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FOOD TECHNOLOGY

Physicochemical and technological characteristics of arrowroot flour modified by ultrasound and low-temperature heat treatment

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ABSTRACT: *Arrowroot is a plant abundant in starch content, and because it does not possess gluten proteins in its composition, its utilization is of great interest in the production of food for people who are intolerant to these proteins. The substitution of gluten involves the use of thickening agents, such as pre-gelatinized starches or flours, which can be obtained by physical processes. In this context, the aim of this study was to evaluate the physicochemical and technological characteristics of arrowroot flour (AF_U) modified by ultrasound, in the functioning of intensity and time, and modified by low humidity heat treatment (LHHT) as a function of temperature and time. Besides characterizing AF_U and AF_{LHHT}, we aimed their future application in products without gluten. All independent variables affected ($P<0.05$) water absorption index (WAI) and water solubility index (WSI) at 28 °C; WSI was at 80 °C, peak viscosity, final viscosity, setback and enthalpy of gelatinization (ΔH). The selected AF_U was processed in 15 min at an ultrasound intensity of 43.5%, while AF_{LHHT} was at 105 °C for 15 min. Neither of them presented significant differences in relation to their proximal composition. It is concluded that the modification of AF by both methods is feasible, and it is possible to predict its use in the formulation of foods without gluten, due to their physicochemical and technological characteristics which are more appropriate than those of AF.*
Key words: *Maranta arundinacea L.,hydration, RVA, DSC, dietary total fiber.*

Características físico-químicas e tecnológicas da farinha de araruta modificada por ultrassom e por tratamento térmico de baixa umidade

RESUMO: *A araruta é uma planta que apresenta conteúdo abundante de amido, e por não apresentar as proteínas do glúten em sua composição desperta o interesse da sua utilização na produção de alimentos para pessoas intolerantes a essas proteínas. A substituição do glúten envolve a utilização de agentes espessantes, como amidos ou farinhas pré-gelatinizados, que podem ser obtidos por meio de processos físicos. Neste contexto, o objetivo deste estudo foi avaliar as características físico-químicas e tecnológicas da farinha de araruta (FA), FA modificada por ultrassom (FA_U) em função da intensidade e tempo, e FA modificada por tratamento térmico de baixa umidade (FA_{TTBU}) em função da temperatura e tempo, além de caracterizar FA_U e FA_{TTBU} selecionadas, visando sua futura aplicação em produtos sem glúten. Todas as variáveis independentes afetaram ($P<0.05$):* índice de absorção de água (IAA) e o índice de solubilidade em água (ISA) a 28 *°C, ISA a 80 °C, viscosidade de pico, viscosidade final, tendência a retrogradação e entalpia de gelatinização (ΔH). A FA_U selecionada foi processada em 15 min em intensidade do ultrassom de 43,5%, enquanto FA_{TTBU} a 105 °C por 15 min. Ambas não apresentaram diferenças significativas em relação à composição proximal. A modificação da FA tanto por ultrassom como por tratamento térmico com baixa umidade é viável, e é possível prever a sua utilização na formulação de alimentos sem glúten, devido as suas características físico-químicas serem mais apropriadas que a da FA.*
Palavras-chave: *Maranta arundinacea L., hidratação, RVA, DSC, fibra alimentar total.*

INTRODUCTION

Arrowroot (*Maranta arundinacea* L.) of the family *Marantaceae*, is a perennial plant. It is cultivated for its edible rhizomes in all the tropical countries of the world (ODEKU, 2013). Arrowroot rhizome contains abundant amounts of starch, in addition to non-starch polysaccharides, sugars, protein, lipids and inorganic material (KUMALASARI et al., 2012). Arrowroot by products do not contain gluten proteins, being suitable for the diet of individuals with food intolerance to these proteins, being able to substitute this for wheat flour (LIM, 2016). According to APRIANITA et al. (2014), arrowroot flour has 62.3 g 100 $g^{-1}$of starch in its composition, being able to modify it to obtain pre-gelatinized flour, which is a product that can be used for the production of gluten-free foods (MARTI et al., 2013).

The native starch structure, present in starchy flours, can be modified by physical, chemical, enzymatic or genetic methods. Among the possible physical modifications are those resulting from the use of ultrasound and the low humidity heat treatment (LHHT). Ultrasound can promote changes in swelling power, solubility and pulp properties (BERNARDO et al., 2016). Furthermore, LHHT can promote changes

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in viscosity, pulp stability, heat resistance, acids and mechanical deformation (CHUNG et al., 2009).

In this context, the objective of this study was to evaluate the physicochemical and technological characteristics of AF_U modified by ultrasound as a function of intensity and time, and modified by LHHT as a function of temperature and time, in addition to selecting those with characteristics more suitable for application in pasta and baked foods without using gluten.

MATERIALS AND METHODS

Preparation of AF

Arrowroot of the common variety used in the experiment was planted in organic soil and harvested in July 2017 at Nossa Senhora Aparecida Farm, in Hidrolândia City, Goiás State (latitude 16,965475 South, longitude 49,184229 West and altitude 787m). The rhizomes were washed and sanitized with sodium hypochlorite solution of200 mg 100 g^{-1},peeled manually, cut into transverse slices (50 mm thick), and immediately placed in sodium metabisulfite solution (0.2 g 100 g^{-1}). Slices were dried in a stove with forced air circulation (Tecnal, TE-393/1, Piracicaba, Brazil), under a temperature of 40 °C for 48 h, ground in a knife mill (Tecnal, TE65I/2, Piracicaba, Brazil), with a 0.6 mm diameter sieve. Arrowroot flour was packed in low-density polyethylene bags (LDPE) and stored at -13 °C ± 1 °C.

Yield, starch content and particle size of AF

The yield of AF was calculated according to the relationship between initial weight of the rhizome and the weight of the final product performed in three original replicates. Determination of the starch content was performed using the Lane-Eynon method, using Fehling's reagent, according to the methodology 043/IV proposed by the Adolfo Lutz Institute (IAL, 2008). Particle size was determined using a sieve vibrator (Bertel, 4819, Caieiras, Brazil), according to the methodology proposed by the Association of Official Analytical Chemistry (AOAC, 2012).

Modification of AF by ultrasound

Ultrasound modification of the AF was performed through a central compound rotational design (CCRD) (Table 1). Independent variables were the intensity of the equipment (25-99%) and time of exposure to the ultrasonic waves (5-25min). Concentration of AF was fixed in function of other studies with other starches (corn and marsh lily).We weighed 14.4 g of AF and 105.6 g of distilled water in a glass beaker. Mixture was homogenized and brought to low-frequency ultrasound (Eco-sonics, QR500, Indaiatuba, Brazil) with20 KHz, 500W potency and titanium tip macro (13 mmdiameter). After ultrasonic treatment, samples were oven dried in a stove with forced air circulation at a temperature of 30 °C for 12 h, and milled with knife blades with 0.6 mm diameter sieves. Ultrasound-modified AF was packed in LDPE bags, and stored at -13 °C ± 1 °C.

Modification of AF by low moisture heat treatment

Modification of the AF by low moisture heat treatment (LMHT) was performed according to a methodology proposed by ABRAHAM (1993), with adaptations. The moisture content of the flour was adjusted to 20 g 100 g^{-1} and the amount of water added was determined by the ratio of initial moisture, desired moisture and sample weight. A completely randomized design was used, with factorial arrangement 2×3 (105 °C and 120°C; 15, 30 and 60 min), totaling six treatments (T_1: 105 °C/15 min; T_2: 105 °C/30 min; T_3: 105 °C/60 min; T_4: 120 °C/15 min; T_5: 120 °C/30 min; T_6: 120 °C/60 min), and four original replicates. Samples were placed in a vertical autoclave and heated at the temperatures and times defined in the design. The samples were then placed in a stove with an air circulation oven and dried at 40 °C for 8 h, and then triturated as previously described for the other flours. The AF_{LMHT} was packed in LDPE bags, and stored at -13 °C ± 1 °C.

Thermal and physicochemical properties of AF, AF_U and AF_{LMHT}

Water absorption index (WAI) and water solubility index (WSI) were determined according to the methodology of ANDERSON et al. (1969), with adaptations. Samples of 2 g were weighed into previously tared centrifuge tubes and added with 30 mL of distilled water. Tubes were shaken in a water bath for 30 min at 28 °C and 80 °C, and centrifuged at 5.300 ×G for 10 min. The supernatant was carefully removed with the aid of a 10 mL volumetric pipette and placed in a Petri dish, maintained in an oven with air circulation at 65 °C for 6 h. The WAI value was calculated by the ratio between the weight of the precipitate (WP) and the weight of the sample (WS), on a dry basis (Equation 1), and the result was expressed in g of precipitate per g of dry matter. The WSI was calculated by the ratio between the mass of the dry residue (MDR) of the supernatant and the WS, on a dry basis (Equation 2), and the result was expressed as a percentage.

Table 1 - Rotational composite central planning with coded and real values for applied intensity: X_1 (%) and time of exposure to ultrasonic waves: X_2 (min), with 11 experiments, 3 repetitions at the central point.

Experiment	----------Coded variable----------		----------Real variable----------	
	X_1	X_2	X_1	X_2
1	-1	-1	35.83	7.93
2	+1	-1	88.16	7.93
3	-1	+1	35.83	22.07
4	+1	+1	88.16	22.07
5	-1.414	0	25.00	15
6	+1.414	0	99.00	15
7	0	-1.414	62.00	5
8	0	+1.414	62.00	25
9	0	0	62.00	15
10	0	0	62.00	15
11	0	0	62.00	15

$$WAI = \frac{WP}{ws} \quad \text{Equation (1)}$$

$$WSI = \left\{\left[\frac{MRD}{WS}\right] 3\right\} 100 \quad \text{Equation (2)}$$

The viscoamilographic profile of the treatments was determined according to the methodology 61.02.01 of the American Association of Cereal Chemists (AACC, 2012), using the rapid visco analyzer (RVA) (Perten, RVA 4500, Huddinge, Sweden). Parameters of peak viscosity (PV); breakdown (BD); final viscosity (FV) and setback (SB) were calculated by computer software coupled to the RVA system.

Thermal behavior of the samples was analyzed by differential scanning calorimetry with a calorimeter (TA Instruments, *Q20,* New Castle, UK), according to the methodology described by WEBER et al. (2009), the initial gelatinization temperature (T_i),peak gelatinization temperature (T_p); final gelatinization temperature (T_f),and enthalpy of gelatinization (ΔH_{gel}) being determined. The computer software Statistica 7.0 (Statsoft, Statistica 7.0, Tulsa, USA), was used to analyze the physicochemical and technological data obtained.

Selection of AF_U e AF_{LMHT} and comparison with the physical and chemical characteristics of AF

In order to select theAF_U, the desirability test was performed (BARROS NETO et al., 2001), while Tukey's test ($p<0.05$) was applied to compare the means obtained by the AF_{TTBU}. Selection of both modified AFs was based on physicochemical properties considered to be most suitable for improving yield and quality after baking of foods and bread products.

In order to compare physical and physicochemical characteristics of the flours selected from each heat treatment with those of AF, a new experiment was carried out using a completely randomized design, with three treatments and three original replicates. Analyses of WAI, WSI, paste and thermal properties were performed as previously described, while those related to proximal composition and total dietary fiber were performed according to the AOAC (2012), and the results expressed in g·100 g^{-1}. Total carbohydrate content was calculated by difference, the water activity used a digital electronic hygrometer (Aqua-Lab, CX-2-T, Jarinu, Brazil) at a constant temperature of 25 °C. Determination of the hydrogen ion potential (pH) was performed using a digital potentiometer (Tecnal, TEC-51, Piracicaba, Brazil), according to the methodology proposed by the AOAC (2012). The instrumental parameters of color were determined in a colorimeter (Bankinh Meter Minolta, BC-10, Ramsey, USA):luminosity (L^*), and chromaticity coordinates a^* and b^*.The values of a^* and b^* were used to calculate chroma (C^*) and hue angles (H°), using (Equations 3 and 4), respectively. All analyses were performed in triplicate.

$$C* = \sqrt{(a^{*2} + b^{*2})} \quad \text{Equation (3)}$$

$$H° = \text{arc tg}\left(\frac{b^*}{a^*}\right) \quad \text{Equation (4)}$$

RESULTS AND DISCUSSIONS

Yield, starch content and particle size of AF

The AF presented a yield of 33.68%, higher than the value reported by APRIANITA et al. (2014) of 32%. Starch content determined for AF was 53.61 g $100g^{-1}$, lower than the value obtained by APRIANITA et al. (2014) of 62.30 g·100 g^{-1}. Differences reported for both AF yield and

starch content can be explained due to differences between edaphoclimatic, cultural management and flour processing methods. From the granulometric analysis of AF, it was observed that 85.48% of the same was retained in the sieve with a mesh 0.50 mm in diameter, evidencing a relatively homogenous particle distribution. According to CARVALHO et al. (2012), it is desirable that the particles be uniform in size and density since this parameter can significantly affect the water absorption, texture and uniformity of the final product.

AF modified by ultrasound

All adjusted regression models were significant with a level of significance ranging from 0.003 to 0.048, and explained from 82% to 99% of responses. The models for WAI at 28 °C, WSI at 28 °C and WSI at 80 °C were, respectively: $y = 6.82 + 0.28X_1 - 1.10X_1^2 + 0.53X_2 - 0.99X_2^2$; $y = 23.07 - 3.95X_1^2 - 5.12X_2^2$; $y = 35.30 + 5.29X_1 - 5.97X_1^2 + 5.89X_2 - 5.64X_2^2 + 3.35X_1X_2$, where X_1 is the irradiation intensity (%) and X_2 is the irradiation time (min). Ultrasound modification provided increases relative to WAI and WSI at 28 °C and WAI at 80 °C of AF (3.23 g gel dry matter^{-1}, 6.99 g gel dry matter^{-1}, 12.51 g 100 g^{-1}, respectively) (Figure 1).

The highest WAI values at 28 °C and WSI at 28 °C were observed at intermediate intensity and time conditions (Figure 1A and B), in the areas of the graphs close to 62% ultrasound intensity and 15 min irradiation time, while those with higher WSI at 80 ºC in the areas around 88% intensity and 22 min (Figure 1C). The WSI increase was directly proportional to the increase in temperature (Figure 1B and C). The higher WAI and WSI indices at 28 °C were probably due to partial pre-gelatinization of the starch granules resulting from the physical process of modification under intermediate conditions; whereas, more drastic conditions tend to further destroy the granules and form smaller molecules, which favors the elevation of WSI at 80 °C. For CLERICI & EL-DASH (2008), the partial pre-gelatinization confers to the starch characteristics of greater absorption, solubility in water and gel formation in cold water. The application of pre-gelatinized starches in pasta contributes to the quality of the final product, which has a more homogenous mass and better texture after cooking (SCHMIELE et al., 2013).

The models for PV, BD, FV and SB were, respectively: $y = 154.96 - 423.91X_1 + 420.78X_1^2 - 521.82X_2 + 380.02X_2^2$; $y = 4.38 - 159.23X_1 + 184.58X_1^2 - 294.95X_2 + 193.71X_2^2$; $y = 230.97 - 386.12X_1 + 348.49X_1^2 - 360.10X_2 + 269.10X_2^2$; e $y = 80.33 - 121.44X_1 + 112.29X_1^2 - 133.23X_2 + 82.78X_2^2$. The lowest PV values were obtained in the experiments that used time of exposure to sound waves between 16 and 22 min, and intensity between 70 and 80% (Figure 2A). In order that pasta products have a better quality of cooking, the starch must be pre-gelatinized, which implies according to CAPERUTO et al. (2001), in lower PV of the pre-gelatinized flour in relation to the PV of the raw flour.

The lowest BD values were obtained with intensity of 68-86% and irradiation time between 18 and 23 min (Figure 2B). The BD, for evaluating the stability of the starch when subjected to mechanical agitation at high temperatures, is an important parameter for the preparation of precooked products, since it indicates the ability of the food to maintain its integrity when cooked (TEBA et al., 2009).

The lowest SB values were reached when AF was submitted to ultrasound treatment with intensity between 70 and 80%, and duration between 18 and 22 min (Figure 2C), a result of the greater degradation of macromolecules, which reduced the viscosity peak, and tendency to retrograde. The lowest values of VF were observed when AF was irradiated with intensity between 64 and 88% in 16 to 22 min (Figure 2D). This reduction of VF and SB occurred due to a disintegration of these granules, promoted by the ultrasonic waves together with the heating during the treatment, and with its high viscosity gel formation capacity, which was reduced (ZHU, 2015).

The adjusted model for ΔH was significant ($y = 0.663 - 3.29X_1 + 3.31X_1^2 - 3.82X_2 + 3.11X_2^2$), while the models for Ti, Tp and TF were not significant. The lowest values of ΔH were reported in the treatments with intensity between 73 and 85%, and between 17 and 21 min (Figure 2E). The AF_U when submitted to treatments in these conditions presents lower energy expenditure in the gelatinization process. The variation of the gelatinization energy of the starch can be explained by the difference between the binding forces of the double helix, which results in different alignments of the hydrogen bonds within the starch molecules. When the double helix breaks, the gelatinization energy is reduced, and the crystalline structure is little affected (LUO et al., 2008).

AF modified by LMHT

The T_1 showed a higher WAI value at 28 °C ($p<0.05$), followed by T_4, and by the other treatments, which did not differ from each other (Table 2), indicating a higher water absorption of the AF_{LMHT} processed at a lower temperature and shorter time, followed by higher temperature and shorter time. As for WSI at 28 °C, T_2 and T_6 presented the

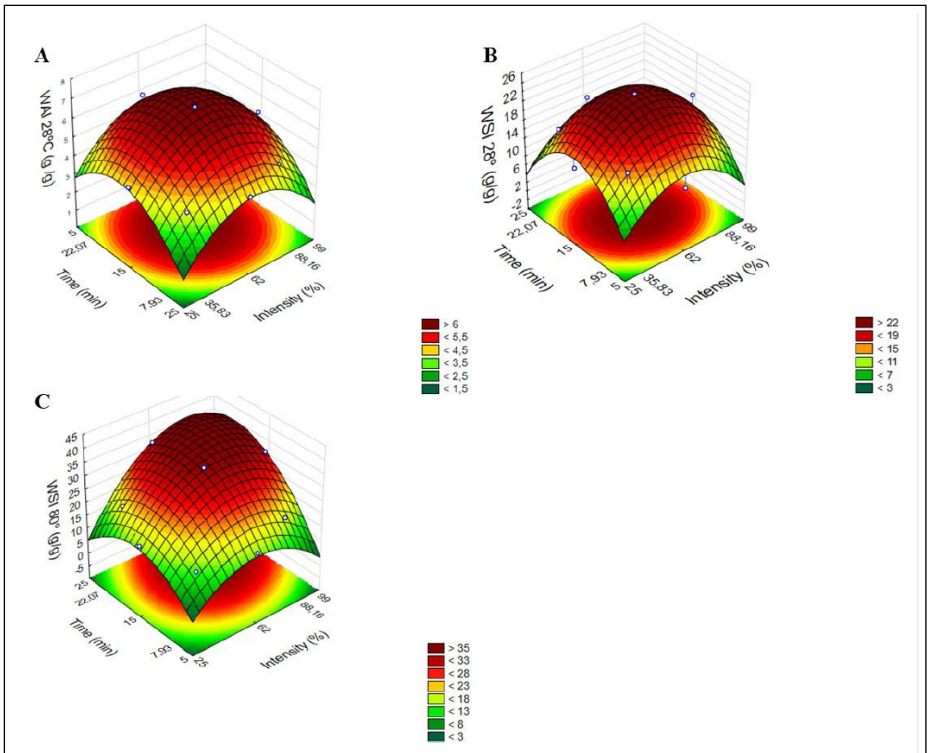

Figure 1 - Hydration properties of AF_U modified by ultrasound varying intensity (%) and time of exposure to the ultrasonic waves (min). A: Water absorption index [WAI 28 °C] (ggel / dry matter); B: Water solubility index [WSI 28ºC] ($g100g^{-1}$); and C: Water Solubility Index [WSI 80 °C] ($g100g^{-1}$).

highest values ($p<0.05$), while T_3, T_4 and T_5 presented the highest values. And for WSI at 80 °C T_1, T_2 T_3 and T_4 presented lower values than the other treatments ($p<0.05$). These values are also related to the pre-gelatinization intensity of the starch. Because all treatments had WAI and WSI values at 28 °C and WSI at 80 °C higher than those presented by AF. T_1 presented the highest water absorption at room temperature and the lowest solubility in hot water in relation to the other treatments, besides being able to form a gel in cold water. That, according to CLERICI & EL-DASH (2008) and SCHMIELE et al. (2013) are the characteristics necessary to obtain good quality pasta.

Values of PV, BD, FV and SB were significantly higher in T_1, due to the treatment being milder (low temperature and time). According to TEBA et al. (2009), a certain percentage of starch granules can conserve part of the starch structure, and present relatively high values of PV due to the existence of granules in a swelling condition when they do not undergo very severe heat treatments. Regarding BD, FV and SB, GOMEZ & AGUILERA (1983) stated that these viscoamilaceous properties are temperature dependent, reaching values usually high for treatments under low temperatures due to the amount of starch granules still available to be gelatinized.

The T_1 presented a significantly lower ΔH value than the other treatments, demonstrating that AF_{LMHT} when submitted to lower temperature and exposure time, presents a lower energy expenditure in the gelatinization process (Table 2). This result can be attributed to the fact that under higher heat treatment conditions and time in the autoclave, an increase in the content of resistant starch occurs, which, in turn, increases the energy required for gelatinization (POLESI & SARMENTO, 2011).

Selection of AF_U and AF_{LMHT}, and comparison with the physical and chemical characteristics of AF

The AF_U selected for future application in pasta and gluten-free baked goods was processed in 15 min at 43.5% ultrasound intensity (no experimental point evaluated) according to the desirability diagram, while, AF_{LMHT} was processed at 105 °C for 15 min (T_1).

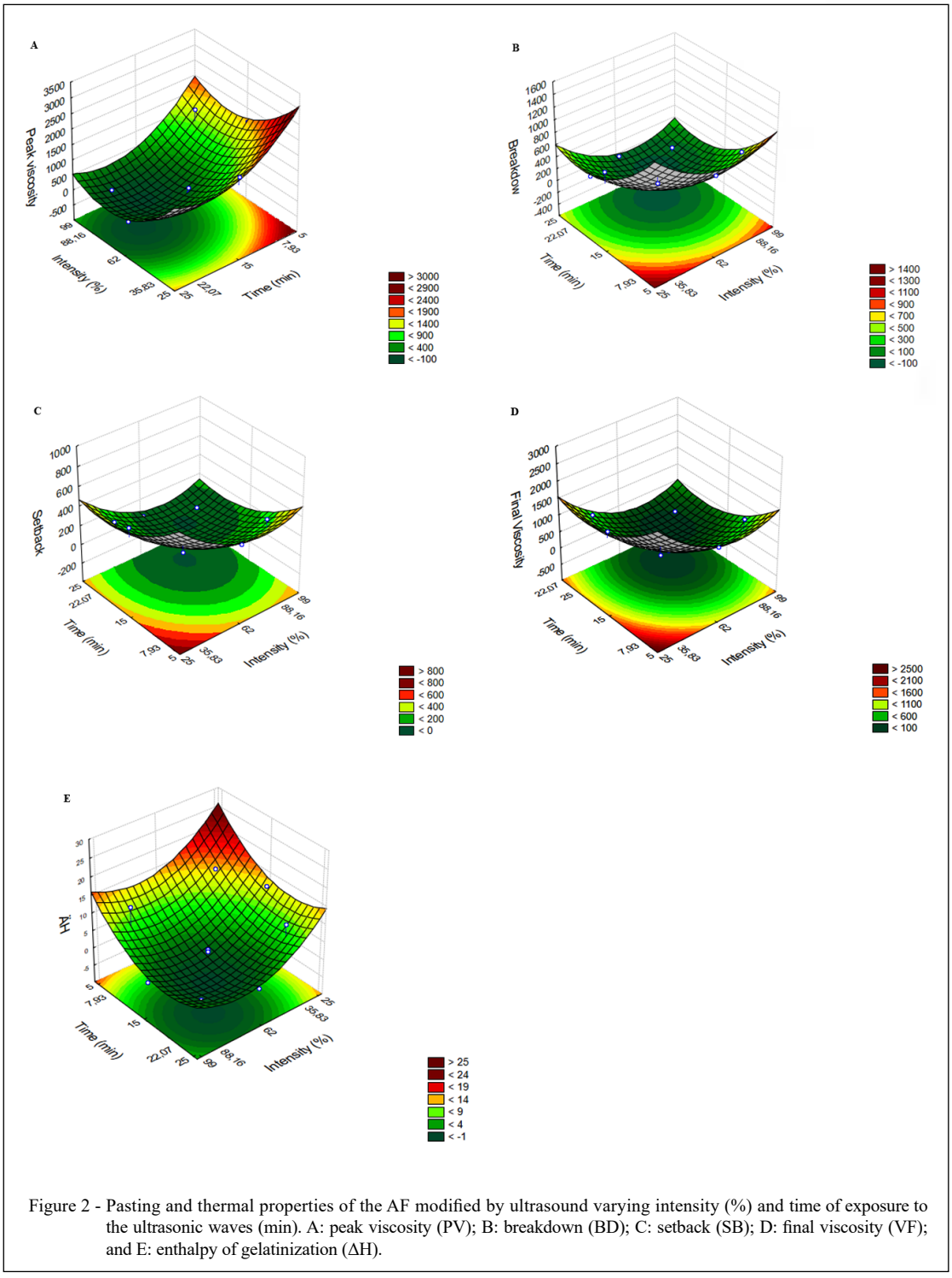

Figure 2 - Pasting and thermal properties of the AF modified by ultrasound varying intensity (%) and time of exposure to the ultrasonic waves (min). A: peak viscosity (PV); B: breakdown (BD); C: setback (SB); D: final viscosity (VF); and E: enthalpy of gelatinization (ΔH).

The WAI at 28 °C of FA presented a significantly lower value than the modified flours (Table 3). Native starch has a crystalline structure that limits the absorption and solubilization of the granules in water, so when in contact with the cold water, the starch granules swell slightly from 10 to 20% (DENARDIN & SILVA, 2009). The value of WAI is related to the availability of the hydrophilic groups in binding to the water molecules and to the gel-forming capacity of the starch molecules, thus,

Table 2 - Water absorption index, water solubility index at different temperatures (28 °C and 80 °C), peak viscosity, breakdown, final viscosity, setback and enthalpy of gelatinization (averages and standard deviations) and processing time (min) in AF modified by low-temperature heat treatment as a function of temperature (°C).

Parameter	T_1[1]	T_2	T_3	T_4	T_5	T_6
Water absorption index at 28 °C[2,3]	5.02^{a} ± 0.15	3.52^{c} ± 0.10	3.81^{c} ± 0.13	4.43^{b} ± 0.06	3.55^{c} ± 0.05	3.94^{c} ± 0.19
Water solubility index at 28 °C[4]	13.68^{bc} ± 0.33	15.34^{a} ± 0.28	12.30^{d} ± 0.32	12.82^{cd} ± 0.33	12.71^{cd} ± 0.59	14.41^{ab} ± 0.55
Water solubility index at 80 °C[4]	16.51^{b} ± 0.70	18.02^{b} ± 0.65	16.84^{b} ± 0.07	17.32^{b} ± 0.64	26.31^{a} ± 0.92	26.27^{a} ± 1.19
Peak viscosity[5]	568.00^{a} ± 1.41	217.50^{b} ± 7.78	60.50^{d} ±2.12	276.00^{c} ± 2.83	45.50^{e} ±0.71	42.00^{e} ±0.00
Breakdown[5]	172.00^{a} ± 2.83	17.00^{b} ± 0.83	4.00^{b} ±0.00	29.00^{b} ±0.00	3.00^{b} ±0.00	2.00^{b} ±0.03
Final viscosity[5]	495.00^{a} ± 11.0	286.00^{b} ± 5.66	85.50^{c} ± 3.79	337.00^{b} ± 1.41	64.00^{c} ± 1.41	59.50^{c} ± 2.12
Setback[5]	64.00^{c} ± 0.74	85.50^{b} ± 0.71	47.83^{d} ± 1.82	90.00^{a} ± 1.41	21.50^{e} ± 1.12	19.50^{e} ± 0.71
Enthalpy of gelatinization[6]	6.32^{c} ± 0.29	9.31^{a} ± 0.43	9.78^{a} ± 0.45	7.75^{b} ± 0.32	7.64^{b} ± 0.36	10.31^{a} ± 0.24

[1]Treatments :T_1: 105 °C/15 min; T_2: 105 °C/30 min; T_3: 105 °C/60 min; T_4: 120 °C/15 min; T_5: 120 °C/30 min; T_6: 120 °C/60 min; [2]averages followed by different letters in each column differ from each other by the Tukey test (P<0.05); [3]g gel 100 g^{-1}; [4] g 100 g^{-1}, [5]RVU; [6]cal g^{-1}.

high WAI values are due to a higher gelatinization, that is, a larger number of hydroxyls available to form hydrogen bonds with water (CARVALHO et al., 2012; CLERICI & EL-DASH, 2008). The AF_U was the one with the highest WAI in relation to the others. According to CLERICI & EL-DASH (2008), flours with higher WAIs are considered more desirable in the preparation of bakery products and pastas, since it is possible to add a larger volume of water in the production, improving handling of the mass and avoiding the drying of the product during storage.

Ultrasound modification increased the WSI of AF significantly relative to AF and FA_{LMHT} (Table 3). According to SINGH et al. (2003), sonification causes damage to the semicrystalline structure of the starch, leaving hydroxyl groups free to bind to water molecules

Table 3 - Water absorption index; water solubility index; peak viscosity; breakdown; final viscosity; setback; initial gelatinization temperature; peak gelatinization temperature; final gelatinization temperature and enthalpy of gelatinization (mean and standard deviation) of AF, selected AF_U and AF_{LMHT}.

Parameter	AF	AF_U	AF_{LMHT}
Water absorption index[2]	2.52^{c} ± 0.14	5.50^{a} ± 0.11	5.02^{b} ± 0.15
Water solubility index[3]	11.72^{c} ± 0.62	15.24^{a} ± 0.39	13.68^{b} ± 0.33
Peak viscosity[4]	1100.50^{a} ± 13.50	1127.00^{a} ± 2.83	568.00^{b} ± 1.41
Breakdown[4]	612.50^{a} ± 16.26	404.00^{b} ± 14.14	172.00^{c} ± 2.83
Final viscosity[4]	673.0^{b} ± 2.83	1063.50^{a} ± 19.09	605.00^{c} ± 1.41
Setback[4]	185.00^{b} ± 0.00	340.50^{a} ± 7.78	134.50^{c} ± 6.36
Initial gelatinization temperature[4]	65.61^{b} ± 1.33	65.74^{b} ± 1.17	73.39^{a} ± 0.05
Peak gelatinization temperature[5]	78.92^{b} ± 0.02	78.08^{c} ± 0.00	82.76^{a} ± 0.19
Final gelatinization temperature[5]	89.64^{a} ± 1.46	86.72^{b} ± 0.61	89.11^{ab} ± 0.75
Enthalpy of gelatinization[6]	11.96^{a} ± 0.55	6.13^{b} ± 0.130	6.32^{b} ± 0.35

[2]Averages followed by different letters in each column differ from each other by the Tukey test (P<0.05); [2]g gel 100 g^{-1} ;[3] g 100 g^{-1}, [4] RVU; [5]°C; [6] cal g^{-1}.

through hydrogen bonding. Since WSI is a parameter measuring starch degradation, increasing that index indicates an increase in the number of fragmented water-soluble molecules.

The PV of the FA did not differ from the FA_U (Table 3), possibly because the ultrasonic treatment had retained part of the starch structure of a certain percentage of starch granules. Nevertheless, both showed higher values than FA_{LMHT}, whose more drastic treatment may have further damaged the starch structure.

AF had a higher BD value ($P<0.05$), followed by AF_U and AF_{LMHT} (Table 3), which can be explained by the fact that AF had a greater ability to gelatinize than the others, which had already undergone partial gelatinization during their treatments higher in the AF_{LMHT} than in the AF_U. Thus, AF has greater stability. The BD is important for evaluating starch stability when subjected to high temperatures and mechanical agitation. This variable is directly related to the ability of the product to maintain its integrity during cooking (TEBA et al., 2009).

The AF_U showed significantly higher values of SB and FV in relation to AF and AF_{LMHT} (Table 3). The higher values of FV, according to AUGUSTO-RUIZ (2003) can be a positive factor, because flours with higher PV can be used in the preparation of products that require lower temperatures to be ready, as in the case of soups and instant desserts.

AF_U and AF_{LMHT} showed relatively lower enthalpy of gelatinization than AF, a positive factor, since flours and starches with a lower gelatinization temperature can provide easier cooking, so that time and heat are reduced in the cooking step (SNOW & O'DEA, 1981).

There was no significant difference in proximal composition, including total dietary fiber of AF, AF_U and AF_{LMHT} (Table 4). Moisture content of the samples ranged from 6.53 to 6.60 g $100g^{-1}$, according to RDC Resolution 263/2005, which limits the maximum humidity to 15 g $100g^{-1}$(BRASIL, 2005). The ash content of AF, AF_U and AF_{LMHT} ranged from 4.86 to 4.87 g $100g^{-1}$, higher than that reported by NASCIMENTO et al. (2015), which was 0.70 – 0.80 g $100g^{-1}$for AF. Values of lipids and proteins determined varied between 0.57 to 0.59 g $100g^{-1}$ and 6.14 to 6.19 g $100g^{-1}$, respectively, values higher than those reported by NASCIMENTO et al. (2015), 0.10 and 1.00 g $100g^{-1}$, respectively, but lower than the protein obtained by APRIANITA et al. (2014) in AF of 7.7 g $100g^{-1}$. Such divergences between results may be due to the type of genetic material or the differences in cultivation conditions. AF, AF_U and AF_{LMHT} presented high carbohydrate content, and about 65.5% of the carbohydrate content is represented by the starch.

The brightness (L^*) is a color parameter that can range from zero (black) to 100 (white), while the chromaticity coordinate a^* varies from green (-) to red (+) and b^* to yellow (+). The chroma (C^*) measures the intensity or brightness of the color, the greater the colors are alive, and the angle hue (H°)

Table 4 - Proximal composition, total dietary fiber, water activity, pH- and color-instrumental parameters (L^*, a^*, b^*, C^* and H°) (mean and standard deviation), raw AF, selected AF_U and AF_{LMHT}.

Parameter	AF	AF_U	AF_{LMHT}
Moisture[1,2,3]	$6.53^a \pm 0.13$	$6.60^a \pm 0.15$	$6.60^a \pm 0.21$
Ashes[1]	$4.87^a \pm 0.12$	$4.86^a \pm 0.09$	$4.89^a \pm 0.15$
Protein[1]	$6.14^a \pm 0.16$	$6.19^a \pm 0.06$	$6.16^a \pm 0.04$
Lipids[1]	$0.57^a \pm 0.02$	$0.59^a \pm 0.02$	$0.57^a \pm 0.02$
Carbohydrate[1]	$81.89^a \pm 0.34$	$81.76^a \pm 0.22$	$81.78^a \pm 0.28$
Total dietary fiber[1]	$3.67^a \pm 0.01$	$3.71^a \pm 0.01$	$3.70^a \pm 0.04$
Wateractivity	$0.345^a \pm 0.045$	$0.374^a \pm 0.017$	$0.386^a \pm 0.007$
pH	$6.67^a \pm 0.03$	$6.66^a \pm 0.02$	$6.63^a \pm 0.02$
Luminosity	$83.48^b \pm 0.22$	$85.22^a \pm 0.38$	$85.45^a \pm 0.33$
a*	$1.47^c \pm 0.10$	$1.90^b \pm 0.09$	$2.40^a \pm 0.06$
b*	$14.33^a \pm 0.54$	$12.95^b \pm 0.18$	$14.50^a \pm 0.21$
Chroma	$14.41^a \pm 0.54$	$13.09^b \pm 0.19$	$14.70^a \pm 0.20$
Hue angle	$84.37^a \pm 0.42$	$81.66^b \pm 0.29$	$80.60^c \pm 0.36$

[1]Averages followed by different letters in each column differ from each other by the Tukey test ($P<0.05$); [2] $g \cdot 100g^{-1}$; [3]wet basis.

refers to the hue of the color, and according to this parameter the red is in the area close to 0º and yellow at 90 °, green at 180 ° and blue at 270 ° (MORAIS et al., 2002). All flours had a high luminosity value, suggesting a tendency to whiteness (Table 4). AF_{LMHT} and AF_{U} presented higher values of the chromaticity coordinate a^* than AF; therefore, they have more reddish tones. All flours presented positive values of b^*, with tendency to yellowish coloration. The C^* values of all the flours were relatively low, characterizing flours with low brightness or low color intensity, while those of H° varied between 80, 60 and 84.37°, close to yellow; in other words, yellow to slightly orange. The conventional pasta presents yellow coloration, so it is important to pay attention to the ingredients that can confer the same color (PADALINO et al., 2013), such as raw or thermally modified sausage flour.

CONCLUSION

The intensity and time for AF_{U}, as well as temperature and time for AF_{LMHT}, affected ($P<0.05$) WAI and WSI at 28 °C, WSI at 80 °C, PV, FV, SB and ΔH. The AF_{U} selected was processed in 15 min at ultrasound intensity of 43.5%, while AF_{LMHT} at 105 °C for 15 min. Neither of them presented any significant differences in relation to the proximal composition. Modification of AF by both ultrasonic and low moisture heat treatment is feasible, and it is possible to predict its use in the formulation of pasta and baked goods without gluten because its physicochemical characteristics are more appropriate than those of crude FA.

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DECLARATION OF CONFLICTS OF INTERESTS

The authors declare no conflict of interests. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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