIII program. Differences were considered significant with p < .05.

### 3. Results and discussion

#### 3.1. Experimental design

Table 1 presents the combination of factors yielded by the experimental design with their respective response variable: protein percentage, obtained experimentally. It may also be observed that the combination of factors obtaining the highest protein value was formulation 6 with a protein value of 32.24% (Table 1).

Table 1 shows a graphic representation of the response surface design through maximum optimization of the protein content, concerning the percentages of each raw material used in the STP formulation (Figure 1).

As observed in the graphics obtained from the optimization of the response surface experimental design, if the quinoa flour percentage, yucca starch percentage and water percentage factors are combined in the amounts presented in Table 1 a maximum protein value of 32.96% is obtained, which was corroborated experimentally, as noted in the formula for the OSTP from Table 2.

The variance analysis (ANOVA) of the response surface model to optimize the protein percentage (Figure 1) indicated that the quinoa flour percentage, yucca starch percentage, and water percentage had statistically significant differences (p < .05), influencing directly at protein level on the STP formulations. The R² value indicates that the predictive model explains 76.33% of the variability in protein. The lack of adjustment was not significant (p > .05), indicating that the model adequately explains the effect of quinoa flour, cassava starch and water on the protein content.

The above results indicate that for the formulations obtained the lower the content of quinoa flour, the higher the value of protein, in this sense, this behavior is evident in the optimal paste, which has a protein percentage of 32.96% compared to a commercial quinoa paste that has a percentage around 16% protein. Indeed, what differs in formulations 1 and 6 is the level of quinoa flour, in which

Table 1. Combination of factors yielded by the experimental design with their respective protein analysis.

| Formulations | Quinoa flour (%) | Yucca starch (%) | Water (%) | Protein (%) |
|--------------|------------------|------------------|-----------|-------------|
| 1            | 75.00            | 1.50             | 32.50     | 21.81       |
| 2            | 67.50            | 5.00             | 40.00     | 24.24       |
| 3            | 60.00            | 5.00             | 32.50     | 30.36       |
| 4            | 67.50            | 3.25             | 32.50     | 23.76       |
| 5            | 67.50            | 1.50             | 40.00     | 27.00       |
| 6            | 60.00            | 1.50             | 32.50     | 32.24       |
| 7            | 75.00            | 5.00             | 32.50     | 24.79       |
| 8            | 60.00            | 3.25             | 40.00     | 25.56       |
| 9            | 67.50            | 5.00             | 25.00     | 22.63       |
| 10           | 75.00            | 3.25             | 25.00     | 19.92       |
| 11           | 75.00            | 3.25             | 40.00     | 19.94       |
| 12           | 67.50            | 3.25             | 32.50     | 23.76       |
| 13           | 60.00            | 3.25             | 25.00     | 21.57       |
| 14           | 67.50            | 1.50             | 25.00     | 18.47       |
| 15           | 67.50            | 3.25             | 32.50     | 23.76       |
| PTSO         | 60.00            | 1.50             | 35.28     | 32.96       |

STP: formulations of spaghetti-type pasta; OSTP: optimal spaghetti-type pasta. Source: Statgraphics Centurion XVIII program.

PTS: formulaciones de pastas tipo espagueti; PTSO: pasta tipo espagueti óptima. Fuente: Programa Statgraphics Centurión XVIII.
formulation 6 has a lower level and higher protein content, this could be due to the fact that the proportion of egg white and cassava starch in formulations with lower quinoa flour content develop a stronger network formation, which would retain proteins and derive increasing values (Milde et al., 2020). In formulation 5, it has a moderate level of quinoa flour and an average moisture level, which causes the water-soluble amino acids that make up quinoa to dissolve in the greatest proportion through the formation of hydrogen bonds, therefore, the total nitrogen content was not determined through the Kjeldahl analysis.

Table 2. Composition of the formula for the optimal spaghetti-type pasta (OSTP), obtained through response surface design.

| Factors          | Minimum Level | Maximum Level | Optimal (OSTP) |
|------------------|---------------|---------------|----------------|
| % Quinoa flour   | 60.00%        | 75.00%        | 60.00%         |
| % Yucca starch   | 1.50%         | 5.00%         | 1.50%          |
| % water          | 25.00%        | 40.00%        | 35.28%         |

OSTP: optimal spaghetti-type pasta. Source: Statgraphics Centurion XVIII program.

Figure 1. 3-D response surface graphics showing the interactive effects of the process on the protein content regarding: a) quinoa flour percentage factor; b) yucca starch percentage factor; and c) water percentage. Source: Statgraphics Centurion XVIII program.

Figura 1. Gráficos de superficie de respuesta 3D que muestran los efectos interactivos del proceso sobre el contenido de proteína frente a: a) factor porcentaje de harina de quinua; b) factor porcentaje de almidón de yuca, y c) porcentaje de agua. Fuente: Programa Statgraphics Centurión XVIII.
Likewise, (Bouasla et al., 2017) indicated that the excessive amount of quinoa flour hinders starch transformation in a homogeneous starch-protein matrix, causing diminished firmness, therefore a lower retention of protein in the matrix. Additionally, formulation 7 has the highest starch percentage and intermediate water content, which propitiates an intermolecular interaction between the proteins and the starch, where the protein encapsulates the starch and the same phenomenon will occur in decreased firmness shown in pasta 5 and associated with reduced starch gelatinization (Bouasla et al., 2017). Similarly, firmness is a parameter that is affected by the amount of fiber in its composition. Regarding formulation 3, the water content is not high, meaning that the firmness characteristics will be affected in greater proportion, give that hard pasta would be obtained. In this sense, what is sought with the optimization is to generate a balanced formula in the proportions of the factors with an optimal response variable. These results agree with those reported by (Ayseli et al., 2020). Other research has found a strong relation between protein content and the formation of the matrix network, which influences directly the pasta’s firmness and cohesion (Bruneel et al., 2010). Proteins that form gluten in wheat are quite different from the prolamins and the molecular interaction found in the quinoa flour, which is why differences are expected in the mechanical properties analyzed.

### 3.2. Rheological properties

The rheological properties of STP, storage modulus ($G'$) and loss modulus ($G''$), were characterized upon completing the extrusion process, as shown in Figures 2 and 3, respectively. The rheological behavior of the masses and the quality attributes are strongly influenced by the water absorption capacity of the flours. In this sense, the cohesion of the masses is influenced by the protein content and structural formation. As observed in Figure 2, storage modulus ($G'$) was higher than the loss modulus ($G''$), indicating elastic behavior of the 15 extruded STP that formed a gel structure due to the intermolecular interactions of the starch. This behavior is observed commonly in elastic solids (Diantom et al., 2018). Similar results were observed by Larrosa et al. (2016), where they establish that starch masses generally show a dependence of the oscillatory stress modules in which $G'$ and $G''$ remain independent to the critical value of deformation, and then deviate when the sample starts to flow.

As was expected, the OSTP had higher storage modulus values, that is, a greater elastic behavior; this is attributed to the starch content of the quinoa flour and the swelling (gelatinization) of the starch granules during cooking through extrusion, related at the same time with the reticulation of abundant amylose and amyllopectin free molecules (Romero & Zhang, 2019). Indeed, the OSTP formulation has an optimal level of quinoa flour of 60% and a level of cassava starch of 1.5% and according to (Tyl et al., 2020) the viscoelastic properties of the paste are dictated by a complex network of protein and starch interactions, where proteins and the cross-linking of a net capable of trapping and anchoring starch granules during cooking are key to optimal quality, thus a balanced proportion of quinoa flour and cassava starch benefit cross-linking, consequently, viscoelastic properties that make the storage module larger. In this sense, mechanical and thermal processes such as extrusion firing contribute to a series of modifications and interactions of the components (polysaccharide, protein, lipid). Such modifications allow the formation of a continuous three-dimensional network of retrograded amylose and other structures, such as amylose-lipid complex crystals, that would stabilize the network by triggering starch gelatinization. In addition to allowing a significant degradation leading to a high solubility in water, explained by the action of cutting forces that break the molecular network of the starch matrix-protein showing a more elastic

![Figure 2](Figura 2. Datos experimentales del módulo de almacenamiento ($G'$) a 25°C para las 15 formulaciones (PTS).)
than viscous behavior with good bonding characteristics and dense internal structure (Bouasla et al., 2017).

3.3. Texture and color
The following presents the results obtained from the analysis of maximum breaking force and color conducted in the 15 STP formulations and the OSTP, upon completing the extrusion process and drying (Table 3).

The results obtained show no statistically significant differences, that is, no correlation existed between the factors and the response variables. In this respect, it is worth mentioning that the maximum breaking force is directly related to the pasta firmness, finding values in a range between 2.80 and 5.73 N for STP. This difference can be attributed to the lack of the gluten network and the presence of fiber fractions of the quinoa flour in different proportions, which can lead to the formation of cracks or discontinuities within the pasta thread, weakening its structure (Burgos et al., 2019), these results agree with those obtained during the optimization of the formulation and with the observations made in the rheology analysis of the masses regarding water absorption and distribution, given that the quinoa proteins interact through weak hydrophobic forces. Similar results in the maximum breaking force of dry spaghetti from the different formulations were reported by Mariotti et al. (2011).

Color is a determinant parameter of quality and acceptability by consumers. In the pasta obtained, this property is strongly related to the raw materials used in their formulation, showing values of L* between 46.49 and 54.77, indicating medium luminosity in pasta in the scale from 0 to 100 in the CIEL*a*b* coordinates. Although the appearance of a brown tonality in the pasta could cause certain concern to consumers accustomed to consuming bright yellow pasta, the current trend toward “healthier” foods may represent an opportunity to introduce this type of pasta (Aranibar et al., 2018). Regarding coordinate a* (red/brown tonalities), the formulations had values between 2.76 and 4.54 lower with respect to b* (yellow tonalities) that had values between 9.91 and 16.40; these results are attributed to the characteristic color of the quinoa flour. Similar values were reported by Guzmán, 2012.

3.4. Sensory assessment
Figure 4 presents the spider diagrams for each attribute of the OSTP sensory assessment. In general, the score in appearance, acceptability in color, odor, and flavor was high. Shows that the degree of acceptance for the appearance of the OSTP is within acceptable limits, that is, it is not disliked or liked much; this response could be attributed to consumers expecting to see a bright pasta with a smooth surface, like conventional pasta. In terms of color, an average score of 1 was obtained, as shown in Figure 4, which means that its color is likes moderately. This result is confirmed through the instrumental measurement of color and is attributed to the characteristic yellow coloring of the quinoa used in our study, which will not influence significantly its acceptability, given that in the current market commercial pasta can be found in different colors according to the origin of their raw material. In contrast, odor and flavor are two closely linked attributes; to distinguish flavors, the brain needs information provided by the sense of smell. These sensations are transmitted to the brain from the nose and mouth (Sharp & Dohme, 2019). In this sense, the retronasal smell presented by the OSTP for odor and flavor are satisfactory, showing high acceptance, attributed to the mild flavor characteristic of quinoa flour.

Regarding the OSTP texture (Figure 4), it had a varied acceptance sensory profile evidenced in pleasant firmness, mastication, and adherence. This result agrees particularly with that observed in the rheology and texture analysis, where the intermolecular interaction of the components of the pasta mass to produce desired sensory properties is in the function of the cooking process through extrusion and its conditions of temperature and short processing time, which provides an opportunity to use quinoa flour as raw material to elaborate pasta of acceptable quality without additives.

Thus, the results on the base by the panelists who participated in the sensory assessment of pasta with gluten-free

Figure 3. Experimental data of the loss modulus (G") at 25°C for the 15 formulations (STP).
Figura 3. Datos experimentales del módulo del de pérdida (G") a 25°C para las 15 formulaciones (PTS).
Table 3. Physical-chemical characterization performed on the formulations of spaghetti-type pasta (STP) and the optimal pasta (OSTP).

Tabla 3. Caracterización fisicoquímica realizada a las formulaciones de las pastas alimenticias tipo spaghetti (PTS) y la pasta óptima (PTSO).

| Formulations | Physical-chemical analysis |
|--------------|---------------------------|
| STP | Rupture force (N) | L* | a* | b* |
| 1 | 3.65 ± 0.952 | 51.82 ± 0.000 | 4.22 ± 0.019 | 14.12 ± 0.030 |
| 2 | 2.99 ± 0.796 | 54.77 ± 0.005 | 4.54 ± 0.015 | 16.40 ± 0.026 |
| 3 | 5.15 ± 0.770 | 48.83 ± 0.029 | 3.70 ± 0.021 | 12.62 ± 0.051 |
| 4 | 2.80 ± 1.125 | 50.31 ± 0.006 | 4.40 ± 0.017 | 13.58 ± 0.021 |
| 5 | 5.73 ± 2.707 | 49.97 ± 0.008 | 3.50 ± 0.017 | 12.33 ± 0.019 |
| 6 | 4.59 ± 0.882 | 51.02 ± 0.005 | 4.17 ± 0.021 | 14.11 ± 0.048 |
| 7 | 5.24 ± 1.430 | 50.49 ± 0.005 | 3.60 ± 0.015 | 13.08 ± 0.013 |
| 8 | 4.36 ± 1.128 | 50.11 ± 0.010 | 3.65 ± 0.014 | 13.33 ± 0.013 |
| 9 | 2.96 ± 0.729 | 48.72 ± 0.006 | 3.88 ± 0.000 | 11.77 ± 0.029 |
| 10 | 3.64 ± 0.843 | 47.06 ± 0.000 | 3.23 ± 0.008 | 10.23 ± 0.035 |
| 11 | 2.93 ± 1.902 | 51.06 ± 0.008 | 2.76 ± 0.010 | 12.74 ± 0.019 |
| 12 | 2.80 ± 1.299 | 50.31 ± 0.001 | 4.40 ± 0.002 | 13.58 ± 0.022 |
| 13 | 3.87 ± 1.315 | 49.16 ± 0.005 | 3.51 ± 0.005 | 12.17 ± 0.026 |
| 14 | 5.11 ± 2.399 | 46.49 ± 0.013 | 2.82 ± 0.014 | 9.91 ± 0.022 |
| 15 | 2.80 ± 0.975 | 50.31 ± 0.006 | 4.40 ± 0.0017 | 13.58 ± 0.026 |
| OSTP | 2.89 ± 0.953 | 50.99 ± 0.000 | 4.20 ± 0.0019 | 14.08 ± 0.023 |

STP: formulations of spaghetti-type pasta. Results in the table represent the average of the measurements in triplicate. Median ± standard deviation.

PTS: formulaciones de pastas tipo espagueti. Los resultados en la tabla representan el promedio de las mediciones por triplicado. Media ± desviación estándar.

Figure 4. Sensory profile evaluated in 5 attributes for OSTP.

Figura 4. Perfil sensorial evaluado en 5 atributos para PTSO.

Quinoa flour could be considered a product of good acceptability by consumers. Nevertheless, it must be kept in mind that acceptability in products with quinoa can differ between geographic locations and eating habits, as well as age groups (Ayseli et al., 2020).

4. Conclusions

Application of the experimental design through the RSM was used effectively to optimize processing variables (quinoa flour percentage, yucca starch percentage, and water percentage) and obtain an optimal pasta formulated with quinoa flour. Total replacement of wheat flour was determinant in the physical changes, like mass texture and rheology, evidencing that the protein content causes diminished firmness. Regarding the sensory characteristics of the optimal pasta elaborated with quinoa flour, it is a promising product in the market with good acceptability for its consumption, given its sensory characteristics and high protein content.

Disclosure statement

We declare that we do not have potential competing interest. We declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

The authors are grateful for the financial support provided by the Vice- Rector’s Office for Research at the University of Quindio to carry out this research and publish the article.

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