Research article

Effects of long-term frozen storage on the quality and acceptance of gluten-free cassava pasta

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ABSTRACT

Cold storage conditions during long-term periods can be critical for the quality of gluten-free products. The objective of this work was to elaborate gluten-free pasta using cassava starch and study the influence of different storage conditions on the textural and sensorial properties of gluten-pasta compared to regular pasta. Samples were initially frozen at two different temperatures, -50 °C and -150 °C, and then stored for six months at -25 °C. Physicochemical and rheological analyses were used to characterize the pasta dough. Then microbiological, instrumental texture, and sensorial analysis were used to further characterize the pasta throughout the cold storage period of 6 months. The gluten-free pasta's nutritional composition showed low fat and protein content and high crude fiber, carbohydrates, and energy value content in relation to the gluten-containing pasta. Both kinds of pasta dough presented a pseudoplastic behavior; however, the wheat flour pasta presented lower apparent viscosity. The texture profile of frozen pasta during the evaluation period did not significantly vary when comparing the two freezing temperatures. Although the firmness, chewability, and cohesiveness parameters slightly decreased during the storage, losses of firmness were not detected by the judges at the sensorial analysis. Finally, cassava starch pasta had a high acceptance. According to the purchase intention research, the judges routinely consume gluten-free pasta, showing the high commercialization potential of the obtained product.

1. Introduction

Pasta is one of the oldest forms of food. It is highly versatile due to low cost, simple production technology, and nutritional quality. Additionally, it has a high acceptability index worldwide and is included in all age groups and social classes (Simonato et al., 2015).

Generally, wheat flour is the most common raw material for pasta production (Fuad and Prabhasankar, 2010). Because wheat flour contains gluten, new researches are being developed to find alternatives that meet the technological and sensorial standards of the regular pasta (Giménez-Bastida et al., 2015; Ribeiro et al., 2018), providing economic benefits and meeting the needs of a fraction of population with food restrictions and celiac diseases. Besides the celiac consumers, in recent years, the glúten-free products presented growth in demand from the general consumers that aim for a healthier diet (Silva et al., 2019). Thus, a suitable alternative could be cassava starch. Cassava starch is a gluten-free product with relevant properties for the food industry. Therefore, in addition to its low cost and high availability, it can be used

to change or control characteristics such as texture, appearance, moisture, consistency and storage stability (Cereda, 2001; Koteswara Reddy, Kimi and Haripriya, 2016). Recent reports show that cassava starch can increase the added value of both cassava itself and food products such as bread, cakes and pasta to which it was included (Shittu et al., 2008; Fiorda, Soares, da Silva, Grosmann and Souto, 2013; Milde et al., 2017).

When considering the development of new products, knowledge of the best storage methods is critical to increasing its shelf life. According to Kondakci et al. (2015), freezing is one of the most suitable methods to reduce pasta's microbial and enzymatic activity. However, from literature, only a few works focused on understanding the impact of pasta freezing on the shelf life and the sensorial and instrumental textural properties (Olivera & Salvadori, 2009, 2011; Liu et al., 2019).

Studies on frozen of raw pasta are relevant for industries due to the appeal of industrialization. The freezing process contributes to reducing spoilage losses and production costs, thereby increasing productivity and convenience for the consumed (Mezaize et al., 2010; Cappa et al., 2017). Besides helping to extend the shelf-life, freezing also hinders starch aging

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Table 1. Rheological models for fitting flow curves of dough formulations.

Model	Ostwald-de-Waelle	Mizrahi–Berk	Bingham
Equation	$\tau = K\gamma^n$	$\tau^{0,5} = K_{oM} + K_M\gamma^{0,5}$	$\tau = \tau_O + n_P\gamma$

τ = shear stress (pa); k0 m = shear stress (pa); km = consistency index (pa.sn); γ = shear strain (s-1); k = consistency index (pa.sn); n = flow behavior index; τo = yield stress(pa); np = plastic viscosity.

and facilitates transportation. However, some hurdles are still defying its full implementation due to internal structural alterations such as starch modification and disruption of the gluten network. These two phenomena result in the appearance of roughness, fissures, or even collapse of the food surface and internal structure that result in undesirable alterations on sensorial properties such as firmness, masticability and elasticity (Wang et al., 2017; Feng et al., 2020; Yu et al., 2020).

Some studies on the effects of frozen storage on wheat pasta have been reported. Jia et al. (2019) found an increasing spoilage after lower freezing rates, higher temperatures, and more extended storage periods. Another study reported that alterations on the ice crystal size within the food material caused damage to the structure by varying the freezing storage temperature. Consequently, a loss on textural properties was found throughout the storage period (Liu et al., 2019).

Therefore, this study aimed to produce gluten-free pasta using cassava starch, characterize its nutritional quality, rheological properties, and study the effects of storage time on the instrumental texture and sensorial properties of the frozen pasta throughout six months.

2. Materials and methods

2.1. Obtaining cassava starch

The cassava was purchased from the local market, washed in running water to remove the dirt, then peeled and cut into smaller pieces. The starch was isolated according to the methodology proposed by Silva et al. (2013) with adaptations. Therefore, the material was balled in a 0.5% sodium bisulfite solution for 10 min and then crushed together with distilled water at a ratio of 1:2 (material: water) for about 4 min to be filtered in organza bags (mesh opening close to 100 mesh). The filtered starch suspension was decanted in a refrigerated environment at 5 °C for 24 h and then the suspension had its supernatant discarded. Three washes of the starch with distilled water were performed. The cassava starch was frozen at -25 °C for 24 h and lyophilized at -50 °C for 48 h, using a bench-top lyophilizer (Christ - ALPHA 1–2 Ldplus).

2.2. Production of pasta samples

Two different formulations were developed. These two formulations comprised of (F1) 100% cassava starch (30 g); (F2) 100% wheat flour (30 g). Other ingredients were coconut milk (120 mL) and eggs (2 whole units of approximately 60 g each), both purchased from local markets in Campina Grande (Paraíba, Brazil), except the cassava starch, used with the same quantities in all formulations. All ingredients were weighed separately and mixed together in a container until a homogeneous mixture was formed. Then, with the help of a spatula this mixture was spread in a frying pan with dimensions of 0.13 m × 0.13 m x 0.001 m of width, height, and thickness, respectively, conferring a rectangular shape to the pasta, being heated for a minute using conventional stove (model CF475AR, Consul, Joinville, Brazil) at 180 ± 5 °C according to the methodology described by Vieira et al. (2020). After cooling to room temperature [25±2 °C] pasta samples were stored and heat sealed on flexible laminated PET-metallized with a LDPE film. The packages have a nominal total weight of 120 g/m^2, a water vapor transmission rate of 5.38 g m^{-2}/day, an oxygen permeability of 60 cc. m^{-2}/day with 0.16 m × 0.22 m width and height, respectively.

2.3. Pasta characterization

The F1 and F2 masses were characterized, in triplicate, according to the following physicochemical parameters: moisture content, pH, total titratable acidity, ash, protein and fibers (AOAC, 2012). Water activity (a$_w$) at 25 °C was determined by direct reading using Aqualab (model 3TE, Decagon Devices, city). Lipid content was determined using the method described by Bligh e Dyer (1959). Carbohydrate content was determined using the arithmetic difference, including raw fiber, according to the formula: % Carbohydrates = 100 – (% humidity+ % protein+ % lipids+ % ashes), and the total energy value was determined using the Atwater values (or combustion heat) for lipids (9 kcal/g), protein (4,02 kcal/g) and carbohydrates (3,87 kcal/g) (Atwater and Woods, 1896). As for the specific cooking analyses, the volume increase was evaluated according to the method proposed by AACC (2000).

2.4. Rheological behavior

Viscosity and torque measurements were made on raw pasta samples (F1 and F2) using a Brookfield viscometer (RV + model, Brookfield Engineering Laboratories Inc., MA, USA) at a temperature of 25 °C with nine spindle speeds ranging from 50 to 200 rpm. The temperature was maintained using a thermostatically controlled water bath. All experiments were replicated three times. Average shear stress and shear rates were calculated by the method of Mitschka (1982). Shear strain and shear stress data were fitted to the following rheological models: Ostwald-Waelle (Power law), Mizrahi-Berk, and Bingham, according to Table 1.

2.5. Pasta freezing and storage

Pasta samples F1 and F2 were initially frozen at two different temperatures, -50 °C and -150 °C for 5 h until both samples were frozen. Then the frozen pasta samples were stored at -25 °C for six months. Samples were unfrozen every month for analysis, and after 24 h microbiological analysis was performed. Then samples were characterized using instrumental textural and sensorial analysis.

2.6. Microbiological analysis

Microbiological analysis was performed on samples F1 and F2 after 24 h frozen storage. The analysis comprised thermal tolerant coliforms, *Staphylococcus* coagulase-positive, and *Salmonella* sp., according to (APHA, 2001).

2.7. Instrumental texture analysis

Instrumental texture (TPA) of samples F1 and F2 was determined using a TA-XT Plus texture analyzer (TA-XT Plus, Stable Micro Systems, Surrey, UK). A P/36R probe-type cell was used to compress the samples with an initial rate of 2.0 mm/s and then a test rate of 1.0 mm/s was used until a depth of 20.0 mm was reached. The parameters evaluated were firmness, adhesivity, masticability, and cohesiveness.

Table 2. Physicochemical characterization of gluten-free pasta (F1) and wheat flour pasta (F2) after cooking and before freezing.

	F1	F2
Water Activity - a_w	$0.995^a \pm 0.002$	$0.996^a \pm 0.001$
Water Content (% w.b.)	$67.44^b \pm 0.91$	$69.78^a \pm 0.09$
pH	$7.12^b \pm 0.03$	$7.29^a \pm 0.01$
Titratable Acidity	$0.39^b \pm 0.00$	$0.58^a \pm 0.01$
Ash(% w.b.)	$0.67^a \pm 0.02$	$0.61^b \pm 0.02$
Fat (% w.b.)	$3.70^b \pm 0.01$	$4.73^a \pm 0.03$
Protein content (% w.b.)	$7.18^b \pm 0.50$	$10.10^a \pm 0.33$
Total Fibers (% w.b.)	$2.71^a \pm 0.64$	$1.07^b \pm 0.48$
Carbohydrates (% w.b.)	$20.46^a \pm 0.24$	$14.78^b \pm 0.42$
Energy (kcal/g)	$142.79^a \pm 0.81$	$140.39^b \pm 0.30$
Volume increase (%)	$1.06^a \pm 0.01$	$1.03^a \pm 0.02$

F1- Pasta 100% cassava starch; F2- Pasta 100% wheat flour; *Average values followed by the same letter on the same line are not statistically different according to the Tukey test at 5% probability.

2.8. Sensorial analysis

The sensorial analysis was conducted under previous approval by the Human Research Ethics Committee (CAAE 88009818.3.0000.5182) and accordingly to local Brazilian resolution nº466/12 of the Brazilian National Health Council. The tasters were aware of the research objectives, according to the Informed Consent Form. The F1 and F2 pasta were submitted to a sensorial analysis performed by 60 non-trained judges from both genders and ages ranging from 18 to 50 years old. 10 g samples were served to the judges in individual cabinets and were assessed under white light, a room temperature of 30 ± 2 °C. The samples were served unfrozen with a commercial tomato sauce on the side. Before serving all samples and sauce were heated for 30 s using a 1390 W microwave oven (Electrolux, Curitiba – PR, Brazil). Each sample was coded with a three digit aleatory number and served using a polystyrene tray along with a glass of mineral water for palate cleaning.

The acceptance test was carried out using the 9-point hedonic scale (9 = like immensely, 5 = neither like nor dislike, and 1 = dislike extremely) for the attributes color, aroma, taste, texture and overall acceptance (DUTCOSKY, 2011). Acceptance results were complemented by questioning the purchase intent regarding each sample, using the 5-point scale (5 = definitely would buy, 3 = might or might not buy, 1 = definitely would not buy).

2.9. Statistical analysis

Physicochemical and sensorial analyses were performed under a random experimental design. The average classification was performed using the Tukey test at 5% of probability using software ASSISTAT version 7.7. Instrumental texture parameters were presented by graphs built with Origin 6.0. Rheological models were fitted using non-linear regression, method quasi-newton using STATISTICA 7.0.

3. Results and discussion

3.1. Physicochemical characterization

In Table 2, the physicochemical characterization of both types of pasta formulations is presented before storage.

Water activity presented no significant difference (p < 0.05) between both samples. Water activity for both formulations showed values superior to 0.9, demonstrating its susceptibility to microbial growth, thus requiring proper techniques for its processing. According to Quek et al. (2007), water activity is a critical parameter because it directly influences the product's shelf life. Resta and Oliveira (2013), analyzed 14

samples of fresh pasta and found similar water activity values (0.96). Even though both types of pasta dough were heat-treated, the high average water activity is related to the high average water content present.

The pH values were found to be neutral for both pasta formulations. Thus, the titratable acidity was found low for both formulations. Silva, Brinques and Gurak (2019) report a decrease in pH while using freeze-dried flour the sample. However, in our study the lyophilized cassava starch used on formulation F1 did not decrease the pH. Ash content values were 0.67 and 0.61 for F1 and F2, respectively. Ciccoritti, Nocente, Sgrulletta and Gazza (2019), while studying traditional pasta elaborated with three different wheat cultivars, obtained similar values. According to the authors, ash content can be correlated with the quantity and distribution of nutrients on the sample. Similarly to protein content, pasta with wheat flour presented higher fat content (3.7%). According to Giuberti et al. (2015), gluten-free pasta, presented less fat content when compared to the traditional pasta, reporting that such behavior is intrinsic to the raw material used. Similarly to our study, Volpato, Ruiz, & Pagamunici (2013) while producing pasta with partial substitution of wheat flour for cassava starch and quinoa flour, found a higher lipid content in the control formulation (100% wheat flour).

Wheat flour pasta (F2) had the highest average protein content of 16% above the cassava starch pasta (F1) which is similar to the result found by Cornicelli et al. (2018). The authors, while analyzing commercial foods with gluten and gluten-free, found less protein content on gluten-free products. The protein content of the pasta can be influenced by the egg inclusion on the formulation. The eggs are used to obtain flavor effects and can help on the structure formation. Besides contributing positively in the protein value of the pasta, it helps in the formation of a more rigid protein network which makes the product firmer before and after cooking (Larrosa et al., 2016).

Gluten-free pasta (F1) presents a higher content of total fibers than the wheat flour pasta (F2). Milde, Chade, Silva and Zubreski (2017) it was found in its dough made with cassava starch a higher fiber content compared with this study. According to the authors, the high value of fibers in the gluten-free pasta is due to the fact that resistant starch is considered a dietary fiber formed during the cooking of the pasta.

Cassava starch pasta presented higher carbohydrate content and, therefore, higher energy value than wheat flour pasta. According to Fernandes et al. (2017), the difference is due to the high carbohydrate content of cassava. In the same study, the authors found 71.73 (g/100 g) for the carbohydrate content and 287 kcal/100 g for energy, both values higher than the ones found in the present study due to the lower water content.

There was no statistical difference (p < 0.05) regarding volume increase between F1 and F2 masses. According to Fogagnoli and Seravalli (2014) the volume increase depends of the cooking time, the pasta shape, the gluten quality and content. Ribeiro, Bolanho, Montanuci and Ruiz (2018) detected no volume increase when varied passion fruit peels flour contents in pasta formulation.

3.2. Rheological properties

The rheological properties of the dough are important for product quality since there is always a relationship between the rheological properties and textural properties. Subsequently, these parameters influence product acceptability. The effect of shear rate on the F1 and F2 pasta's apparent viscosity is presented in Figure 1. For both pasta, it is observed that the apparent viscosity decreases with increasing shear rate which is a typical non-newtonian behavior, specifically shear thinning or pseudoplastic behavior. According to Das and Bhattacharya (2019) this effect is typical of pasta and is caused by a perturbation of the dough macromolecular structure. Moreover, the formulation F2 presented higher apparent viscosity for all shear rates than the formulation F1. However, both viscosity curves are similar. This result indicates that gluten-free pasta does not require additives to present a similar viscosity
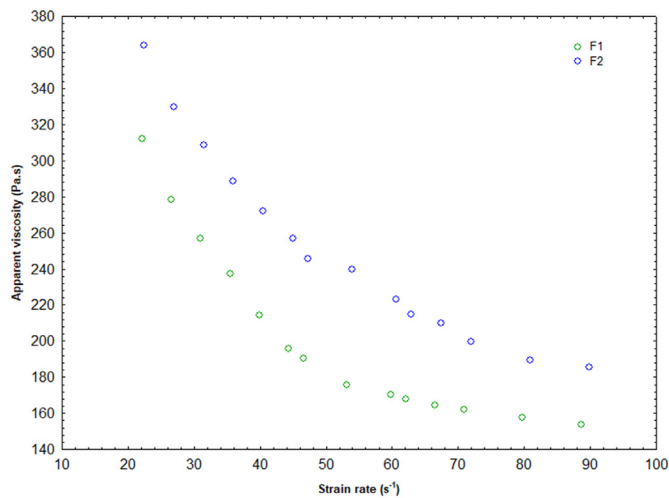
Figure 1. Dynamic flow behavior of the pastas with cassava starch (F1) and wheat flour (F2).

profile. According to Demirkesen et al. (2013) gluten has a particular rheologic pattern constituting a technological challenge for gluten-free products to mimic such behavior.

Experimental data were fitted to three rheological models, and the regressed parameters are presented in Table 3. All determination coefficients (R^2) are more significant than 90.00 (%) and all mean square deviations are lower than 0.2. This result indicates that all three models are adequate to estimate the rheological data of both formulations pasta. However, the Mizrahi–Berk model presented the higher coefficient of determination and the lower mean square deviations showing a better fit to the experimental data (Figure 2). Das and Bhattacharya (2019), while evaluating the rheological behavior of gluten-free pasta, also found the higher coefficient of determination and lower mean square deviations and consequently better fitting for the experimental data with the Mizrahi-Berk model.

Flow behavior índex (n) presented values below 1 for both Ostwald-de-Waele and Mizrahi-Berk models and both formulations. A value below 1 characterizes a non-newtonian fluid with pseudo-plastic behavior, i.e., the viscosity drops with increasing shear strain (Silva, Santos, Silva, Sousa and Arguello, 2015). For both models, the cassava starch pasta (F1) presented higher n values. Yield stress is given by the Bigham model and is related to the initial pressure required to start the flow of a fluid. Yield stress is an indicator of the attraction forces within the fluid and is related to the fluid viscosity (Mathias, Andrade, Rosa and Silva, 2013). Similar behavior was found in this study where the wheat flour pasta presented

higher yield stress and higher viscosity. The consistency indexes, K, and K_m from Ostwald-de-Waele and Mizrahi-Berk models showed lower values for the gluten-free pasta (F1). According to Meyer et al. (2016), this parameter is strongly related to the consistency of the fluid, i.e., with its viscosity and with total solids content. Additionally, this behaviour could be related to the presence of gluten, since the F2 formulation presents higher apparent viscosity than F1. According to Ferreira et al. (2014), this behavior is related to the presence of a network formed by the gluten. More specifically, by a group of proteins comprising gliadins and glutenins that are responsible by the pasta extensibility and elasticity, respectively. After the addition of water, both proteins produce secondary interactions by hydrogen bridging and di-sulfite interactions that confer specific rheological properties to the food where present. According to Fischer et al. (2009) food products are produced from natural materials, so the ingredients have native structural and textural properties, producing an high impact on the flow behavior of the final food.

3.3. Instrumental texture analysis

Figure 3 presents the instrumental texture profile of all frozen pasta formulations analyzed throughout the six months of cold storage. The storage temperature available was -25 °C which is different than the domestic cold storage of -18 °C. Even though the temperatures are different, it is believed that the results are analogous. The data presented is for firmness and masticability, both fitted using a first order polynomial, and adhesivity fitted by a second order polynomial equation.
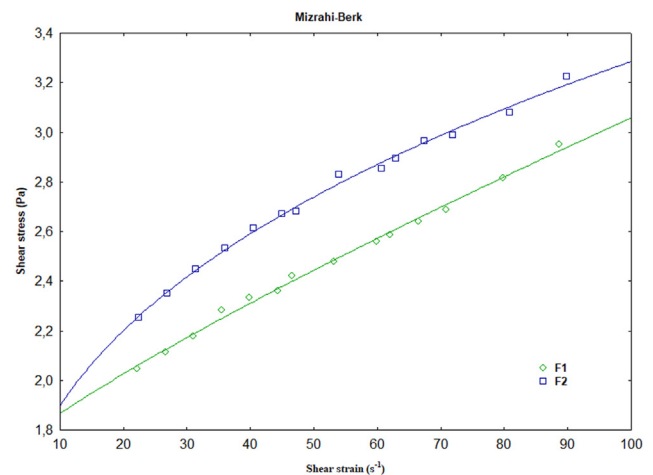

Figure 2. Flow curves for cassava starch (F1) and wheat flour (F2).

Table 3. Rheological parameters determined for Ostwald-de-Waele, Mizrahi-Berk and Bingham models.

Model	Samples	Parameters			R^2 (%)	MSD
		K	n			
Ostwald-de-Waele	F1	0.7595	0.5330		98.211	0.1693
	F2	1.0485	0.5042		99.372	0.1183

Model	Samples	Parameters			R^2 (%)	MSD
		Koh	Km	n		
Mizrahi–Berk	F1	1.6642	0.0294	0.8380	99.529	0.0175
	F2	0.8538	0.4491	0.3668	99.521	0.0189

Model	Samples	Parameters			R^2 (%)	MSD
		τO	nP			
Bingham	F1	2.7639	0.0647		99.423	0.0962
	F2	3.6384	0.0753		99.023	0.1477

F1- Pasta with cassava starch; F2- Pasta with wheat flour.
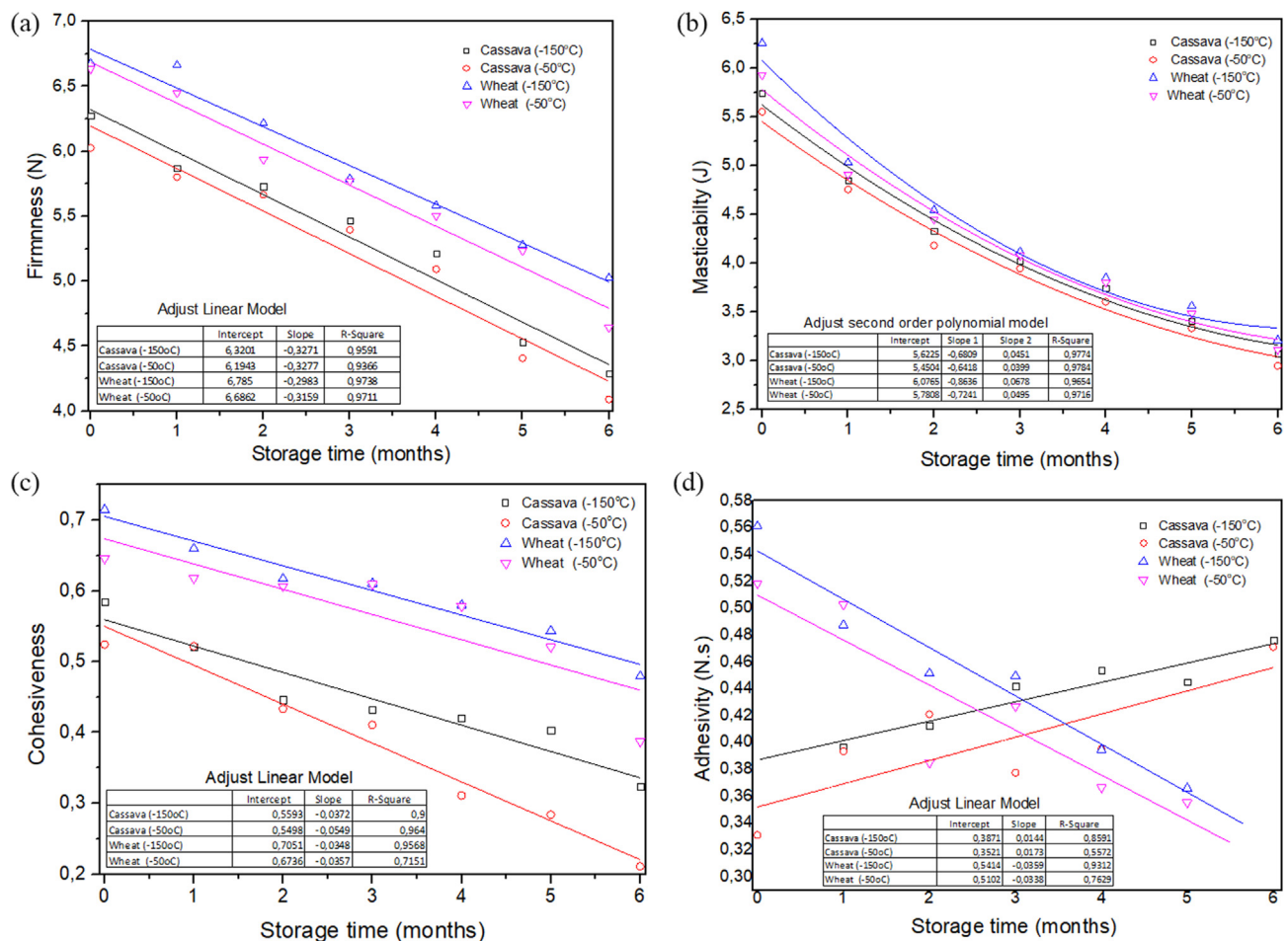
Figure 3. Instrumental texture parameter (a) firmness, (b) masticability, (c) cohesivity and (d) adhesivity of both pastas during cold storage. F1$_{-150\,°C}$ – Cassava starch pasta stored at -150 °C; F1$_{-50\,°C}$ - Cassava starch pasta stored at -50 °C; F2$_{-150\,°C}$ – Wheat flour pasta stored at -150 °C; F2$_{-50\,°C}$ - Wheat flour pasta stored -50 °C.

Except for adhesivity, a reduction on all properties as a function of time is observed. Samples frozen at -150 °C presented higher texture parameter values than the samples frozen at -50 °C, at any storage time. Freezing temperature and water diffusion influence the ice crystal size. Thus our result suggests that the bigger ice crystals formed at -50 °C have more impact on texture properties.

Firmness is related to the material mechanical resistance when a force is applied. This property is often related to the human first bite, and thus the firmer the food material is, the more force is required for the first bite. This factor is extremely relevant when considering the inherent food characteristics and consumer approval. From Figure 3a it is observed that the firmness decreased linearly for all samples throughout the cold storage period, as it is corroborated by the value of the slope of -0.32707 and -0.32768 for cassava pasta at -150 °C and -50 °C, respectively, and -0.29828 and -0.31589 for wheat pasta at the same temperatures.

However, wheat flour pasta presented higher firmness than cassava starch pasta. According to Larrosa et al. (2016), the gluten on wheat flour is the main contributor to establish a protein network. Gusmão et al. (2019) observed in their study that to provide firmness characteristics similar to products with gluten, it was necessary to use some additives such as transglutaminase. Therefore, our results suggest that despite the egg protein acts as a binder after heating (Silva and Damy-Benedetti, 2018), the effect of this binding is less than that of gluten and, therefore, the cassava starch pasta presents a difference in firmness in relation to the pasta made with wheat flour.

Masticability (Figure 3b) presented a similar trend compared to firmness, but instead of a linear decrease with time, a polynomial decrease was found. For all pasta samples, the initial value was 6 J and decayed to a final value of 3.2 J. Similarly to our work Olivera and Salvadori (2009), found that slower freezing reduced firmness, and consequently less masticability on pasta was found. Cohesiveness values also decayed linearly throughout the six months of frozen storage. The decay on cohesiveness was 30% less than the initial value for samples F1$_{-150}$, F2$_{-150}$, and F2$_{-50}$. As for samples, F2$_{-150}$ cohesiveness dropped 45% when compared to the initial value. While adhesivity increased for cassava starch pasta, wheat flour pasta presented a loss on adhesivity during the frozen storage period.

3.4. Sensorial analysis

Microbiologic assays were performed on all samples before any sensorial tests. Results demonstrated that the unfrozen pasta presented microbiological standards in accordance with the current legislation on food regulation (Brasil, 2001). The tested pasta is absent of bacteria Salmonella sp., the coliforms at 45 °C presented values below 5×10^2 NMP/g and the coagulase positive staphylococcus presented less than 5×10^3 CFU/g. Comparing the results with the legislation it is concluded that all samples are suitable for consumption.

The sensorial analyses were always performed with 60 untrained judges. The gender and age had slight variations during the period of storage and conducting sensory tests. On average, 63.09% were female and 36.90% male, with an age frequency of 77.62% from 18 to 30, 17.86% between 31 and 40 years old, and 4.52% between 41 and 50 years old. All participants were characterized as regular pasta consumers.

Table 4 presents the average scores of sensorial analyses performed during the frozen storage period. The parameters evaluated were

Table 4. Evolution of average scores of all samples throughout the frozen storage period.

Parameters	Samples	Months						
		0	1	2	3	4	5	6
Appearance	F1-150	7.05[a]	6.78[a]	7.02[a]	7.10[a]	7.25[a]	7.40[a]	7.48[a]
	F1-50	7.07[a]	6.75[a]	7.23[a]	7.22[a]	7.50[a]	7.22[a]	7.30[a]
	F2-150	7.03[a]	6.72[a]	6.92[a]	7.35[a]	7.28[a]	7.27[a]	7.32[a]
	F2-50	6.87[a]	6.70[a]	6.80[a]	7.37[a]	7.42[a]	7.45[a]	7.35[a]
Aroma	F1-150	6.50[ab]	6.28[ab]	6.38[ab]	6.30[ab]	6.98[ab]	6.93[ab]	6.33[ab]
	F1-50	6.58[ab]	6.43[ab]	6.68[ab]	6.73[ab]	6.93[ab]	7.10[a]	6.62[ab]
	F2-150	6.57[ab]	6.25[ab]	6.27[ab]	6.33[ab]	6.72[ab]	6.90[ab]	6.42[ab]
	F2-50	6.17[ab]	6.40[ab]	6.08[b]	6.43[ab]	6.83[ab]	6.82[ab]	6.48[ab]
Flavor	F1-150	6.28[b]	6.35[ab]	6.75[ab]	6.65[ab]	7.08[ab]	6.82[ab]	6.99[ab]
	F1-50	6.73[ab]	6.63[ab]	6.87[ab]	7.03[ab]	7.05[ab]	6.78[ab]	7.00[ab]
	F2-150	6.75[ab]	6.27[b]	6.72[ab]	6.85[ab]	7.02[ab]	6.98[ab]	7.03[ab]
	F2-50	6.40[ab]	6.58[ab]	6.53[ab]	6.85[ab]	7.28[a]	6.95[ab]	6.87[ab]
Texture	F1-150	6.52[cd]	6.45[d]	6.05[abcd]	7.78[abcd]	7.43[a]	7.18[abcd]	7.42[abcd]
	F1-50	6.72[abcd]	6.47[d]	7.12[abcd]	7.25[abcd]	7.25[abcd]	7.17[abcd]	7.20[abcd]
	F2-150	6.93[abcd]	6.65[abcd]	6.87[abcd]	7.37[abc]	7.40[abc]	7.32[abcd]	7.40[abcd]
	F2-50	6.53[bcd]	6.83[abcd]	7.93[abcd]	6.03[abcd]	7.27[abcd]	7.22[abcd]	7.32[abcd]
Global impression	F1-150	6.63[abc]	6.48[bcd]	6.07[abcd]	7.67[abcd]	7.28[abc]	7.08[abcd]	7.43[a]
	F1-50	6.60[abcd]	6.68[abcd]	7.27[abcd]	7.03[abcd]	7.22[abcd]	7.15[abcd]	7.37[a]
	F2-150	7.05[abc]	6.45[cd]	6.92[abcd]	7.15[abcd]	7.32[ab]	7.23[abcd]	7.25[abcd]
	F2-50	6.42[d]	6.78[abcd]	7.79[abcd]	6.00[abcd]	7.13[abcd]	7.22[abcd]	7.33[ab]

F1-150 °C – Cassava starch pasta stored at -150 °C; F1-50 °C - Cassava starch pasta stored at -50 °C; F2-150 °C – Wheat flour pasta stored at -150 °C; F2-50 °C - Wheat flour pasta stored -50 °C. *Average values followed by the same letter on the same line are not statistically different according to the Tukey test at 5% probability.

appearance, aroma, flavor, texture, and overall acceptance. Generally, all formulations presented good sensorial acceptance with scores varying from 6 (liked slightly) to 7 (liked moderately).

In the appearance, no statistical difference ($p < 0.05$) between the samples was found during the storage period. This attribute is relevant since the appearance of the product initially attracts many consumers. The parameter flavor presented the lowest scores when compared to the other sensorial attributes. Some judges pointed out on the score sheet a residual egg flavor. Thus, this residual egg flavor could be the reason for the lowest scores. However, the addition of eggs to the pasta is considered beneficial to gluten-free products. It increases the protein content and promotes a network that hinders water penetration on starch granules and consequent swelling during the pasta preparation (Makdoud and Rosentrater, 2017). A future project could be related to study a better way to add the egg in the process, seeking to reduce the characteristic aroma of this ingredient. Giménez et al. (2015) also found the judge's descriptions of their sensorial analysis about the aroma and flavor of egg present in pasta. There was no statistical difference between samples throughout the frozen-storage period, except in the second month for F2-50 and the fifth months for F1-50. For the flavor, samples do not present a statistical difference throughout the tested months, attesting the feasibility of the frozen storage on keeping the quality of the pasta.

The texture is an essential attribute of food, especially on pasta. When the instrumental and sensorial texture is correlated, it is observed no influence on the judge's scores. This result suggests the judges did not notice the loss on instrumental firmness even after prolonged frozen storage. In the first month, cassava starch formulations (F1-150) and (F1-50) presented statistical differences and had lower scores compared to wheat flour samples. After the fourth month, formulations (F1-150) and (F2-150) showed statistical differences, with higher scores for cassava starch. According to Hera et al. (2013) the production of gluten-free products is a technological challenge because gluten confer several properties that are fundamental on the pasta production.

When developing gluten-free foods, the difference between properties such as texture is related to the lack of a gluten network. Mimicking such a network still constitutes one of the major challenges for researchers.

The overall acceptance is calculated from the average of the scores between all attributes. On the one hand, formulations (F1-50) and (F2-50), at the first moment, received the lowest scores, while (F1-150) and (F2-150) also received the lowest scores on the first month. On the other hand, (F1-150) and (F2-150) received the highest scores in the fourth month. Thus, no clear trend is identified on the judge's scores when considering the initial freezing temperature. Makdoud and Rosentrater (2017), studying gluten-free pasta using rice flour, quinoa, and amaranth in comparison with commercial gluten-free pasta, received similar scores for overall acceptance. According to the same authors, the critical sensorial attribute to be improved is texture. However, flavor and aroma should also be improved due to discrepancies in these scores.

Figure 4 presents the purchase intent of all pasta samples. Analyzing the histograms, the scores were concentrated between 3 (might or might not buy) to 5 (definitely would buy). Generally, samples presented good purchase intention, suggesting that if the product would be available to commercialization would be bought. This fact features the commercialization potentiality of the cassava starch pasta. Ribeiro, Bolanho, Montanuci and Ruiz (2018), while determining the purchase intention of gluten-free pasta with flour from passion-fruit peels, reported similar trends, where traditional pasta had higher purchase intention, but gluten-free pasta received close approval.

4. Conclusion

Gluten-free pasta was produced using cassava starch and compared to the wheat pasta. The results revealed similar chemical composition with higher presence of fibers in the gluten-free pasta. Considering the rheological properties, it was concluded that even without gluten or other additives, the gluten-free pasta presented a similar non-newtonian rheological profile although with lower apparent viscosity. From our results it is also concluded that a lower initial freezing temperature impacts the final sensorial properties possibly due to smaller ice crystal formation. It was also concluded that low temperature freezing, at -150 °C, is a good method for gluten-free pasta storage for long periods. Finally, the high acceptability of gluten-free pasta, high purchase intention, chemical composition and rheological properties allow us to
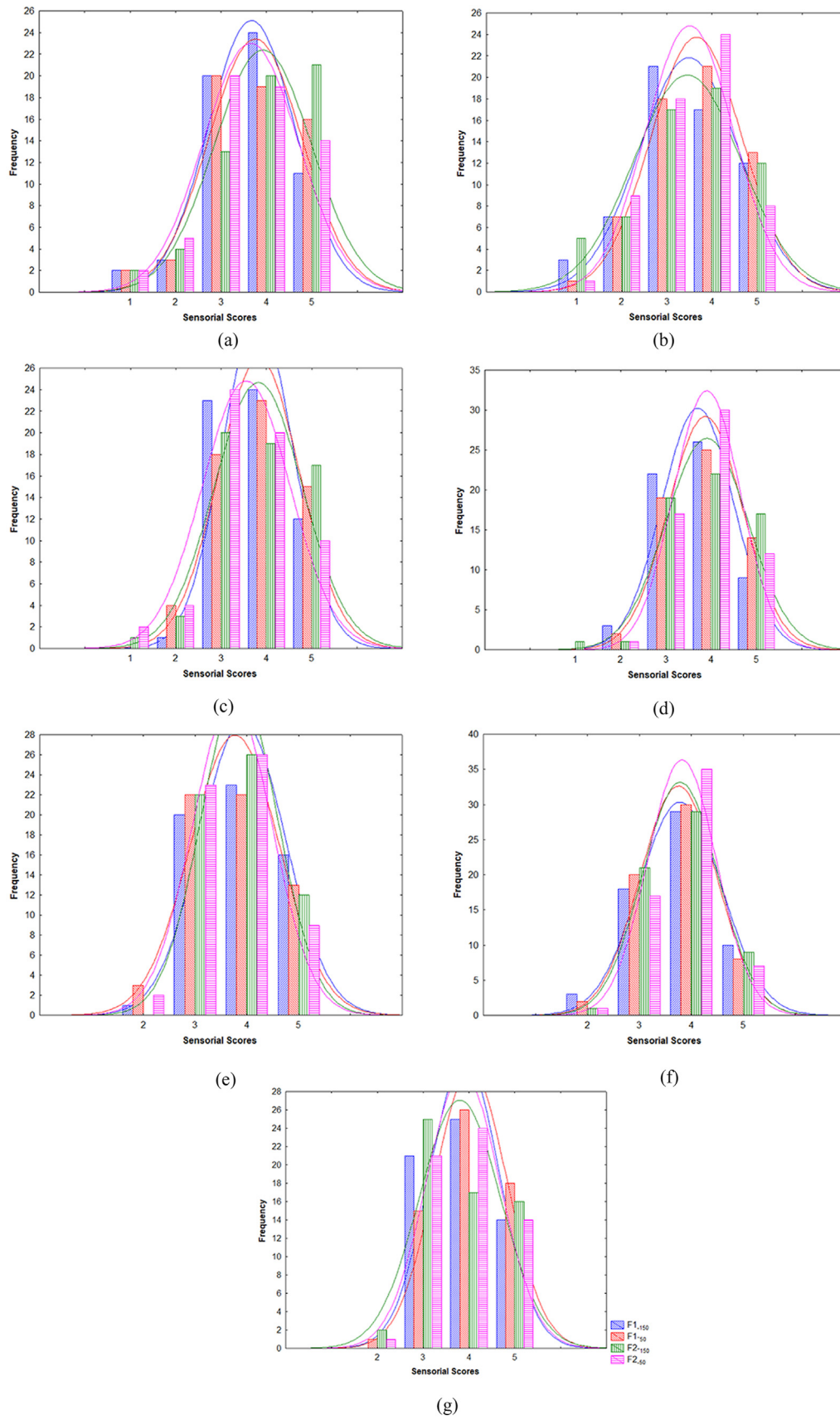
(a)

(b)

(c)

(d)

(e)

(f)

(g)

Figure 4. Frequency distribution of purchase intention during the frozen-storage period: (a) 0, (b) 1, (c) 2, (d) 3, (e) 4, (f) 5 e (g) 6, in months.

conclude that this product would be consumed regularly, demonstrating its full commercial potential. It is suggested for future researches the use of cassava starch mass for the preparation of ready-to-eat frozen meals without gluten. This suggestion is due to the results obtained in this study and the scarcity of products in this segment for celiacs.

Declarations

Author contribution statement

Agdylannah Vieira: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Amanda Silva, Thais Rodrigues, Layanne Silva: Performed the experiments.

Aline Albuquerque, Renata Almeida: Performed the experiments; Analyzed and interpreted the data.

Maria Duarte, Mario Cavalcanti-Mata: Contributed reagents, materials, analysis tools or data.

Ana Rocha: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data associated with this study has been deposited at UFCG Library System at the link http://dspace.sti.ufcg.edu.br:8080/jspui/handle/riufcg/12660.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

American Association of Cereal Chemists, 2000. Approved Methods, 10° ed. AACC, St.Paul.

APHA – American Public Health Association, 2001. Compendium of Methods for the Microbiological Examination of Foods. Washington, DC.

Association of Official Analytical Chemists – AOAC, 2012. Official Methods of Analysis of the Association of Official Analytical Chemist (18° Ed). Washington, D.C.

Atwater, W.O., Woods, C.D., 1896. The Chemical Composition of American Food Materials (28° Ed). Washington.

Bligh, E.G., Dyer, W.J., 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Physiol. 37, 911–917.

Brasil, M. da S., 2001. Resolução RDC n° 12 de 02 de janeiro de 2001 da Agência Nacional de Vigilância Sanitária–ANVISA. Regulamento técnico sobre padrões microbiológicos para alimentos, p. 37 (Diário Oficial da União).

Cappa, C., Franchi, R., Bogo, V., Lucisano, M., 2017. Cooking behavior of frozen gluten-free potato-based pasta (gnocchi) obtained through turbo cooking technology. LWT 84, 464–470.

Cereda, M.P., 2001. Propriedades Gerais Do Amido, 1. Fundação Cargill, Campinas.

Ciccoritti, R., Nocente, F., Sgrulletta, D., Gazza, L., 2019. Cooking quality, biochemical and technological characteristics of bran-enriched pasta obtained by a novel pasta-making process. LWT 101, 10–16.

Cornicelli, M., Saba, M., Machello, N., Silano, M., Neuhold, S., 2018. Nutritional composition of gluten-free food versus regular food sold in the Italian market. Dig. Liver Dis. 50 (12), 1305–1308.

Das, A.B., Bhattacharya, S., 2019. Characterization of the batter and gluten-free cake from extruded red rice flour. LWT 102, 197–204.

Demirkesen, I., Sumnu, G., Sahin, S., 2013. Quality of gluten-free bread formulations baked in different ovens. Food Bioprocess Technol. 6 (3), 746–753.

Dutcosky, S.D., 2011. Análise sensorial de alimentos (3o ed). Curitiba: Editora Universitária Champagnat.

Feng, W., Ma, S., Wang, X., 2020. Quality deterioration and improvement of wheat gluten protein in frozen dough. Grain Oil Sci. Technol. S2590259820300042.

Fernandes, R.O.C., Silva, G.T., Candido, C.J., Arakaki, G., Bogo, D., Hiane, P.A., Guimarães, de C.A., 2017. Development of cassava-based pasta (MANIHOT ESCULENTA CRANZ): physico-chemical, microbiological and sensory evaluation. Int. J. Dev. Res. 7, 5.

Ferreira, M.S.L., Mangavel, C., Rogniaux, H., Bonicel, J., Samson, M.-F., Morel, M.-H., 2014. A MALDI-TOF based study of the in-vivo assembly of glutenin polymers of durum wheat. Food Res. Int. 63, 89–99.

Fiorda, F.A., Soares, M.S., da Silva, F.A., Grosmann, M.V.E., Souto, L.R.F., 2013. Microestructure, texture and colour of gluten-free pasta made with amaranth flour, cassava starch and cassava bagasse. LWT - Food Sci. Technol. 54 (1), 132–138.

Fischer, P., Pollard, M., Erni, P., Marti, I., Padar, S., 2009. Rheological approaches to food systems. Compt. Rendus Phys. 10 (8), 740–750.

Fogagnoli, G., Seravalli, E.A.G., 2014. Aplicação de farinha de casca de maracujá em massa alimentícia fresca. Braz. J. Food Technol. 17 (3), 204–212.

Fuad, T., Prabhasankar, P., 2010. Role of ingredients in pasta product quality: a review on recent developments. Crit. Rev. Food Sci. Nutr. 50 (8), 787–798.

Giménez, M.A., Gámbaro, A., Miraballes, M., Roascio, A., Amarillo, M., Sammán, N., Lobo, M., 2015. Sensory evaluation and acceptability of gluten-free Andean corn spaghetti: sensory evaluation and acceptability of gluten-free Andean corn spaghetti. J. Sci. Food Agric. 95 (1), 186–192.

Giménez-Bastida, J.A., Piskuła, M., Zieliński, H., 2015. Recent advances in development of gluten-free buckwheat products. Trends Food Sci. Technol. 44 (1), 58–65.

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

Gusmão, T.A.S., de Gusmão, R.P., Moura, H.V., Silva, H.A., Cavalcanti-Mata, M.E.R.M., Duarte, M.E.M., 2019. Production of prebiotic gluten-free bread with red rice flour and different microbial transglutaminase concentrations: modeling, sensory and multivariate data analysis. J. Food Sci. Technol. 56 (6), 2949–2958.

Hera, E. de la, Martinez, M., Gómez, M., 2013. Influence of flour particle size on quality of gluten-free rice bread. LWT - Food Sci. Technol. 54 (1), 199–206.

Jia, R., Jiang, Q., Kanda, M., Tokiwa, J., Nakazawa, N., Osako, K., Okazaki, E., 2019. Effects of heating processes on changes in ice crystal formation, water holding capacity, and physical properties of surimi gels during frozen storage. Food Hydrocolloids 90, 254–265.

Kondakci, T., Zhang, J.W., Zhou, W., 2015. Impact of flour protein content and freezing conditions on the quality of frozen dough and corresponding steamed bread. Food Bioprocess Technol. 8 (9), 1877–1889.

Koteswara Reddy, C., Kimi, L., Haripriya, S., 2016. Variety difference in molecular structure, physico-chemical and thermal properties of starches from pigmented rice. Int. J. Food Eng. 12 (6), 557–565.

Larrosa, V., Lorenzo, G., Zaritzky, N., Califano, A., 2016. Improvement of the texture and quality of cooked gluten-free pasta. LWT - Food Sci. Technol. 70, 96–103.

Liu, Q., Guo, X.-N., Zhu, K.-X., 2019. Effects of frozen storage on the quality characteristics of frozen cooked noodles. Food Chem. 283, 522–529.

Makdoud, S., Rosentrater, K.A., 2017. Development and testing of gluten-free pasta based on rice, quinoa and amaranth flours. J. Food Res. 6 (4), 91.

Mathias, T.R., dos, S., Andrade, K.C.S., Rosa, C.L. da S., Silva, B.A., 2013. Avaliação do comportamento reológico de diferentes iogurtes comerciais. Braz. J. Food Technol. 16 (1), 12–20.

Meyer, J.P., Adio, S.A., Sharifpur, M., Nwosu, P.N., 2016. The viscosity of nanofluids: a review of the theoretical, empirical, and numerical models. Heat Tran. Eng. 37 (5), 387–421.

Mezaize, S., Chevallier, S., Le-Bail, A., de Lamballerie, M., 2010. Gluten-free frozen dough: influence of freezing on dough rheological properties and bread quality. Food Res. Int. 43 (8), 2186–2192.

Milde, L.B., Chade, M.E., Silva, C.G., Zubreski, E.R., 2017. Premezcla de fécula de mandioca para pastas. Características químicas y vida útil en anaquel. 5.

Mitschka, P., 1982. Simple conversion of Brookfield R.V.T. readings into viscosity functions. Rheol. Acta 21 (2), 207–209.

Olivera, D.F., Salvadori, V.O., 2009. Effect of freezing rate in textural and rheological characteristics of frozen cooked organic pasta. J. Food Eng. 90 (2), 271–276.

Olivera, D.F., Salvadori, V.O., 2011. Instrumental and sensory evaluation of cooked pasta during frozen storage: instrumental and sensory evaluation of frozen cooked pasta. Int. J. Food Sci. Technol. 46 (7), 1445–1454.

Quek, S.Y., Chok, N.K., Swedlund, P., 2007. The physicochemical properties of spray-dried watermelon powders. Chem. Eng. Process: Process Intensification 46 (5), 386–392.

Resta, M.S.A., de Oliveira, T.C.R.M., 2013. Avaliação do padrão estafilococos coagulase positiva estabelecido pela legislação brasileira para massas alimentícias. Braz. J. Food Technol. 16 (4), 319–325.

Ribeiro, T.H.S., Bolanho, B.C., Montanuci, F.D., Ruiz, S.P., 2018. Physicochemical and sensory characterization of gluten-free fresh pasta with addition of passion fruit peel flour. Ciência Rural. 48 (12).

Shittu, T.A., Dixon, A., Awonorin, S.O., Sanni, L.O., Maziya-Dixon, B., 2008. Bread from composite cassava–wheat flour. II: effect of cassava genotype and nitrogen fertilizer on bread quality. Food Res. Int. 41 (6), 569–578.

Silva, G.A.S., et al., 2013. Utilização do amido da amêndoa da manga Tommy Atkins como espessante em bebida láctea. Revista Brasileira de Engenharia Agrícola e Ambiental 17 (12), 1326–1332.

Silva, L. M. M. da, dos Santos, A.R.L., Silva, C.N., da Sousa, J. A. R. de, Arguello, V.M., 2015. Estudo do comportamento reológico da polpa E da geléia de UMBU(spondias tuberosa arr). Revista Brasileira de Produtos Agroindustriais 10.

Silva, N.A.B., da Silva, J.C., Silva, S.L., dos, R., Gonçalves, A.C.A., Silva, W. A. da, Pires, C.V., Trombete, F.M., 2019. Desenvolvimento e avaliação sensorial de massa de pizza sem glúten, fonte de fibras e adicionada de psyllium. Caderno de Ciências Agrárias 11, 1–8.

Silva, M.L.T., Brinques, G.B., Gurak, P.D., 2019. Utilização de farinha de subproduto de brotos para elaboração de massa alimentícia fresca. Braz. J. Food Technol. 22, e2018063.

Silva, P.R.A., Damy-Benedetti, P.c., 2018. Desenvolvimento E aceitação de bolinho integral de aveia com recheio de brigadeiro de açaí. Rev. Científica (Maracaibo) 1 (1), 1–9.

Simonato, B., Curioni, A., Pasini, G., 2015. Digestibility of pasta made with three wheat types: a preliminary study. Food Chem. 174, 219–225.

Vieira, A., Almeida, R., Santos, R., Gusmão, T., Albuquerque, A., Silva, L., Rocha, A., 2020. Preparation of gluten-free frozen lasagnas with different sauces, 164(7), 20.

Volpato, A.A., Ruiz, S.P., Pagamunici, L.M., 2013. Desenvolvimento de massa alimentícia fresca com adição fécula de mandioca e farinha de quinoa Development of fresh food nutritious functional adding wheatmeal of manioc and quinoa.

Wang, C.C., Whitehead, L., Bayes, S., 2017. Global mobility in nursing: why Chinese students leave to study nursing in Australia. J. Nurs. Educ. Pract. 7 (11), 51.

Yu, W., Xu, D., Zhang, H., Guo, L., Hong, T., Zhang, W., Xu, X., 2020. Effect of pigskin gelatin on baking, structural and thermal properties of frozen dough: comprehensive studies on alteration of gluten network. Food Hydrocolloids 102, 105591.