Article

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Optimization of hot-air drying conditions for cassava flour for its application in gluten-free pasta formulation

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Abstract

The design and development of gluten-free foods requires a comprehensive understanding of the behavior of the raw materials to attain the same cooking and nutritional quality as gluten-based food. The objective of this study was to determine the optimal hot-air drying conditions for elaboration of cassava flour to be used in a gluten-free pasta formulation. The results showed that the operational conditions to minimize the hot-air drying time (57 min) to produce cassava flour with higher water holding capacity was 57 °C at 3 m/s. Then, the optimal formulation for the pasta was found to be cassava (26 g/100 g), amaranth flour (12 g/100 g), and carboxymethyl cellulose (0.23 g/100 g), which maximized the A_w (0.160), moisture content (3.10 g/100 g), hardness (5.02 N), and protein content (9.30 g/100 g), and it is used for the sensorial analysis, which showed that an earthy taste was the main problem with consumer satisfaction.

Keywords

Cassava drying, gluten-free pastas, celiac disease, flour properties, amaranth flour

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INTRODUCTION

Celiac disease (CD) is an autoimmune enteropathy that causes failure to thrive during the first few years of life and is the result of an anomalous reaction with the gluten present in some cereals, such as wheat, oats, and barley; this reaction damages the small intestine walls, affecting the absorption of all nutrients (Barker and Liu, 2008). CD affects 0.3–1.0% of the world population and it is believed to be present in up to 1 in 100 individuals. Females are more commonly affected than males (ratio 2:1), and in general, only approximately 10–15% of those affected are clinically diagnosed (Ferreira et al., 2016).

One of the main problems of CD is that it has few medical treatments. One of the existing medical treatments is the consumption of cyclosporine, interleukin-10, alemtuzumab, cladribine, CHOP (a combination of doxorubicin, cyclophosphamide, vincristine, and prednisolone) (Evans and Sanders, 2012); however, the only way to manage the disease is by following a strict gluten-free diet, which requires the consumption of naturally gluten-free cereals, such as rice, maize, sorghum, and pseudocereals (amaranth, quinoa, and buckwheat) (Giuberti et al., 2015; Marti and Pagani, 2013).

The development of gluten-free foods must aim to satisfy the needs of individuals with CD. In addition, gluten-free food development must be based on CODEX STAN 118-1979, which establishes the maximum amount of gluten that can be present in

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a gluten-free food. The maximum amount of gluten in a gluten-free food cannot be higher than 20 mg/kg, while in a gluten-reduced food, this amount can vary between 20 and 100 mg/kg (Remes-Troche et al., 2018).

However, the design and development of gluten-free foods requires new raw materials with functions similar to traditional materials. Most gluten-free products have poor cooking quality and they are nutritionally inferior in minerals and biocompounds. For these reasons, the main focus has been to improve the nutritional and sensory quality of gluten-free products (Marti and Pagani, 2013). One interesting option for the development of gluten-free foods is cassava; according to Aristizábal and Sanchez (2007), cassava is the fourth most important food product after rice, wheat, and corn, and it had a worldwide production of close to 170 million tons during 2014. One of the alternatives for the processing of cassava is drying, which aims to eliminate the water present in the food through the use of hot air to stabilize the raw material by reducing water activity (A_w) (Kumar et al., 2012). In this sense, several authors have reported the use of drying for the processing of cassava (Charmongkolpradit and Luampon, 2017; Pornpraipech et al., 2017; Precoppe et al., 2016). Cassava has been used to develop bread (Jensen et al., 2015; Shittu et al., 2007), cookies (Lertworasirikul and Tipsuwan, 2008; Saeleaw and Schleining, 2011), soup (Wongsagonsup et al., 2014), and snacks (Fiorda et al., 2015). Additionally, other raw materials have been reported to be useful in gluten-free food production. For example, Machado et al. (2015) used quinoa and amaranth flour in bread making. In the same way, Miñarro et al. (2012) reported the use of legume flours, such as pea, chickpea, and soya flour, in the formulation of gluten-free bread. Menga et al. (2017) developed a gluten-free pasta based on rice flour and incorporated chia (*Salvia hispanica* L.) for its thickening and nutritional properties. Additionally, the use of carboxymethyl cellulose (CMC) and xanthan gum has been reported as texture improvers in gluten-free products (Mohammadi et al., 2014).

Pasta is a traditional food product widely consumed because of its convenience, palatability, and easy transportation, handling, cooking, and storage properties. According to Tudorica et al. (2002), in recent years, pasta has become popular because of its nutritional properties related to a low glycemic index. Ingestion of low glycemic index foods decreases hunger and increases satiety in short-term human intervention studies. However, the main constituent in the sensorial and physical properties of pasta is gluten. According to Marti and Pagani (2013), a high protein content and "strong" gluten (viscoelasticity) are needed to process semolina to produce a pasta with optimal cooking properties. However, during the last decade, people with CD and others who prefer to eliminate gluten from their diets for health reasons have been consuming gluten-free pasta (Marti and Pagani, 2013). Finally, there are some reports of the use of cassava to obtain gluten-free pasta (Fiorda et al., 2013; Lateef et al., 2004). Considering this background, the objective of this study was to determine the optimal hot-air drying conditions for elaboration of cassava flour to be used in a gluten-free pasta formulation.

MATERIALS AND METHODS

Materials

Cassava tubers (variety *Manihot esculenta coffee blanca*), amaranth, CMC, egg white powder, sunflower oil (Lloreda, Colombia), and traditional gluten containing pasta (Doria, Colombia) used as a control for the sensory analysis were obtained from a local market in Medellín, Colombia. Cassava tubers were selected, cleaned, and disinfected with a solution of CITROSAN (Diken International, Mexico) at 0.30 ml/100 ml per kg of sample. Once disinfected, the cassava tubers were peeled and cut into slices of 2.00 ± 0.25 mm using a food processor (Javar, model Cheff-z, Colombia) and frozen at $-20 \pm 2\,^{\circ}C$ until use and analysis. The enzyme xylanase (Veron© 191 S, AB Enzymes, Germany) was kindly supplied by a local food formulation and product development laboratory in Medellin, Colombia. Veron© is an enzyme family of xylanase that has been incorporated into bakery products and pasta to improve dough properties and has positive effects on the texture. Different authors have reported the use of the Veron© enzyme, either as an additive or as an improver of the properties of the dough or the properties of gluten-free products (Ognean et al., 2011; Tsatsaragkou et al., 2014). The activity of the enzyme was 1000 U/g formulation (Giannone et al., 2016).

Proximate analysis of cassava tuber

The proximate analysis of the raw cassava tuber consisted of moisture content and protein and ash measurements, which were performed using the AOAC (2002) methods. The total starch content was measured according to the AACCI (1999a) Methods 76-13.01. All assays were performed in triplicate ($n = 3$) and expressed as the mean ± standard deviation.

Drying kinetics of the cassava slices

Hot air-drying processing of the cassava slices. Cassava samples were cut into slices 2.00 ± 0.25 mm thick and put into a rectangular plate homogenously covering a drying area of 12.70 cm^2.

The drying process was performed in a hot-air dried tunnel (DIES, model TS 120, Colombia) using a combination of two temperatures (43–57 °C) and two air velocities (2.70–3.80 m/s) based on a 2^2+star experimental design. The change in the weight was measured online using a balance (Traveler Ohaus, TA502, New Jersey, USA) with a precision of ±0.01 g. The moisture ratio (MR) was calculated according to

$$MR_t = \frac{X_t - X_e}{X_0 - X_e} \tag{1}$$

where X_t is the moisture content at any time (g water/g dry basis), X_e is the moisture content at equilibrium (g water/g dry basis), and X_0 is the initial moisture content (g water/g dry basis). The values of X_e are relatively small compared to X_t or X_0. Thus, $(X_t - X_e)/(X_0 - X_e)$ can be simplified to (X_t/X_0) (Duarte et al., 2017). To obtain the effective diffusion (D_{eff}) under different air flow rates and temperatures, the solution for a diffusion equation with convective boundary conditions in a slab of thickness $2L$ without edge effects is given by the following expression (Luikov, 1968)

$$MR = \sum_{n=1}^{\infty} \frac{4\sin\lambda_n}{2\lambda_n + \sin(2\lambda_n)} \cos\left(\frac{x}{L}\lambda_n\right) \exp\left(-\lambda_n^2 \frac{D_{eff}t}{L^2}\right) \tag{2}$$

where λ_n is the n root of

$$\lambda_n \tan\lambda_n = \frac{k_m L}{D_{eff}} \tag{3}$$

where D_{eff} is the effective diffusion coefficient and k_m is the surface convective coefficient. From the previous expression, we can obtain the following average moisture in the sample

$$1 - MR = 4\sum_{n=1}^{\infty} \frac{\sin\lambda_n}{2\lambda_n + \sin(2\lambda_n)} \cos(\lambda_n) \times \exp\left(-\lambda_n^2 \frac{D_{eff}t}{L^2}\right) \tag{4}$$

It is a well-established fact that for longer times, the expression can be truncated to the first term ($n = 1$)

$$1 - MR = \frac{4\sin\lambda_1}{2\lambda_1 + \sin(2\lambda_1)} \cos(\lambda_1) \exp\left(-\lambda_1^2 \frac{D_{eff}t}{L^2}\right) \tag{5}$$

where λ_1 is the first root of equation (3). The preexponential factor is also simplified, considering that the initial value for MR must be 1

$$MR = 1 - \exp\left(-\lambda_1^2 \frac{D_{eff}t}{L^2}\right) \tag{6}$$

Thus, the process kinetics depend on two parameters, D_{eff} and k_m, which are included in λ_1. To compute λ_1, the following approximation based on Yovanovich (1996) was used

$$\lambda_1 = \frac{\pi}{2\left[1 + \left(\frac{2.24 D_{eff}}{k_m L}\right)\right]^{1.02}} \tag{7}$$

The mass transfer coefficient can be obtained from the Sherwood number ($Sh = k_m L/D_{eff}$). In this experiment, the appropriate expression for Sherwood (Sh) is unknown. However, it is well established that in forced convection, Sh is a function of the Reynolds number (Re) and Schmidt number (Sc)

$$Sh = a\mathrm{Re}^m Sc^n \tag{8}$$

$$\frac{k_m L}{D_{eff}} = a\left(\frac{\rho v_{air} L}{\mu}\right)^m \left(\frac{\mu}{\rho D_{eff}}\right)^n \tag{9}$$

Considering that the magnitudes of the physical constants vary less than the velocity, the previous expression was simplified to consider how k_m varies with the air flow rate, v_{air}, as given in equation (10)

$$k_m = a \times v_{air}^b \tag{10}$$

where a and b will be obtained from the fit of equation (10) by nonlinear regression of the MR data from all experiments.

The diffusion coefficient is temperature dependent. The Arrhenius expression is used to model this dependence

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \tag{11}$$

where D_0 is the so-called preexponential factor and E_a is the activation energy (J/mol K).

Thus, the model for the drying kinetics is dependent on four parameters: two associated with the bulk diffusion in the sample, D_0 and E_a, and two associated with the convective mass transfer coefficient, a and b.

Cassava flour characterization

The cassava flour was obtained by milling the dried cassava slices using a hammer mill model TRF 300 (TRAPP, Brazil) for 5 min. Characterization of the flour consisted of particle size analysis, apparent density, water activity, water holding capacity (WHC), oil holding capacity (OHC), and color. All assays were performed in triplicate (n = 3) and expressed as the mean ± standard deviation.

Particle size analysis. A sieve shaker (Pinzuar, PS 32, Colombia) was used to separate the flour into six fractions according to the sieve mesh size. One hundred grams of sample were sieved using U.S. standard sieves (Prufsieb, Germany) No. 45 (355 µm), No. 50 (300 µm), No. 60 (250 µm), No. 80 (180 µm), No. 100 (150 µm), and No. 140 (106 µm) over 15 min.

The particle size distribution was obtained by weighing the retained sample in each sieve, and then the percentage with respect to the total mass was calculated. The mean overall diameter of the flour particles was calculated by

$$d_v = \frac{\sum d}{\sum m} \tag{12}$$

where d_v (µm) is the mass mean diameter, d (µm) is the average diameter, and m (g) corresponds to the mass retained on the sieve (Fellows, 2000).

Apparent density. Apparent density was determined according to Osorio et al. (2014). Briefly, 5.0 g of the cassava flour was placed into a 25 ml graduated glass cylinder and the flour was tapped manually by lifting and dropping the cylinder until a negligible difference in the volume was observed. The mass (m) and the apparent (tapped) volume (V) of the flour were used to calculate the flour density (g/ml).

Water activity (a_w). The a_w was measured in a water activity meter (AQUALAB, model 3TE, USA) using 1.0 g of sample at 25 ± 2 °C (Osorio et al., 2014).

WHC. The WHC was measured according to Duarte et al. (2017) with some modifications. One gram of cassava flour was mixed with 10 ml of distilled water and shaken for 2 min before being incubated for 20 h at 25 °C. The mixture was then centrifuged at 314 × *g* (radius of rotor 70 mm) for 30 min. Finally, the volume of the supernatant was measured. The results were expressed as ml of water/g of sample.

OHC. The OHC was obtained by mixing 1 g of sample with 10 ml of vegetable oil (PREMIER sunflower oil, Colombia, density = 0.90 g/ml) for 2 min at 25 °C. Then, the oil mixture was centrifuged at 314 × *g* (radius of rotor 70 mm) for 30 min. The supernatant volume was measured (Duarte et al., 2017). The results were expressed as ml of oil/g of sample.

Color determination. The cassava flour color was measured according to Pasqualone et al. (2016). Then, the color parameters l, a*, b* were determined. For color determination, an X-RITE, model SP62 S, USA, was used, with illuminant D65 at 10° for reference. For the color analysis, 3 g of cassava flour sample was used.

Formulation, elaboration, and characterization of cassava flour-based pasta

Cassava flour-based pasta was prepared using cassava flour (26, 28, or 30 g/100 g), amaranth flour (12, 14, or 16 g/100 g), CMC (0.21, 0.23, or 0.25 g/100 g), egg powder (2.10 g/100 g), enzyme Veron © 191 S (0.03 g/100 g), and water (ranging between 51.64 g/100 g and 59.64 g/100 g) (Table 4). The water was added while the dough was forming, until the desired texture was achieved.

The different mixtures determined by the different contents of the cassava flour, amaranth flour, and CMC were blended for 10 min. Then, the dough was sheeted between two rolls of a pasta machine (Marcato, Atlas 180, Italy) until a thin sheet was formed. The dimensions of the obtained pasta were as follows: width 1 cm, thickness 0.2 cm, and length 15 cm. Finally, the sheet was cut into strips of 15 cm and dried at 55 °C for 4 h.

The different pastas obtained from each formulation were characterized in terms of water activity, moisture content, hardness, protein content, and color.

The moisture content and protein content were measured according to AOAC (2002), and the water activity was determined according to Osorio et al. (2014).

A texture analysis was performed according to Mirhosseini et al. (2015) with some modifications. A TA-XT2i Texture Analyzer (Stable Micro Systems Ltd, Godalming, Surrey, UK) fitted with a 50 kg load cell was used and a PerSpex cutting probe was used. The pasta sample was placed centrally under the 2 mm compression tip with a speed of 2 mm/s. The test was applied to five samples per formulation. A force–distance curve was used to determine the hardness of the dried gluten-free pasta.

The color of the pasta was measured according to Pasqualone et al. (2016). Three grams of milled dried gluten-free pasta was put into the cell and analyzed using a colorimeter (X-RITE, model SP62 S, USA). The results were expressed in the CIELAB space as

L* (lightness; 0 = black, 100 = white), a* (+a = redness, −a = greenness), and b* (+b = yellowness, −b = blueness) values (Islas-Rubio et al., 2014).

Once these results were obtained, the optimal pasta formulation based on multiobjective optimization that maximized the water content, water activity, hardness, and protein content was determined and analyzed with respect to the gluten content and the acceptability of the final product, which was tested by means of a sensory analysis.

The gluten content was determined according to the AOAC (2012) using a commercial kit, RIDASCREEN® gliadin (R-Biopharm, Darmstadt, Germany). Basically, 2.50 ml of Radiscreen® gliadin was added to 0.25 g of homogenized sample, and the two were mixed for 40 min at 50 °C. Then, the sample was allowed to cool to room temperature. Next, 7.50 ml of ethanol (80%) was added and the sample was mixed for 1 h at 25 °C. Then, the sample was centrifuged at 658 × *g* (radius of rotor 70 mm) for 10 min, and the supernatant was collected in Eppendorf tubes of 10 ml. Finally, the samples were diluted according to the kit instructions, and the absorbance of each ELISA plate was measured in a microplate reader (Rayto, model RT-2100C, China) at 450 nm.

The sensory analysis was performed on pasta that was cooked using a methodology described by Larrosa et al. (2015) with some modifications of AACCI (1999b) Method 66-50. Basically, 25 g of pasta was cooked in 250 ml of distilled boiling water for 10 min. After cooking, the samples were cooled by soaking in cold water for 1 min, and the excess water was removed with a paper towel. After that, the pasta was served for the sensory evaluation. The sensory analysis of the pasta was performed based on NTC3929 (NTC, 2009) approved by ISO6564:2005. The panelists measured the attributes related to different tastes, such as bitter, metallic, astringent, salty, earthy, umami, sweet, cereal, and starch, and these attributes were measured on a scale ranging from 0 to 5, where 0 corresponds to absence of some of the different tastes defined before, 1 is a very weak presence of some tastes, 2 is the weak presence of some tastes, 3 is the moderate presence of some tastes, 4 is strong, and 5 is an intense presence of some of the tastes. The analysis was conducted with six trained panelists: five women and one man, with ages between 40 and 55 years. The sensory study was conducted in the Food Sensory Analysis Laboratory at the Universidad de Antioquia, Colombia.

Statistical analysis

Two experimental statistical designs were applied: one for optimizing the cassava drying conditions to obtain a suitable flour and the second to optimize the pasta elaboration.

For cassava drying, an experimental design based on central composite 2^2 with 4-star points and a replicate in the central point (ten experiments) was used (Table 1). Two factors, the air-drying temperature (45–55 °C) and airflow rate (2.70–3.30 m/s), with two levels (−1, 1) and a significance level of 95% were used. The optimization of the drying conditions to get a product that then will be converted to cassava flour was based on minimizing moisture and A_w while maximizing the WHC, diffusion coefficient, and brightness.

For the pasta making optimization, a surface response methodology with a Box–Behnken design using three factors with two levels, cassava flour (26–30 g/100 g), amaranth flour (12–16 g/100 g), and CMC (0.21–0.25 g/100 g), was used (Table 4). The water activity, moisture content, hardness, protein content, and color were the response variables and were investigated using a response surface methodology and fitting the experimental values to the following second-order equation

$$Y = b_0 + \sum_{i=1}^{2} b_i X_i + \sum_{i=1}^{2} b_{ii} X_i^2 + \sum_{i<j=1}^{2} b_{ij} X_i X_j \quad (13)$$

where Y is the response variable, b_0 is a constant, b_i are model coefficients linked to a linear effect, b_{ii} are the coefficients related to the quadratic effect, b_{ij} are the constants for the interaction effect, and X_i and X_j are the variables. The data and RMS were analyzed and performed using STATGRAPHICS Centurion XVI software (Statistical Graphics Corporation, Version 16.0.07, Rockville, USA).

Table 1. Experimental conditions applied to study the effect of drying condition on cassava flour using a 2^2 plus star points design

Run	Air temperature (°C)		Air flow rate (m/s)	
1	50.0	0	3.4	1.4
2	45.0	−1	3.3	1
3	50.0	0	3	0
4	55.0	1	2.7	−1
5	57.1	1.4	3	0
6	50.0	0	3	0
7	45.0	−1	2.7	−1
8	55.0	1	3.3	1
9	42.9	−1.4	3	0
10	50.0	0	2.6	−1.4

RESULTS AND DISCUSSION

Proximal analysis of the cassava tubers

The proximal analysis of the cassava tubers showed that the moisture content was 63.80 g of water/100 g of sample, the starch content was 82 g/100 g of sample (dry basis), the protein content was 3.30 g/100 g of sample (dry basis), and the ash content was 2.67 g/100 g (dry basis).

The moisture value obtained in this work was very close to that reported by Vega et al. (2018), who found a moisture value for cassava of 59 g of water/100 g of sample. Furthermore, this moisture value is higher than that of other tubers, such as Andean potatoes, the water content of which can vary from 72 to 82 g of water/100 g of sample (Calliope et al., 2018), but lower than other non-Andean tubers such as the *Alocasia indica* tuber, the moisture content of which is approximately 42.8 g/100 g of sample (Basu et al., 2014).

The starch content in the cassava was higher than that reported for Andean potatoes and other kinds of tubers, such as *Dioscorea pyrifolia*, for which Elmi Sharlina et al. (2017) reported a starch content of 26.64 g of starch/100 g of sample. The higher starch content has a direct relationship with the dry matter content, which, as previously mentioned, was higher than that of the Andean potatoes. Finally, Adekunle et al. (2016) determined a carbohydrate content of 73% for the cassava variety ADP 3.

The protein content obtained was lower than the protein content determined by Adekunle et al. (2016), who found that this value was 6 g/100 g for sweet cassava variety ADP 3. This was higher than the protein content of the cassava used to feed poultry, which was approximately 1.0–3.0 g/100 g (Morgan and Choct, 2016). However, the protein content of the cassava was lower than that reported for Jerusalem artichoke (*Helianthus tuberosus*), with 9.99 g protein/100 g of sample (Rubel et al., 2018). Furthermore, Ceballos et al. (2006) found that the variation of crude protein of cassava roots analyzed in different countries of the world ranged from 0.95 to 6.42%.

The ash content for cassava was higher than that reported for the Andean potatoes, but lower than the close to 7 g/100 g reported by Adekunle et al. (2016) for the sweet cassava variety ADP 3.

Other values of proximal analyses have been reported by Anyanwu et al. (2015). They found that moisture, starch, and protein contents in cassava root in Nigeria were 70, 24, and 1%, respectively. In general, cassava has similar or higher yields than typical tuber crops, such as many varieties of Andean potatoes. Thus, cassava is an attractive crop for starch or flour production.

Hot air drying of cassava slices considering the convective boundary condition

Stored samples (−20 °C) were unfrozen at 4 °C for 24 h and then left at room temperature for 5 h before drying. Because all of the samples had the same freezing treatment, we assumed that for all samples, the cells of the cassava slices were equally affected by the ice crystals and the cellular damage was the same for all the samples. This damage is an advantage, because it favors the diffusion processes, as reported by Ramírez et al. (2011).

Figure 1 presents curves obtained from the drying process of the cassava slices. The results of the effective diffusion by second Fick's law model are summarized in Table 2. One of the most important considerations in obtaining the D_{eff} values was to account for the effect of convection as a boundary condition because the product experienced an air flow rate (v_{air}) during the drying process, and this was considered using equation (8). Through nonlinear regression of all of the experimental MR, the values for a and b were found to be 3.40 and 0.80, respectively. On the other hand, the fit for the Arrhenius equation showed a D_0 of 2.09×10^{-5} m^2/s and E_a of 66 kJ/mol K. The D_0 value reported here is higher than that reported for yacon 5.04×10^{-7} m^2/s using an air rate of 1.5 m/s (Shi et al., 2013). The activation energy value obtained in this work was higher than that obtained for yacon by Shi et al. (2013) (30 kJ/mol K) but within the range reported by Falade et al. (2007) for yam (59.94–69.45 kJ/mol K).

Since D_{eff} is a material parameter, it should not vary with the air effects or the air flow rate. The contribution

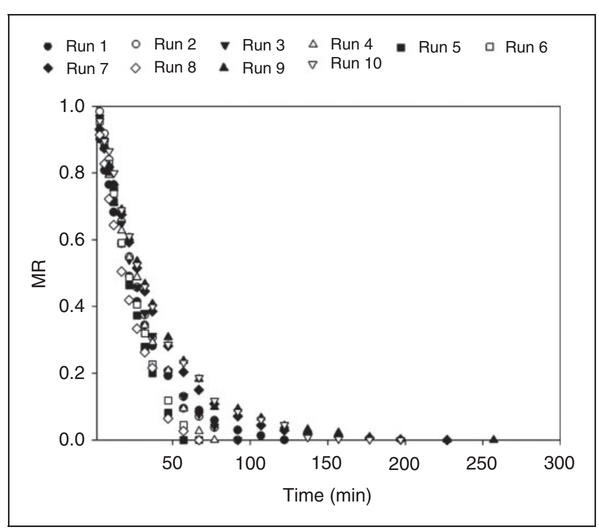

Figure 1. Cassava drying curves at different air temperature and flow rate based on the different experimental design runs.

Table 2. Effective diffusion (D_{eff}) values obtained by second Fick's law model including convective boundary condition effects

Run	Processing time (min)	Effective diffusion (m^2/s)	R^2	Sum of square error
1	122	4.51×10^{-6}	0.995	0.021
2	92	3.06×10^{-6}	0.999	0.031
3	92	4.51×10^{-6}	0.999	0.028
4	77	6.56×10^{-6}	0.995	0.047
5	57	7.65×10^{-6}	0.999	0.048
6	67	4.51×10^{-6}	0.998	0.047
7	227	3.06×10^{-6}	0.992	0.023
8	67	6.56×10^{-6}	0.994	0.056
9	257	2.60×10^{-6}	0.992	0.024
10	197	4.51×10^{-6}	0.993	0.024

of the convective air flow is considered in the model formulation, which decouples the estimation of D_{eff} from the surface effects. The response surface analysis indicated that the air flow rate did not have a significant effect on D_{eff}. This confirms the assumptions in the model proposed for the drying kinetics. The statistical analysis shows that only the temperature had a significant effect on D_{eff}, presenting an R^2 of 99.98% and an R^2-adjusted of 99.98% with a significance of 95%. Finally, the surface response can be represented by the following equation

$$D_{eff} \times 10^{-6}(\mathrm{m^2 s}) = 17.47 + 0.87 \times T + 0.012T^2 \quad (14)$$

From Table 2, it is possible to note that D_{eff} ranged from 2.60×10^{-6} to 7.65×10^{-6} m^2/s, where the lowest value was obtained at processing conditions of 42.9 °C and 3 m/s, and the highest value was obtained at 57.1 °C and 3.0 m/s. The results are out of the range presented for vegetables in Saravacos and Maroulis (2001) with a range between 2.20×10^{-12} and 3.05×10^{-7} m^2/s but are in the range presented for legumes (2.06×10^{-14} to 1.07×10^{-6} m^2/s) and cereal (8.33×10^{-12} to 4.04×10^{-6} m^2/s) products (Saravacos and Marouli, 2001).

Considering the processing time, which was defined as the time required to dry cassava until it reached the equilibrium moisture, the highest processing time was obtained for run 7 (45 °C and 2.70 m/s), 9 (42.9 °C and 3 m/s), and 10 (50 °C and 2.60 m/s) with 227, 257, and 197 min, respectively. In contrast, the shortest processing time was obtained in run 5 (57.1 °C and 3.0 m/s) with 57 min.

Cassava flour elaboration and characterization

Each of the dried samples under the 10 different air temperature and air flow rate conditions was milled and transformed into cassava flour. The average diameter of the flour particles (D_v) ranged from 228 to 248 µm with a mean value of 236 ± 6 µm for the 10 experiments. According to CODEX STAN 152-1985 (2008), the particle size required to emulate a product based on wheat flour must be 212 µm. The particle size values reported in our work were used by Dayakar Rao et al. (2016) to produce a product based on sorgo flour (particle size ranging from 152 to 251 µm).

For each flour sample obtained under the 10 conditions associated with the experimental design, the water activity, moisture content (g/100 g), apparent density (g/ml), WHC (g of water/g of flour), and OHC (g of oil/ g of flour) were measured (Table 3). For example, water activity was affected by temperature and air flow rate. The response of this variable can be represented by a linear model with R^2 84.18% and an R^2-adjusted of 79.66%, which is not representative of the real data

$$a_w = 0.5679 - 0.0068 \times T + 0.0563 \times v_{air} \quad (15)$$

The moisture content, apparent density, WHC, and OHC were not significantly affected by the drying conditions ($p>0.005$). The moisture content ranged between 7.61 g/100 g at 45 °C and 3.30 m/s to 4.61 g/100 g at 55 °C and 2.70 m/s. The mean value obtained for all of the experimental runs was 5.91 ± 0.84 g/100. The highest apparent density was 0.49 at 50 °C and 3.40 m/s, while the lowest was 0.41 at 55 °C and 3.30 m/s. The mean value calculated from the 10 runs was 0.45 ± 0.02. Finally, the WHC and OHC were measured. In general, the values ranged between 0.44 and 0.51 g of water/g of flour with a mean value for the 10 runs of 0.48 ± 0.02 g of water/g of flour. The WHC value reported for cassava was lower than those reported for wheat, and the values were approximately 0.56–0.66 g/g (Duyvejonck et al., 2012) and an inclusive upper value of 1.24 g/g was reported by Kaur et al. (2014). WHC is a good measurement to determine the flour performance, and lower WHC values (<0.51 g/g) indicate that the flour performs well for cookie making (Duyvejonck et al., 2012).

The results of the statistical design analysis indicated that neither the temperature nor the air flow rate were significant factors for the L*, a*, and b* parameters (Table 3). A global analysis considering the 10 runs performed showed a mean value of 54.46 ± 5.65 for L*, a mean value of 0.37 ± 0.28 for a*, and a mean value of 7.24 ± 0.84 for b*. For example, Kaur et al. (2014) reported mean values of L*, a*, and b* of 93.45,

Table 3. Cassava flour properties measured for each run at the end of drying process

Run	Water activity	Moisture content (g/100 g)	Apparent density (g/ml)	WHC (g water/ g flour)	OHC (g oil/g flour)	Mean diameter (μm)	Color parameters		
							L*	a*	b*
1	0.430 ± 0.004b	6.11 ± 0.84b	0.492 ± 0.010a	0.48 ± 0.19a	4.33 ± 0.13b	248	48.93 ± 0.55a	0.89 ± 0.21a	6.38 ± 0.21a
2	0.463 ± 0.002a	7.61 ± 0.06a	0.454 ± 0.010b,c	0.51 ± 0.11a	4.57 ± 0.23a,b	238	48.15 ± 8.43a	0.09 ± 0.03d	6.45 ± 0.94a
3	0.388 ± 0.003d	5.41 ± 0.76b,c	0.467 ± 0.008b	0.45 ± 0.04a	4.33 ± 0.14 b	230	50.24 ± 5.64a	0.46 ± 0.09b	5.60 ± 0.67a
4	0.339 ± 0.011f	4.61 ± 0.18c	0.458 ± 0.001b,c	0.47 ± 0.10a	4.55 ± 0.11a,b	232	47.62 ± 2.15a	0.83 ± 0.03a	7.36 ± 0.28b
5	0.341 ± 0.000f	5.98 ± 0.07b	0.432 ± 0.002d	0.48 ± 0.09a	4.44 ± 0.11b	237	53.86 ± 1.29a,b	0.27 ± 0.12c	7.80 ± 0.13b,c
6	0.379 ± 0.002e	5.53 ± 0.93b	0.460 ± 0.003b,c	0.48 ± 0.05a	4.58 ± 0.07a,b	235	54.21 ± 1.27a,b	0.16 ± 0.00c, d	7.60 ± 0.27b,c
7	0.400 ± 0.002c	5.47 ± 0.07b	0.435 ± 0.003d	0.46 ± 0.05a	4.80 ± 0.22a,b	228	59.98 ± 4.88b,c	0.23 ± 0.08c, d	7.44 ± 0.77b
8	0.373 ± 0.002e	5.62 ± 0.64b	0.408 ± 0.001e	0.44 ± 0.03a	4.27 ± 0.08 b	240	58.77 ± 5.37b,c	0.26 ± 0.04c	7.89 ± 0.62b,c
9	0.428 ± 0.010b	6.96 ± 0.07a	0.431 ± 0.020d	0.50 ± 0.04a	4.76 ± 0.19a	236	63.46 ± 4.92c	0.12 ± 0.07c, d	7.44 ± 0.57b
10	0.403 ± 0.004c	5.82 ± 0.15b	0.449 ± 0.001c	0.50 ± 0.14a	4.83 ± 0.41a	239	59.24 ± 2.30b,c	0.45 ± 0.11b	8.41 ± 0.47c

OHC: oil holding capacity; WHC: water holding capacity.
Results are presented as mean ± standard deviation using n = 3 samples.
a,b,c: different letters mean that there were significant differences ($p < 0.05$) between treatments for the average.

0.30, and 9.46, respectively, for wheat flour. This suggests that the L* value was lower than that reported for wheat. Therefore, the cassava flour is less white than wheat flour. The values of b* shown in Table 3 are similar to those reported by Fiorda et al. (2013) for a cassava starch.

Considering all of the measurements performed on the cassava flour obtained from cassava dried at different temperatures and air flow rates and considering that the drying conditions only affected the processing time, D_{eff} and A_w, optimization of the drying process based on these variables indicated that the best drying conditions were those of run 5 (57.1 °C and 3.0 m/s). Therefore, the cassava-based pasta was created with cassava flour obtained under the conditions of run 5.

Analysis of different formulations for cassava-based pasta

The 15 different pasta formulations based on cassava (C), amaranth flour (A), and CMC were created based on a Box–Behnken experimental design, and the results for the water activity, moisture content, hardness, protein content, and color parameters (L, a, and b) for each experimental run are presented in Table 4.

In general, the water activity results were independent of the formulation used and had an average value of 0.150. The results of the statistical design analysis for water activity indicated that only the cassava flour content had a significant effect ($p<0.05$). This effect was positive when the cassava flour increased from 26 to 30 g/100 g. Notably, the polynomial model obtained to represent the water activity response presented an R^2 and R^2-adjusted below 30%.

The moisture content ranged between 2.11 g/100 g and 5.10 g/100 g. The lowest value was obtained for run 2, while the maximum moisture content was obtained for run 15. Based on this, the obtained model presented an R^2 of 61% and an R^2-adjusted of 54%, which suggested that the model is not representative of the data. Cassava flour played an important role in keeping the moisture content in the pasta. In general, the values of the water activity and moisture content were below those obtained in commercial pasta (with gluten), which has a water activity of 0.57 and moisture content of 10.83 g/100 g. This behavior is because the pasta has a lower water absorption capacity in comparison with pasta containing gluten. In this sense, the gluten content in the pasta guarantees a higher moisture retention (Yazar et al., 2017). Finally, the moisture values reported for gluten-free pastas oscillate between 10 and 13% (Rodrigues et al., 2016; Zandonadi et al., 2012), and these values are higher than those shown in Table 4. In terms of a_w,

Table 4. Characterization of pastas formulated with different amount of cassava flour, amaranth flour, and carboxymethyl cellulose (CMC) under a Box–Behnken design

Run	Cassava flour (g/100 g)	Amaranth flour (g/100 g)	CMC (g/100 g)	Water activity[a]	Moisture content[a] (g/100 g)	Hardness[a] (N)	Protein content[a] (g/100 g)	Color parameters[a]		
								L*	a*	b*
1	30	16	0.23	0.176 ± 0.002a	4.30 ± 0.73a,b,c	2.31 ± 1.07a,b	9.30 ± 0.01c,d	78.50 ± 9.35a	3.79 ± 6.47a	17.94 ± 0.77d
2	26	14	0.21	0.152 ± 0.003c,d	2.11 ± 0.56f	1.82 ± 1.43b	9.50 ± 0.09b	78.87 ± 0.53a	3.33 ± 3.19a	16.57 ± 0.88e
3	30	14	0.25	0.161 ± 0.001b,c	2.30 ± 0.43e,f	3.53 ± 1.99a	9.00 ± 0.11f,g	76.73 ± 2.51a	4.38 ± 0.05a	18.87 ± 0.33b,c
4	28	16	0.25	0.152 ± 0.009d	2.90 ± 0.83d,e	1.84 ± 1.70b	10.00 ± 0.03a	79.51 ± 8.42a	5.20 ± 0.08a	20.42 ± 0.95a
5	26	16	0.23	0.143 ± 0.002e	3.52 ± 0.94c,d	3.20 ± 1.24a,b	9.90 ± 0.02a	76.31 ± 0.68a	5.59 ± 0.87a	20.41 ± 0.49a
6	26	12	0.23	0.160 ± 0.001b	3.10 ± 0.23d,e	5.02 ± 1.65a	9.30 ± 0.14c,d	74.93 ± 6.13a	4.91 ± 0.21a	19.21 ± 0.38b
7	28	14	0.23	0.158 ± 0.004b,c	4.11 ± 0.45b,c	2.51 ± 2.28a,b	9.50 ± 0.05b	78.79 ± 3.81a	4.78 ± 4.05a	19.18 ± 0.11b
8	28	12	0.25	0.152 ± 0.003c,d	3.96 ± 0.63b,c	4.54 ± 2.50a,b	9.10 ± 0.02e,f	75.09 ± 5.39a	4.30 ± 0.11a	18.27 ± 0.52c,d
9	30	12	0.23	0.161 ± 0.001b	2.40 ± 0.01e,f	2.40 ± 0.53a,b	8.40 ± 0.04h	78.89 ± 4.76a	4.72 ± 0.09a	19.76 ± 0.12a,b
10	28	12	0.21	0.147 ± 0.002d,e	4.52 ± 0.07a,b	2.16 ± 0.62b	9.20 ± 0.08d,e	76.53 ± 0.25a	4.24 ± 2.29a	18.89 ± 0.09b,c
11	28	16	0.21	0.125 ± 0.010f	4.90 ± 0.38a	3.53 ± 0.99a,b	9.30 ± 0.12c,d	79.37 ± 1.89a	4.56 ± 2.35a	19.54 ± 0.05a,b
12	26	14	0.25	0.117 ± 0.002f	4.70 ± 0.79a,b	4.23 ± 2.37a,b	8.90 ± 0.08g	77.44 ± 2.97a	4.71 ± 1.09a	19.45 ± 0.70b
13	28	14	0.23	0.150 ± 0.011c,d,e	5.10 ± 0.13a	2.75 ± 1.13a,b	9.40 ± 0.06b,c	77.68 ± 9.58a	4.66 ± 1.53a	18.88 ± 0.16b,c
14	30	14	0.21	0.154 ± 0.005c	4.20 ± 0.08a,b,c	3.65 ± 1.65a,b	8.50 ± 0.01h	77.91 ± 7.41a	4.12 ± 0.38a	17.86 ± 0.41d
15	28	14	0.23	0.150 ± 0.001c,d,e	5.10 ± 0.81a	2.75 ± 2.10a,b	9.40 ± 0.07b,c	78.79 ± 1.05a	4.78 ± 0.03a	19.18 ± 0.73b

[a]The values are presented as means ± standard deviation using $n = 3$ replicates.
a,b,c…h: different letters mean that there were significant differences ($p < 0.05$) between treatments for the average.

Makdoud and Rosentrater (2017) reported a value of 0.59 for a gluten-free pasta based on quinoa, amaranth, and rice flour. According to the authors, the values reported are in the range of those obtained for commercial gluten-free pastas (0.57–0.62), which are higher than those obtained in this work.

The hardness of the dried pasta ranged from 1.82 to 5.02 N for the formulations corresponding to run 2 and run 6, respectively. These results are similar to those reported by Bouasla et al., (2016) who determined the hardness was between 3.76 and 4.94 N for a pasta made with rice flour. However, the hardness values shown in Table 4 are lower than the value of the commercial pasta, which is 18.33 N; this may be because the starch present in the cassava flour generates less capacity to support the structure, since it directly affects the texture of the pasta, producing a product with lower hardness (Granito et al., 2003). However, the hardness of the pasta made with cassava flour can be increased with a higher concentration of CMC in the formulation, which is in relation to that reported by Chillo et al. (2007).

The statistical analysis of the experimental design showed that only the combination of amaranth flour and CMC affected the hardness of the pasta, but the model based on the values of R^2-adjusted < 25% was not representative of the data.

The protein content did not vary much among the runs, and it had an average value of 9.24 ± 0.43 g/100 g. The range of the protein content varied from 8.4 (run 9) to 10.0 g/100 g (run 4), which suggested that the amaranth flour played an important role in increasing the protein content. The *Amaranthus* species have been described as protein sources with values between 12 and 16%, higher than wheat (10%), corn (10%), and rice (7%) (Arcila and Mendoza, 2006); besides, it has been demonstrated that the protein content of amaranth is 1.94, higher than the 0.54 found for wheat flour (Yánez et al., 1994). As shown in Table 4, the protein values for the pasta developed in this investigation ranged between 8.4 and 10%. These values are similar to those reported by Bouasla et al. (2016), who determined the protein content between 8.25 and 12% for a gluten-free pasta made with rice flour. Mariotti et al. (2011) quantified values of protein between 8.51 and 10.79% for a gluten-free pasta made with corn flour, rice flour, and pea protein isolate.

The statistical analysis reflected the importance of cassava, amaranth, and the combination of both in the protein content response. The amount of CMC was not significant for the pasta protein content ($p > 0.05$). In addition, the quadratic component of cassava and the linear component of amaranth were significant factors. This finding suggests the presence of an optimal cassava flour value of 28 g/100 g and an optimal amaranth value of 16 g/100 g for a maximum protein content. The model that represents the behavior of the protein content (P) is as follows

$$\mathrm{P} = -48.27 + 4.13 \times C + 0.2 \times A - 0.08 \times C^2 \tag{16}$$

where R^2 and R^2-adjusted were 93.67 and 91.38%, respectively. Thus, to get the maximum content of protein (10.00 g/100 g), it is necessary to use the formulation from run 4.

The above can be explained by the protein richness of amaranth flour, the grains of which have 15 g/100 g of protein, 60 g/100 g of starch, and 8 g/100 g of fat. Moreover, amaranth flour is a source of thiamine, niacin, riboflavin, and folic acid, and dietary minerals including calcium, iron, magnesium, phosphorus, zinc, copper, and manganese. These minerals interact with CMC to form a complex that may help generate the formation of a network similar to that formed by gluten, as it has been shown that the complex between proteins and CMC is useful in the formation and stabilization of food systems (Cárdenas-Hernández et al., 2016; Chillo et al., 2007; Koupantsis et al., 2014; Sciarini, 2011).

The color analysis showed that L*, a*, and b* were not influenced by the cassava, amaranth, or CMC content. The range of data reported for L* was between 74.93 and 79.51, which was higher than that obtained for commercial pasta, which had an L* value of 58.24. Additionally, the range present in our pasta was higher than that reported by Mirhosseini et al. (2015) for gluten-free pasta based on pumpkin flour (approximate range of 52–68) and Fiorda et al. (2013) for a gluten-free pasta based on cassava starch.

For component a*, the obtained values ranged between 3.33 and 5.59, which is in the range reported by Mirhosseini et al. (2015) (0.94–11.4). However, the value calculated in our work is lower than that of commercial pasta (a* = 7.70). In the case of component b*, the range obtained in our pastas varied from 16.57 to 20.42, which was below that obtained for commercial pasta (Durum wheat) (b* = 30.55).

The multiobjective optimization showed that the pasta formulation based on 26 g/100 of cassava, 12 g/100 g of amaranth, and 0.23 g/100 g of CMC (run 6) maximized the water activity (0.16), moisture content (3.10 g/1000 g), hardness (5.02 N), and protein content (9.30 g/100 g) of the dried pasta. The pasta created with this formulation was used to perform gluten content, proximal and sensorial analyses.

Gluten content in cassava-based pasta formulated from run 6

Cassava, amaranth, CMC, egg powder, enzymes, and water are all ingredients that are categorized as gluten free. However, the actual gluten content was 26.1 mg/kg. Even though 26.1 mg/kg of gluten is a low value, according to normative standards, the pasta developed in this research cannot be considered a gluten-free product, because the gluten content of gluten-free labeled products must be lower than 20 mg/kg. Therefore, the pasta produced by this research can be considered a reduced gluten product because the gluten content is between 20 and 100 mg/kg.

The presence of gluten is due to the in-processing lines used for the amaranth, which typically are also used to produce ingredients based on wheat, resulting in cross contamination of the amaranth flour. This contamination is typical and has been reported by López et al. (2010), who studied the gliadin content in more than 32 products categorized as gluten free. They found that nine of the products had higher gluten values than allowed by the normative.

Sensorial analysis of pasta

The sensorial analysis was performed to evaluate the taste obtained in cassava flour-based pasta (Figure 2). In Figure 2 it can be observed that the most relevant taste descriptors present in the pasta were fish and cereal flavor with a value of 3; and earthy, umami, and fish taste with 2.5. The presence of these tastes is due to the main ingredient, cassava, which is a tuber. The cereal taste may be related to the incorporation of amaranth flour (Pastor et al., 2007). Finally, the umami taste is typically present in food with a high content of amino acids and protein (Yu et al., 2018), which is the case for pasta, and ingredients such as egg powder and

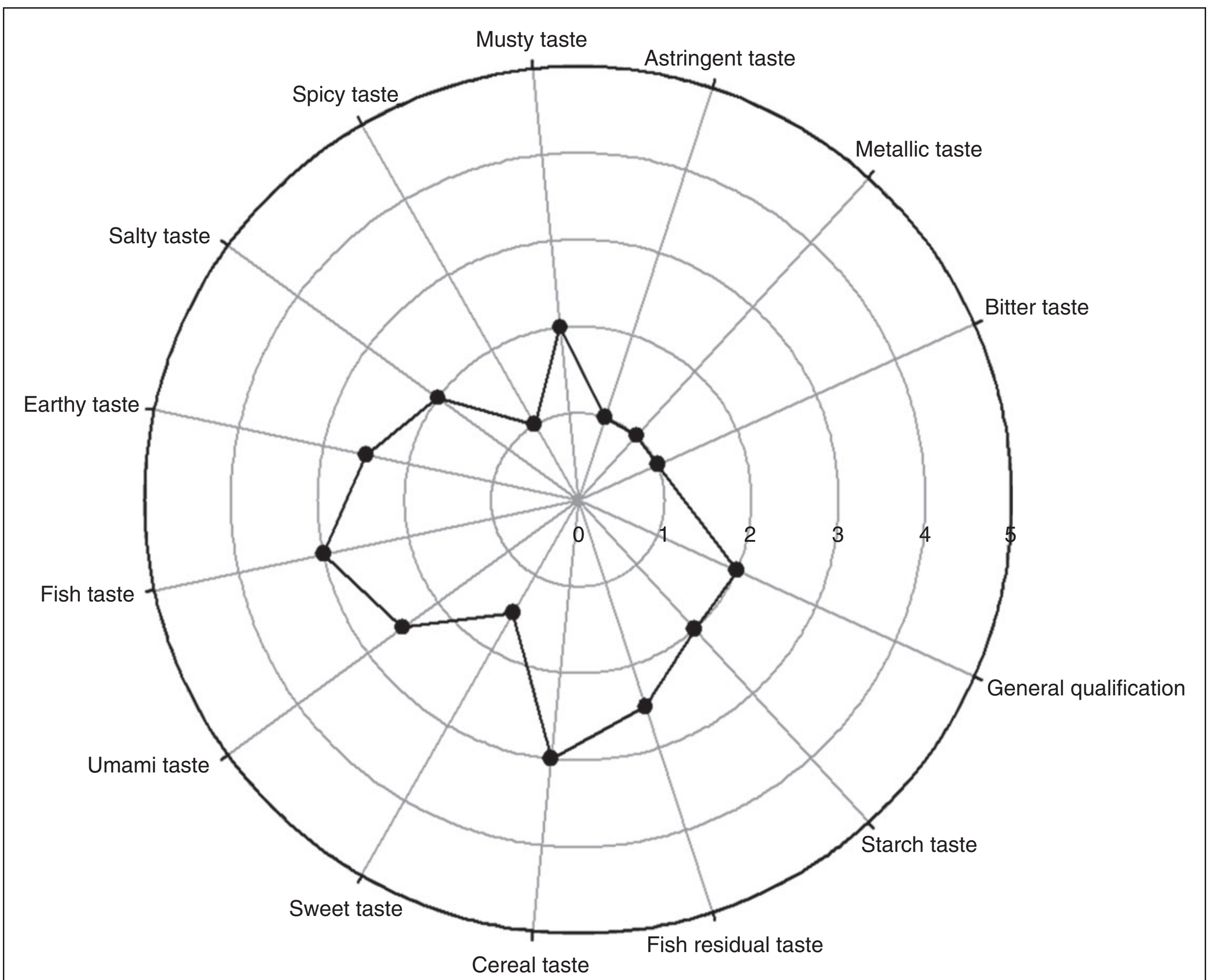

Figure 2. Result of sensorial analysis performed to evaluate the taste obtained in cassava flour-based pasta.

amaranth flour can contribute to the umami taste. Additionally, the panelist performed a general quality evaluation, which obtained a qualification of 2, which means that the main flavors present in the cassava-based pastas were fish and earth, being both flavors characteristic of tubers such as artichoke and cassava (De Santis and Frangipane Teresa, 2018; Oladiran et al., 2018). A recommendation to avoid these flavors is the incorporation of masking flavors.

CONCLUSION

In general, the different combinations of air temperature and air flow rate affected mainly water activity and the moisture content of the flour; however, technological properties such as WHC and OHC were not strongly affected, and therefore, the optimization of the dehydration process was only based on the condition that allowed us to minimize the dehydration time, which was attained at 57 min with 57 °C and an air flow rate of 3.0 m/s.

Cassava flour has great potential to be used—-coupled with other protein rich flours—as an ingredient in gluten-free pasta. The results showed that the pastas produced with cassava flour were comparable to commercial pastas in terms of the protein content, but their hardness, water content, and water activity were lower than those typically reported for gluten-free pastas. Additionally, the sensory analysis indicated that the main problem with this product is the earthy taste of cassava.

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REFERENCES

AACCI. (1999a). *AACC International Approved Methods*. Method 76-13.01. Total Starch Assay Procedure (Megazyme Amyloglucosidase/alpha-Amylase Method). MN, USA: St. Paul.

AACCI. (1999b). *AACC International Approved Methods*. Method 66-50.01 Pasta and Noodle Cooking Quality – Firmness. MN, USA: St. Paul.

Adekunle A, Orsat V and Raghavan V. (2016). Lignocellulosic bioethanol: A review and design conceptualization study of production from cassava peels. *Renewable & Sustainable Energy Reviews* 64: 518–530.

Anyanwu CN, Ibeto CN, Ezeoha SL and Ogbuagu NJ. (2015). Sustainability of cassava (*Manihot esculenta* Crantz) as industrial feedstock, energy and food crop in Nigeria. *Renewable Energy* 81: 745–752.

AOAC (2002). *Official Methods of Analysis of the Association of Official Analytical Chemists*, 17th ed. Gaithersburg, MD: Association of Official Analytical Chemists.

AOAC (2012). *Official Methods of Analysis (19th Edition) Method 2012.01 (32.1.44)*. Gaithersburg, MD: Association of Official Analytical Chemists.

Arcila N and Mendoza Y. (2006). Elaboración de una bebida instantánea a base de semillas de amaranto (*Amaranthus cruentus*) y su uso potencial en la alimentación humana. *Revista de La Facultad de Agronomía* 23(1): 110–119.

Aristizábal J and Sanchez T. (2007). *Guía Técnica Para Producción y Análisis de Almidón de Yuca*. Roma: Boletin de Servicios Agrícolas de la FAO 163.

Barker JM and Liu E. (2008). Celiac disease: Pathophysiology, clinical manifestations and associated autoimmune conditions. *Advances in Pediatrics* 55: 349–365.

Basu S, Das M, Sen A, Choudhury UR and Datta G. (2014). Analysis of complete nutritional profile and identification of bioactive components present in *Alocasia indica* tuber cultivated in Howrah District of West Bengal, India. *Asian Pacific Journal of Tropical Medicine* 7: S527–S533.

Bouasla A, Wójtowicz A and Zidoune MN. (2016). Gluten-free precooked rice pasta enriched with legumes flours: Physical properties, texture, sensory attributes and microstructure. *LWT – Food Science & Technology* 75: 569–577.

Calliope SR, Lobo MO and Sammán NC. (2018). Biodiversity of Andean potatoes: Morphological, nutritional and functional characterization. *Food Chemistry* 238: 42–50.

Cárdenas-Hernández A, Beta T, Loarca-Piña G, Castaño-Tostado E, Nieto-Barrera JO and Mendoza S. (2016). Improved functional properties of pasta: Enrichment with amaranth seed flour and dried amaranth leaves. *Journal of Cereal Science* 72: 84–90.

Ceballos H, Sánchez T, Chávez AL, Iglesias C, Debouck D, Mafla G, et al. (2006). Variation in crude protein content in cassava (*Manihot esculenta* Crantz) roots. *Journal of Food Composition & Analysis* 19(6–7): 589–593.

Charmongkolpradit S and Luampon R. (2017). Study of thin layer drying model for cassava pulp. *Energy Procedia* 138: 354–359.

Chillo S, Laverse J, Falcone PM and Del Nobile MA. (2007). Effect of carboxymethylcellulose and pregelatinized corn starch on the quality of amaranthus spaghetti. *Journal of Food Engineering* 83(4): 492–500.

CODEX STAN 152-1985. (2008). *Codex Standard for Foods for Special Dietary Use for Persons Intolerant to Gluten*. FAO: Codex Alimentarius Commission.

Dayakar Rao B, Anis M, Kalpana K, Sunooj KV, Patil JV and Ganesh T. (2016). Influence of milling methods and particle size on hydration properties of sorghum flour and quality of sorghum biscuits. *LWT – Food Science & Technology* 67: 8–13.

De Santis D and Frangipane Teresa M. (2018). Evaluation of chemical composition and sensory profile in Jerusalem artichoke (*Helianthus tuberosus* L) tubers: The effect of clones and cooking conditions. *International Journal of Gastronomy and Food Science* 11: 25–30.

Duarte Y, Chaux A, Lopez N, Largo E, Ramírez C, Nuñez H, et al. (2017). Effects of blanching and hot air drying conditions on the physicochemical and technological properties of yellow passion fruit (*Passiflora edulis* var. *Flavicarpa*) by-products. *Journal of Food Process Engineering* 40.

Duyvejonck AE, Lagrain B, Dornez E, Delcour JA and Courtin CM. (2012). Suitability of solvent retention capacity tests to assess the cookie and bread making quality of European wheat flours. *LWT – Food Science & Technology* 47(1): 56–63.

Elmi Sharlina MS, Yaacob WA, Lazim AM, Fazry S, Lim SJ, Abdullah S, et al. (2017). Physicochemical properties of starch from *Dioscorea pyrifolia* tubers. *Food Chemistry* 220: 225–232.

Evans KE and Sanders DS. (2012). Celiac disease. *Gastroenterology Clinics of North America* 41: 639–650.

Falade KO, Olurin TO, Ike EA and Aworh OC. (2007). Effect of pretreatment and temperature on air-drying of *Dioscorea alata* and *Dioscorea rotundata* slices. *Journal of Food Engineering* 80(4): 1002–1010.

Fellows PJ. (2000). *Processing Technology. Principles and Practice*, 2nd ed. Washington, DC: Taylor & Francis, p. 575.

Ferreira SMR, de Mello AP, de Caldas Rosa dos Anjos M, Krüger CCH, Azoubel PM and de Oliveira Alves MA. (2016). Utilization of sorghum, rice, corn flours with potato starch for the preparation of gluten-free pasta. *Food Chemistry* 191: 147–151.

Fiorda FA, Soares MS, da Silva FA, de Moura CMA and Grossmann MVE. (2015). Physical quality of snacks and technological properties of pregelatinized flours formulated with cassava starch and dehydrated cassava bagasse as a function of extrusion variables. *LWT – Food Science & Technology* 62(2): 1112–1119.

Fiorda FA, Soares MS, da Silva FA, Grosmann MVE and Souto LRF. (2013). Microestructure, texture and color of gluten-free pasta made with amaranth flour, cassava starch and cassava bagasse. *LWT – Food Science & Technology* 54(1): 132–138.

Giannone V, Lauro MR, Spina A, Pasqualone A, Auditore L, Puglisi I, et al. (2016). A novel α-amylase-lipase formulation as anti-staling agent in durum wheat bread. *LWT – Food Science & Technology* 65: 381–389.

Giuberti G, Gallo A, Cerioli C, Fortunati P and Masoero F. (2015). Cooking quality and starch digestibility of gluten free pasta using new bean flour. *Food Chemistry* 175: 43–49.

Granito M, Torres A and Guerra M. (2003). Desarrollo y evaluación de una pasta a base de trigo, maíz yuca y frijol. *Interciencia* 28(7): 372–379.

Islas-Rubio A, de la Barca AMC, Cabrera-Chavez F, Cota-Gastélum AG and Beta T. (2014). Effect of semolina replacement with a raw popped amaranth flour blend on cooking quality and texture of pasta. *LWT – Food Science & Technology* 57: 217–222.

Jensen S, Skibsted LH, Kidmose U and Thybo AK. (2015). Addition of cassava flours in bread-making: Sensory and textural evaluation. *LWT – Food Science & Technology* 60(1): 292–299.

Kaur A, Singh N, Kaur S, Ahlawat AK and Singh AM. (2014). Relationships of flour solvent retention capacity, secondary structure and rheological properties with the cookie making characteristics of wheat cultivars. *Food Chemistry* 158: 48–55.

Koupantsis T, Pavlidou E and Paraskevopoulou A. (2014). Flavor encapsulation in milk proteins – CMC coacervate-type complexes. *Food Hydrocolloids* 37: 134–142.

Kumar N, Sarkar BC and Sharma HK. (2012). Mathematical modeling of thin layer hot air drying of carrot pomace. *Journal of Food Science & Technology* 49(1): 33–41.

Larrosa V, Lorenzo G, Zaritzky N and Califano A. (2015). Dynamic rheological analysis of gluten-free pasta as affected by composition and cooking time. *Journal of Food Engineering* 160: 11–18.

Lateef O, Bamgbose C and Silifat A. (2004). Production of instant cassava noodles. *Journal of Food Technology* 2: 83–89.

Lertworasirikul S and Tipsuwan Y. (2008). Moisture content and water activity prediction of semifinished cassava crackers from drying process with artificial neural network. *Journal of Food Engineering* 84(1): 65–74.

López LB, Dyner LM, Vidueiros SM, Pallaro A and Valencia ME. (2010). Gliadins determination in food elaborated with amaranth, quínoa and/or chía. *Revista Chilena de Nutrición* 37: 80–86.

Luikov AV. (1968). *Analytical Heat Diffusion Theory*, 2nd ed. New York and London: Academic Press.

Machado Alencar NM, Steel CJ, Alvim ID, de Morais EC and Andre Bolini HM. (2015). Addition of quinoa and amaranth flour in gluten-free breads: Temporal profile and instrumental analysis. *LWT – Food Science & Technology* 62(2): 1011–1018.

Makdoud S and Rosentrater KA. (2017). Development and testing of gluten-free pasta based on rice, quinoa and amaranth flours. *Journal of food Research* 6(4): 91–110.

Mariotti M, Lametti S, Cappa C, Rasmussen P and Lucisano M. (2011). Characterisation of gluten-free pasta through conventional and innovative methods: Evaluation of the uncooked products. *Journal of Cereal Science* 53(3): 319–327.

Marti A and Pagani MA. (2013). What can play the role of gluten in gluten free pasta?. *Trends in Food Science & Technology* 31(1): 63–71.

Menga V, Amato M, Phillips TD, Angelino D, Morreale F and Fares C. (2017). Gluten-free pasta incorporating chia

(*Salvia hispanica* L.) as thickening agent: An approach to naturally improve the nutritional profile and the in vitro carbohydrate digestibility. *Food Chemistry* 221: 1954–1961.

Miñarro B, Albanell E, Aguilar N, Guamis B and Capellas M. (2012). Effect of legume flours on baking characteristics of gluten-free bread. *Journal of Cereal Science* 56(2): 476–481.

Mirhosseini H, Abdul Rashid NF, Tabatabaee Amid B, Cheong KW, Kazemi M and Zulkurnain M. (2015). Effect of partial replacement of corn flour with durian seed flour and pumpkin flour on cooking yield, texture properties, and sensory attributes of gluten free pasta. *LWT – Food Science & Technology* 63(1): 184–190.

Mohammadi M, Sadeghnia N, Azizi M-H, Neyestani T-R and Mortazavian AM. (2014). Development of gluten-free flat bread using hydrocolloids: Xanthan and CMC. *Journal of Industrial & Engineering Chemistry* 20(4): 1812–1818.

Morgan NK and Choct M. (2016). Cassava: Nutrient composition and nutritive value in poultry diets. *Animal Nutrition* 2(4): 253–261.

NTC (2009). *Análisis Sensorial. Metodología. Métodos de Perfil de Sabor (NTC 3929). Norma Técnica Colombiana*. Bogotá: ICONTEC.

Ognean M, Ognean CF and Bucur A. (2011). Rheological effects of some xylanase on doughs from high and low extraction flours. *Procedia Food Science* 1: 308–314.

Oladiran DA, Emmambux MN and de Kock HL. (2018). Extrusion cooking of cassava-soy flour with 200 g/kg wheat bran promotes slower oral processing during consumption of the instant porridge and higher derived satiety. *LWT – Food Science & Technology* 97: 778–786.

Osorio J, Monjes J, Pinto M, Ramírez C, Simpson R and Vega O. (2014). Effects of spray drying conditions and the addition of surfactants on the foaming properties of a whey protein concentrate. *LWT – Food Science & Technology* 58(1): 109–115.

Pasqualone A, Gambacorta G, Summo C, Caponio F, Di Miceli G, Flagella Z, et al. (2016). Functional, textural and sensory properties of dry pasta supplemented with lyophilized tomato matrix or with durum wheat bran extracts produced by supercritical carbon dioxide or ultrasound. *Food Chemistry* 213: 545–553.

Pastor J, Juan R, Alaiz M, Vioque CMJ and Familia A. (2007). Caracterización proteica de las semillas de once especies de amaranto. *Grasas y Aceites* 58(1): 49–55.

Pornpraipech P, Khusakul M, Singklin R, Sarabhorn P and Areeprasert C. (2017). Effect of temperature and shape on drying performance of cassava chips. *Agriculture and Natural Resources* 51: 402–409.

Precoppe M, Tran T, Chapuis A, Müller J and Abass A. (2016). Improved energy performance of small-scale pneumatic dryers used for processing cassava in Africa. *Biosystems Engineering* 151: 510–519.

Ramírez C, Troncoso E, Muñoz J and Aguilera JM. (2011). Microstructure analysis on pretreated apple slices and its effect on water release during air drying. *Journal of Food Engineering* 106(3): 253–261.

Remes-Troche JM, Uscanga-Domínguez LF, Aceves-Tavares RG, Calderón de la Barca AM, Carmona-Sánchez RI, Cerda-Contreras E, et al. (2018). Clinical guidelines on the diagnosis and treatment of celiac disease in Mexico. *Revista de Gastroenterología de México* 83(4): 434–450.

Rodrigues S, De Mello A, Dos Anjos M, Hecke C, Moreira P and Alves M. (2016). *Food Chemistry*. 191: 147–151.

Rubel IA, Iraporda C, Novosad R, Cabrera FA, Genovese DB and Manrique GD. (2018). Inulin rich carbohydrates extraction from Jerusalem artichoke (*Helianthus tuberosus* L.) tubers and application of different drying methods. *Food Research International* 103: 226–233.

Saeleaw M and Schleining G. (2011). Effect of frying parameters on crispiness and sound emission of cassava crackers. *Journal of Food Engineering* 103(3): 229–236.

Saravacos GD and Maroulis ZB. (2001). *Transport Properties of Food*. New York: Marcel Decker.

Sciarini L. (2011). *Estudio del efecto de diferentes aditivos sobre la calidad y la conservación de panes libres de gluten*. Tesis Doc, Universidad Nacional de La Plata, Argentina, p.212.

Shi Q, Zheng Y and Zhao Y. (2013). Mathematical modeling on thin-layer heat pump drying of yacon (*Smallanthus sonchifolius*) slices. *Energy Conversion & Management* 71: 208–216.

Shittu TA, Raji AO and Sanni LO. (2007). Bread from composite cassava-wheat flour: I. Effect of baking time and temperature on some physical properties of bread loaf. *Food Research International* 40(2): 280–290.

Tsatsaragkou K, Gounaropoulos G and Mandala I. (2014). Development of gluten free bread containing carob flour and resistant starch. *LWT – Food Science & Technology* 58(1): 124–129.

Tudorica MC, Kuri V and Brennan CS. (2002). Nutritional and physicochemical characteristics of dietary fiber enriched pasta. *Journal of Agricultural & Food Chemistry* 50: 347–356.

Vega O, Carvajal LM, Rodríguez F, Marín C, Ramírez C, Simpson R, et al. (2018). Effect of thermal pretreatments and cooking characteristics on physicochemical, rheological, and sensorial properties of food products based on cassava (*Manihot esculenta* Crantz). *Journal of Food Process Engineering* 41: 12612.

Wongsagonsup R, Pujchakarn T, Jitrakbumrung S, Chaiwat W, Fuongfuchat A, Varavinit S, et al. (2014). Effect of cross-linking on physicochemical properties of tapioca starch and its application in soup product. *Carbohydrate Polymers* 101: 656–665.

Yánez E, Zacarías I, Granger D, Vásquez M and Estévez AM. (1994). Caracterización química y nutricional del amaranto (*Amaranthus cruentus*). *Archivos Latinoamericanos de Nutricion* 44(1): 57–62.

Yazar G, Duvarci O, Tavman S and Kokini JL. (2017). Nonlinear rheological behavior of gluten-free flour doughs and correlations of LAOS parameters with gluten-free bread properties. *Journal of Cereal Science* 74: 28–36.

Yovanovich M. (1996). Simple explicit expressions for calculation of the Heisler-Grober charts. In: *1996 national heat* *transfer conference*, Houston, TX, 3–6 August 1996, AIAA-96-3968.

Yu Z, Jiang H, Guo R, Yang B, You G, Zhao M, et al. (2018). Taste, umami-enhance effect and amino acid sequence of peptides separated from silkworm pupa hydrolysate. *Food Research International* 108: 144–150.

Zandonadi RP, Botelho RBA, Gandolfi L, Ginani JS, Montenegro FM and Pratesi R. (2012). Green banana pasta: An alternative for gluten-free diets. *Journal of the Academy of Nutrition & Dietetics* 112: 1068–1072.