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Effect of extruded wheat flour and pre-gelatinized cassava starch on process and quality parameters of French-type bread elaborated from frozen dough

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ABSTRACT

This study aimed to verify the potential of extruded wheat flour (EWF) or pre-gelatinized cassava starch (PGS) to improve the process and the quality of French bread elaborated from frozen dough. Three formulations were prepared: 100% control wheat flour (CWF) and the other two formulations with 5% substitution of wheat flour by EWF or PGS. Frozen doughs were frozen stored for seven days and after this period they were thawed, fermented, baked and evaluated for physical, chemical and technological characteristics. Available glucose levels found for EWF (12 g/100 g), and PGS (11.7 g/100 g) in relation to CWF (7.1 g/100 g) showed higher sugar availability for yeasts at the initial stage of proofing, and may also have had a cryoprotective effect when freezing bread doughs. The frozen doughs with EWF or PGS, when thawed and fermented, presented higher volume increase, but after baking, they presented lower volume when compared to the control bread. The results of this study are promising for the use of extruded wheat flour or pre-gelatinized cassava starch as sugar providers for doughs' post-freezing proofing process, improving frozen dough process of French-type bread.

1. Introduction

French bread is the most consumed type of bread in Brazil. It has a short shelf life due to loss of crispness of its crust and gain of firmness of its crumb. It must be consumed immediately or only a few hours after baking. Freshly baked bread has some drawbacks, such as the high cost of production and the presence of a full-time baker in the bakeries during the 7 days of the week, including at night. In order to solve this problem, several alternatives have been tested, such as frozen dough technology, which allows bakeries and consumers to obtain fresh bread at any time of the day, requiring only thawing, proofing and baking of frozen doughs before consumption (Asghar, Anjum, Allen, Daubert, & Rasool, 2009; Fik & Surówka, 2002; Keeratipibul et al., 2010).

This technology allows the production to be centralized, improving standardization and quality control of the final product (Yi, Johnson, & Kerr, 2009), although there are some challenges, such as maintenance of the cold chain, yeast preservation and quality characteristics of breads. When compared with breads produced by the conventional method, breads elaborated from frozen dough have lower volumes, greater crumb firmness and higher staling rates; crumb with thick cell walls (they have large pores with a non-uniform distribution), thick crust with a rough surface, and the possibility of the presence of spots and poor surface cut height. Moreover, problems in processing appear, such as an increase of proofing time (Decock & Cappelle, 2005; Gutkoski, Brehm, Santos, & Mezzomo, 2005; Rosell & Goméz, 2007).

Research on the effect of dough freezing on the final quality of bread has shown that the volume of the baked product is influenced by the physical damage to the gluten network, due to the formation of ice crystals during freezing and by the decrease in yeast cell viability after thawing, which must guarantee carbon dioxide production during proofing (Almeida & Chang, 2014; Havet, Mankai, & Le Bail, 2000; Minervini, Pinto, Cagno, Angelis, & Gobbetti, 2011; Yi et al., 2009).

The inclusion of ingredients, additives and/or technological aids in the formulations can help to reduce problems associated with dough freezing (Selomulyo & Zhou, 2007). However, few studies have considered the incorporation of ingredients to improve the survival of yeast and, consequently, their fermentative capacity after thawing (Huang,

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List of abbreviations

Raw material
CWF control wheat flour
EWF extruded wheat flour
PGS pre-gelatinized cassava starch
BEW blend constituted by 95% wheat flour + 5% extruded wheat flour
BPG blend constituted by 95% wheat flour + 5% pre-gelatinized cassava starch

Frozen dough of French-type bread
WFD frozen bread dough constituted only by wheat flour
EWD frozen bread dough constituted by 95% wheat flour + 5% extruded wheat flour
PGD frozen bread dough constituted by 95% wheat flour + 5% pre-gelatinized cassava starch

French-type bread
WFB French bread constituted only by wheat flour
EWB French bread constituted by 95% wheat flour + 5% extruded wheat flour
PGB French bread constituted by 95% wheat flour + 5% pre-gelatinized cassava starch

Kim, Li, & Rayas-duarte, 2008; Minervini et al., 2011; Sze-Yin & Lai-Hoong, 2013).

Pre-gelatinized starch has the characteristic of dispersing more easily and absorbing more water compared to its respective unmodified starch, forming a gel at room temperature, which can create a protective layer around other molecules (Colonna, Doublier, Melcion, Monredon, & Mercier, 1984; Demiate & Kotovicz, 2011) and microorganisms, such as yeast. Substances that retain water in their structure can contribute to decrease the content of free water. This behavior could minimize water available for ice crystallization in frozen dough, reduce the amount of water drawn from yeast during the freezing cycle, enhancing cell viability (Casey & Foy, 1995). Besides its possible yeast protective effect, the water retained in the starch would help to maintain the crumb moist, reducing its firmness. Pre-gelatinized starch is also ready for attack by amylases from wheat and, thus, could be a good source of fermentable sugars for the yeast, increasing proofing speed.

Extruded wheat flour, as pre-gelatinized starch, could also be an ingredient with these three beneficial properties for frozen dough. The damaged starch and the denatured protein, both generated during the extrusion process, could be a source of fermentable sugars for the yeast and a water retainer (yeast cryoprotection and crumb softness), respectively.

The beneficial effects of these ingredients would not just help to improve product quality, but they would also upgrade the process through of the reduction of proofing time, baking time and energy expenditure in these processing steps.

The use of these two ingredients also has an economic justification, because they would promote the local agribusiness in Brazil. Cassava is among the most produced tubers in this country. Cassava starch is the main product obtained from this tuber. The application of extrusion to wheat flour is explained by the fact that the wheat produced in Brazil does not always provide wheat flour with a quality suitable for bread and pasta production. Therefore, it would be ideal to find novel applications for this soft wheat flour. The effect of these ingredients in bread doughs subjected to freezing has not yet been studied. Nevertheless, current studies show that the use of flour and pre-gelatinized starches alter batter/dough viscosity and also stabilize foams and aerated emulsions, producing better texture features in cakes (Fustier & Gélinas, 1998; Meza et al., 2011), and breads (Keeratipibul et al., 2010).

The study aimed to conduct a comparative study of partial substitution of wheat flour by extruded wheat flour or pre-gelatinized cassava starch in the production of French-type bread elaborated from frozen dough, verifying if these ingredients would improve the technological quality of this product and its process.

2. Material and methods

2.1. Raw materials

The samples used in this work were wheat flour Type 1 (Moinho Paulista, São Paulo, Brazil), pre-gelatinized cassava starch (Cargill Agrícola, São Paulo, Brazil) and extruded wheat flour, obtained from the extrusion of wheat flour Type 1, according to the procedure described in item Section 2.2.1.

2.2. Methods

2.2.1. Production of extruded wheat flour (EWF)

Extruded wheat flour (EWF) was obtained by subjecting wheat flour, previously conditioned to 20% moisture content, to extrusion in a co-rotational twin-screw extruder ZSK-30 (Werner and Pfleiderer, Ramsey, USA). A feed rate of 12 kg/h was used. The screw configuration, starting from the feed extremity towards the die, considering the number of elements: element (n:a/b or KBc/d/a) was: 2:60/30; 1:21/21; 2:60/30; 2:42/21; 1:KB90/5/28; 2:28/14; 1:14/14; 1:20/10; 1:10/10; 2:21/21; 1:KB90/5/28; 1:28/14; 2:20/10; 1:10/10; 1:KB45/5/20; 12:20/10, where “a” is the element length (mm); “b” is the screw pitch of each element (mm); “KB” (*Kneading block*) is a kneading element; “c” is the angle formed by adjacent crests and “d” is the number of crests of the kneading element. The screw rotation speed was set at 200 rpm and heating zones were set at the following temperatures: 1st zone (70 °C); 2nd zone (100 °C); 3rd zone (130 °C) and 4th zone (160 °C). At the exit, a circular die with two holes of 3.8 mm was used. Immediately after the extrusion, the product was dried in a rotary dryer at 125 °C for 50 s, and a product with less than 10% moisture content was obtained. Aiming to obtain a product with a particle size profile close to the control wheat flour, the dried product was ground in a knife and hammer mill 74064G (Treu S.A., Rio de Janeiro, Brazil).

2.2.2. Characterization of raw materials

Control wheat flour (CWF), extruded wheat flour (EWF), pre-gelatinized cassava starch (PGS) and composite blends of 95% wheat flour and 5% extruded wheat flour (BEW) and 95% wheat flour and 5% pre-gelatinized cassava starch (BPG) were analyzed as reported below.

2.2.2.1. Optical microscopy. The samples, dispersed in water, according to Alvim and Grosso (2010), were observed in a BX41 polarizing microscope (Olympus, Tokyo, Japan) with an increase of 1000×. The capture of images, with regular and polarized light, was performed with a Q-Color3 digital camera (Olympus, Tokyo, Japan) adapted to the microscope and the Q-capture software (Olympus, Tokyo, Japan), which was used for opening the images.

2.2.2.2. Glucose in flour blends. The amount of glucose available in CWF, BEW and BPG was determined by AACCI method 76-13.01 (AACCI, 2010), using a Megazyme K-TSTA enzymatic kit (Megazyme International Ireland, Bray, Ireland). To evaluate the amount of glucose available in the raw materials in the early stages of proofing, they were incubated with alpha-amylase enzyme for a total period of 40 min, at 30 °C, the same temperature used for dough proofing.

2.2.2.3. Chemical composition. Moisture, protein and ash determinations were performed by AACCI methods 44-11.01, 46-13.01 and 08-01.01 (AACCI, 2010), respectively. The lipid content was determined according to AOAC method 920.39C (AOAC, 2005). Total carbohydrates were determined by difference. The damaged starch was determined by AACCI method 76-33.01 (AACCI, 2010).

2.2.2.4. Rheological properties and pasting properties. The rheology was empirically evaluated using a farinograph and an alveograph, through AACCI methods 54-21.02 and 54-30.02 (AACCI, 2010), respectively. The pasting properties were determined by AACCI method 76-21.01 (AACCI, 2010), and the sample weight used was 3.50 g, at 14% moisture basis, for all samples.

2.2.2.5. Mean particle size and particle size distribution. The mean particle size and particle size distribution were determined in a LV-950 particle size determiner (Horiba, Kyoto, Japan), at 25 ± 0.5 °C, using the laser diffraction method and dry dispersion module (adapted from Application Notes AN145-HORIBA).

2.2.3. Production of French-type bread made from frozen dough

2.2.3.1. Formulation. Three formulations of French-type bread made from of frozen dough were prepared, using: 100% control wheat flour (CWF) and the other two formulations with 5% of substitution of control wheat flour by EWF or PGS. These formulations were designated, respectively: WFD, EWD and PGD (when in the form of doughs) and WFB, EWB and PGB (when in the form of breads).

The standard formulation used was: 100% of control wheat flour or blends (mentioned above), 58% of water, 3% of fresh baker's yeast, 2% of iodized refined salt (NaCl), 0.1% of sodium stearoyl-2-lactylate (SSL), 0.15% of diacetyl tartaric acid esters of mono-diglycerides (DATEM), 0.0045% of azodicarbonamide, 0.012% of ascorbic acid, 0.02% of fungal alpha amylase (5000 SKB), and 0.012% of xylanase (blend of 30% fungal xylanase and 70% bacterial xylanase).

2.2.3.2. Production process of frozen dough. The ingredients and additives were previously homogenized and cooled. A blend of water and ice was added to start the dough preparation in a HAE 10 dough mixer (Hyppolito, Ferraz de Vasconcelos, Brazil). The water and ice mixture was monitored so that the dough temperatures, at the end of mixing, did not exceed 21 °C. The dough was mixed for 9 min at slow speed (90 rpm), then the process continued at high speed (180 rpm) until the complete development of the gluten network, which happened at 13.5 ± 1.0 min. Baker's yeast and salt were added one minute before the final dough development. The doughs were divided in portions of 65 ± 1 g, rounded by hand, left to rest for 15 min at 21–22 °C and molded in a HM2 Hp 0.5 molder (Hyppolito, Ferraz de Vasconcelos, Brazil). Subsequently, they were frozen in a UK05 mechanical ultra-freezer (Klimaquip, Pouso Alegre, Brazil), with air temperature in convection at −40 °C, until the geometric dough center reached −18 °C (~35 min). After freezing, the doughs were packaged in low density polyethylene bags and stored at −18 ± 2 °C in a FFE24 vertical freezer (Electrolux, Curitiba, Brazil) until the moment of thawing and baking.

2.2.3.3. Thawing and bread production. After 7 days of frozen storage the doughs were placed in drilled trays and thawed for 12 h in a CCKU586820-1 retarder/proofer (Super Freezer, Poços de Caldas, Brazil), at 4 °C and 95% RH. Proofing was performed in the same chamber at 30 °C and 80% RH until the dough optimum proofing time, which was verified manually. The end of proofing was determined when the dough presented its maximum volume development without losing its resistance to touch (Almeida & Chang, 2012). Proofed doughs were baked in an Ipanema IP 4/80 hearth oven (Haas, Curitiba, Brazil), at 210 °C top temperature, and 215 °C hearth temperature, until achieving the desired color. The baking time was monitored visually by the development of crust color.

2.2.4. Characterization of frozen dough, proofed dough and French-type bread

2.2.4.1. Unfreezable water fraction in frozen dough. The unfreezable water fraction, which is the fraction of bound water, was measured as the difference between the total water content and the fraction of freezable water. The fraction of freezable water was obtained by the relation between the total melting enthalpy change of ice in the dough and the latent heat of melting of ice, according to Almeida and Chang (2014). The total melting enthalpy change of ice in the dough was determined in a DSC 8500 differential scanning calorimeter (Perkin Elmer, Walthan, USA). The inner part of frozen doughs, after 7 days of frozen storage, was weighed (about 3 mg) in an aluminum capsule, which was sealed. An empty aluminum capsule was used as reference. Initially, the sample was maintained at 25 °C for 1 min, then cooled at 10 °C/min until −70 °C. The sample was held at this temperature for 2 min, then heated at 10 °C/min until 25 °C. The thermograms of the samples were analyzed using the *Pyris Manager software*.

2.2.4.2. Physical evaluation of proofed dough and French-type bread. The proofed dough was evaluated through the determination of its dimensions (width, height and length), with the aid of a caliper. The bread was evaluated after cooling for 1 h at room temperature, according to the following analyses: specific volume — by AACCI method 10-05.01 (AACCI, 2010); instrumental texture — determination of crumb firmness following AACCI method 74-09.01 (AACCI, 2010); ovenspring, measured in the center of the bread, shape, and cut opening and cut height — determined according to the methodologies described by Almeida and Chang (2012). Crumb color analysis was performed by the CIE$L^*a^*b^*$ system in a HunterLab equipment, and the color difference (ΔE^*) was calculated in relation to the bread made with CWF, by Eq. (1).

$$\Delta E* = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \quad (1)$$

2.2.5. Statistical analysis

All analyses were performed in triplicate, except for instrumental color, which was performed with nine repetitions. The analysis of variance (ANOVA) was performed with a 5% level of significance and average multiple comparison analysis was made through the Tukey test, using Statistica 7.0 software (StatSoft, Inc., Tulsa, USA).

3. Results and discussion

3.1. Characterization of raw materials

3.1.1. Optical microscopy

The images of CWF (Fig. 1a) show the presence of intact starch granules and non-uniform structures that are proteins and other nutrients in the control wheat flour. Under polarized light, the birefringence of the granules of the raw starch was observed. The images of EWF and PGS (Fig. 1b and c, respectively), show that the starch of these ingredients was gelatinized, since the granular structure was disrupted and no birefringence was observed under polarized light. However, it is possible to verify that some starch granules in EWF were less disrupted than other granules of this same sample and then PGS granules.

3.1.2. Available glucose in the raw materials

EWF and PGS presented a higher content of available glucose than CWF after 20 and 40 min incubation (Fig. 2). This was expected because, as was observed in the microscopic images, the starch granules of these ingredients were ruptured. Therefore, their long chain molecules were

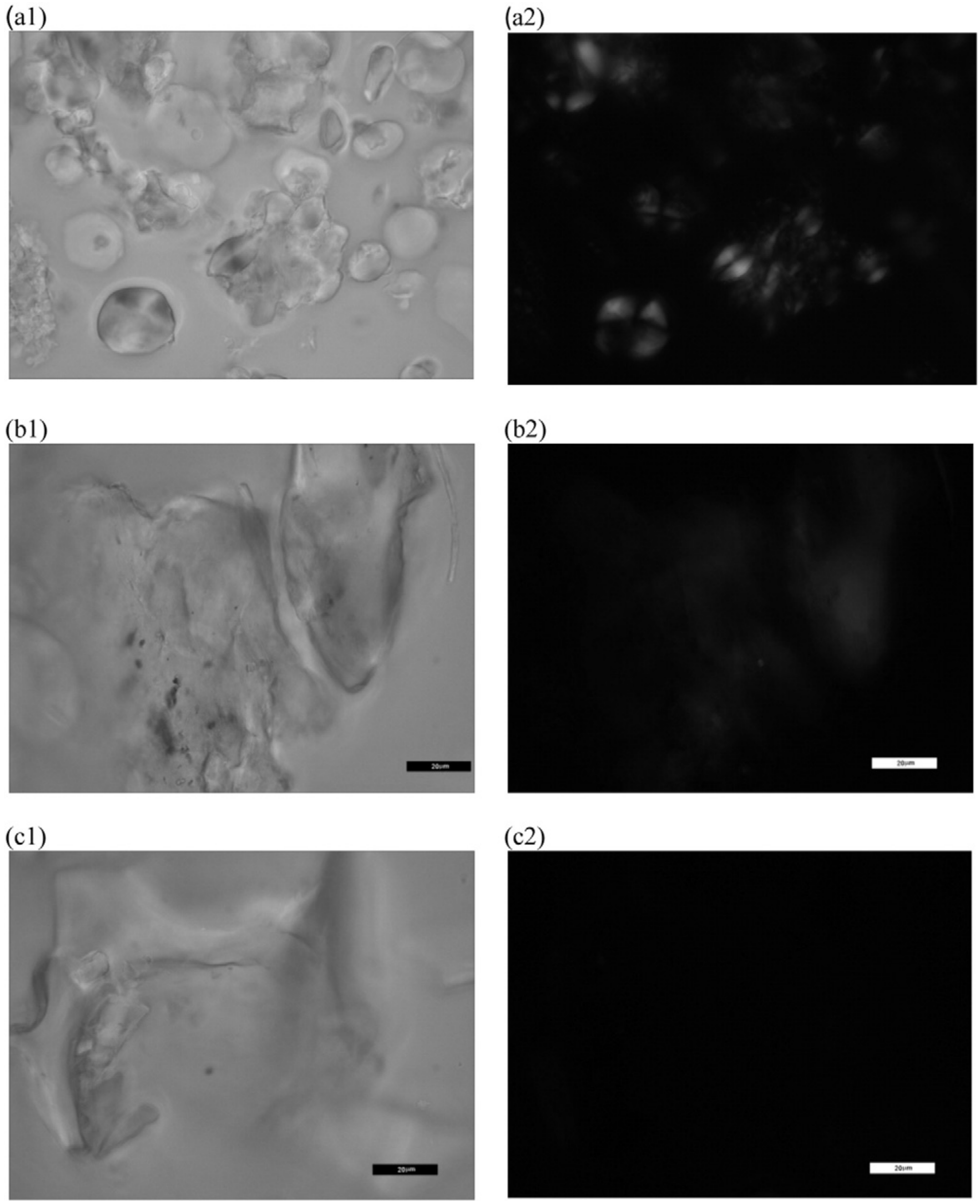

Fig. 1. Regular and polarized light microscopy of CWF (a1, a2), EWF (b1, b2) and PGS (c1, c2), arranged side by side, with a 1000× magnification.

more exposed to enzyme attack. At 20 min after incubation, PGS showed higher available glucose content than EWF, which was also expected due to the presence of some starch granules in EWF for which disruption was not so intensive. For all the raw materials used, there was an increase in the amount of available glucose after 40 min of enzyme incubation. However, the difference observed for available glucose content from EWF and PGS after 20 min was not observed after 40 min. Therefore, after 40 min of incubation, there may not be a difference in glucose supply from these two raw materials to the dough.

3.1.3. Chemical composition and technological properties of the raw materials and blends

The protein content was over 12% for all raw materials evaluated (Table 1), except BPG, which had a lower value (11.75%). Stauffer (1993) suggests that the protein content of flours used to make bread should range between 12% and 14%, also when it is used in the production of bread from frozen dough. The replacement of CWF by 5% EWF (BEW) did not promote changes in protein content, although the type of protein found in the wheat flour is more important than its content (Añón, Le Bail, & León, 2005). The lower protein content found in BPG occurred because replacing part of the wheat flour by PGS caused protein dilution in the blend, which may in turn affect the dough structure and gas retention during proofing and baking. Regarding the ash content, there was no significant difference between the analyzed samples.

The ether extract content was similar for CWF and blends (BEW and BPG), but for EWF, it was 0.39% and significantly lower than the others, probably because the temperature used in the extrusion process promoted the complexation of lipids with starch and/or proteins, reducing their extraction by the method used in this study, according to Chang, Schmiele, and Martinez-Bustos (2009).

The amount of damaged starch in the flour (CWF) and blends (BEW and BPG) evaluated did not differ significantly by the Tukey test ($P \leq 0.05$). Therefore, even with the introduction of EWF and PGS in blends, these raw materials did not contribute to elevate the damaged starch content in relation to CWF. These values found are in accordance with the 5 to 10% range indicated by literature for bread production (Sluimer, 2007).

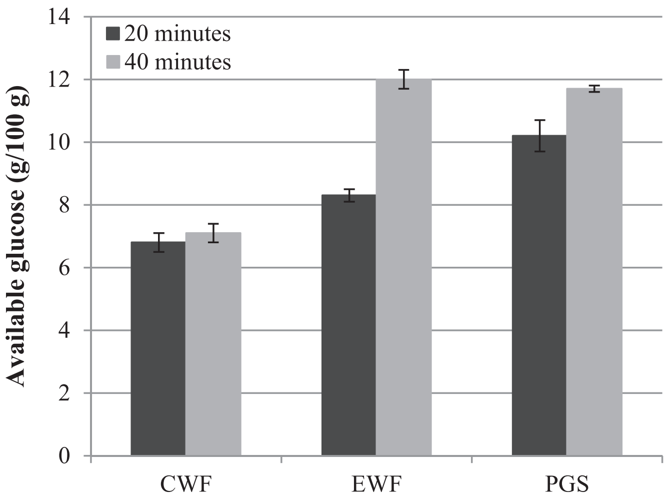

Fig. 2. Available glucose in the raw materials used to make French-type bread from frozen doughs measured after 20 and 40 min incubation with alpha-amylase enzyme.

For farinograph and alveograph parameters, it was observed that PGS caused changes in the rheological behavior of the BPG with respect to CWF. There was a significant reduction of stability (S), an increase in the mixing tolerance index (MTI), and a reduction of elasticity (P). BEW also showed a reduction in technological quality for breadmaking in relation to CWF, however, this reduction was smaller than that found for BPG. Therefore, it appears that, despite EWF having passed through the extrusion process, which changed many of the properties of its components (such as protein denaturation, amount of starch damage, etc.), it still represents a better choice than replacing wheat flour with PGS, as its impact was less intense the rheological quality of CWF.

The similarity between the blends (BEW and BPG) and CWF in the water absorption results is because, in the native wheat flour, proteins are responsible for increasing water absorption by 2.7 to 3.0 times their weight and starch by 0.33 to 0.35 times its weight (Hoseney, 1998). On the other hand, pre-gelatinized flour or starch have the tendency to increase the water absorption of the system, and may have compensated the dilution of native wheat flour proteins.

BEW presented a higher value for P/L in relation to CWF and BPG, as a consequence of an increase of P and a reduction of L. This increase is not related directly to the strengthening of the gluten network, but probably due to the role of the denatured protein and the partially gelatinized starch of the extruded flour, which easily incorporated water, and promoted an increase in dough viscosity.

Observing the pasting properties of the raw materials, EWF had lower values for cold viscosity, peak viscosity, final viscosity, breakdown and retrogradation tendency in relation to PGS. Both of them had the same pasting temperature, 30 °C, because these raw materials have in their constitution pre-gelatinized starch, which reduces the temperature required to form a viscous system.

The lower peak viscosity, breakdown and retrogradation tendency of EWF in relation to PGS can be related to the presence of gluten proteins, which can interact through covalent bonds with the surface of the starch granule, preventing higher interaction with water, having lower breakage and, hence, higher dough stability (Chen, Jansson, Lustrup, & Swenson, 2012; Ragaee & Abdel-Aal, 2006).

The higher value for final viscosity obtained for PGS can be attributed to the concentration of starch in the sample. The pasting properties presented for CWF are close to the values reported by Ragaee and Abdel-Aal (2006) and Morris, King, and Rubenthaler (1997).

According to Neill, Al-Muhtaseb, and Magee (2012), with thermal treatment there is an increase of the ability of starch granules to absorb water due to their pre-gelatinization.

Except for breakdown of BPG, there were no significant changes in pasting properties of the blends used for frozen dough production, in

Table 1
Chemical composition, rheological properties and pasting properties of the raw materials and blends.

	Raw material[1]			Blends[1]	
	EWF	PGS	CWF	BEW	BPG
Chemical composition					
Protein (% db)	12.25 ± 0.17	<0.1	12.35 ± 0.11a	12.34 ± 0.10a	11.75 ± 0.10b
Ash (% db)	0.81 ± 0.02	<0.1	0.82 ± 0.03 ns	0.82 ± 0.03 ns	0.83 ± 0.03 ns
Ether extract (% db)	0.39 ± 0.03	<0.1	1.29 ± 0.04 ns	1.24 ± 0.04 ns	1.25 ± 0.04 ns
Carbohydrates[2] (% db)	86.55	92.00	85.54	85.60	86.17
Farinograph parameters					
Water absorption (%)	–	–	55.5 ± 0.3 ns	57.7 ± 0.2 ns	52.8 ± 3.9 ns
Dough development time (min)	–	–	12.7 ± 0.5a	9.2 ± 0.6b	8.7 ± 0.4b
Stability (min)	–	–	19.1 ± 0.3a	16.6 ± 0.2b	10.2 ± 0.5c
Mixing tolerance index (BU)[3]	–	–	17 ± 2.0b	17 ± 0.1b	56.3 ± 2.9a
Alveograph parameters					
Elasticity, P (mm)	–	–	97.1 ± 1.0b	132.5 ± 7.4a	103.7 ± 3.2b
Extensibility, L (mm)	–	–	67 ± 5.6a	49 ± 3.6b	57.3 ± 6.1ab
Elasticity/extensibility ratio, P/L	–	–	1.45 ± 0.1b	2.71 ± 0.2a	1.82 ± 0.2b
Gluten strength, W (10^{-4} J)	–	–	255.3 ± 18.6 ns	287.3 ± 29 ns	243.3 ± 24.9 ns
Pasting properties					
Pasting temperature (°C)	30.0	30.0	70.6 ± 0.8 ns	70.0 ± 0.5 ns	69.5 ± 0.4 ns
Cold viscosity (cP)	139 ± 19	552 ± 65	82 ± 3 ns	86 ± 2 ns	88 ± 2 ns
Peak viscosity (cP)	422 ± 14	2597 ± 70	1774 ± 125 ns	1658 ± 91 ns	1738 ± 77 ns
Final viscosity (cP)	434 ± 14	6043 ± 485	2994 ± 158 ns	2737 ± 121 ns	2939 ± 117 ns
Breakdown (cP)	154 ± 7	263 ± 9	669 ± 75a	627 ± 44ab	572 ± 43b
Retrogradation tendency (cP)	165 ± 9	3659 ± 495	1889 ± 108 ns	1705 ± 74 ns	1773 ± 44 ns

Different letters in the same row indicate significant differences among the averages ($P \leq 0.05$).
ns = not significant.
[1] EWF = extruded wheat flour; PGS = pre-gelatinized cassava starch; CWF = control wheat flour; BEW = blend of 95% wheat flour + 5% extruded wheat flour; BPG = blend of 95% wheat flour + 5% pre-gelatinized cassava starch.
[2] Carbohydrates were calculated by difference (100-protein-ash-ether extract).
[3] BU = Brabender units.

Table 2
Particle size distribution of the control wheat flour and its blends.

Particle size		Raw materials (%)*		
Diameter (μm)	ASTM mesh	CWF	BEW	BPG
From 20 to 90	From 635 to 170	62.57 ± 0.48	59.65 ± 1.61	63.71 ± 5.07
From 106 to 250	From 140 to 60	87.37 ± 0.54	83.85 ± 1.81	89.10 ± 6.75
From 300 to 850	From 50 to 20	93.85 ± 0.42	91.95 ± 2.19	94.45 ± 3.96
From 1000 to 4000	From 18 to 5	100.00 ± 0.00	100.00 ± 0.00	100.00 ± 0.00

* CWF = control wheat flour; BEW = blend of 95% wheat flour + 5% extruded wheat flour; BPG = blend of 95% wheat flour + 5% pre-gelatinized cassava starch.

relation to CWF, which indicates that it could be possible to replace 5% of CWF by BEW or PGS.

3.1.4. Particle size distribution

BEW and BPG had cumulative values higher than 90% in the diameter range between 300 to 850 μm and values very close to CWF (Table 2). Substituting CWF by 5% EWF or PGS did not affect the particle size distribution of the blends, when compared to CWF. The particle size of flours has a direct influence on water absorption and dough viscosity. It can lead to changes in the texture and sensory characteristics of the products (Walde, Tummala, Lakshminarayan, & Balaraman, 2005). Therefore, differences in these attributes of breads due to the difference of particle size of flours used are not expected.

3.2. Characterization of frozen dough, proofed dough and French-type bread

Table 3 shows the results of the characterization of frozen dough and French-type bread.

3.2.1. Unfreezable water fraction of frozen dough

Doughs elaborated with CWF, BEW or BPG did not differ with respect to the amount of unfreezable water (Table 3). This means that, at 5% substitution level, EWF and PGS did not influence the water binding capacity of blends. It is possible that, at a greater substitution level, an increase of this water fraction might be observed. Pre-gelatinized and/or damaged starch and denatured proteins present in EWF and PGS would be responsible for binding water in their structures, making it unavailable for crystallization during freezing (Wynne-Jones & Blanshard, 1986).

3.2.2. Proofing time

There was a significant decrease in proofing time with the application of EWF or PGS in dough formulations: 5% substitution by EWF contributed to 42.17% reduction in proofing time, and 5% substitution by PGS contributed to 51.81% reduction in proofing time. This is a great gain in the breadmaking process, since there would be a reduction of time of use of the proofing chamber (decreasing processing time), with a consequent reduction in production costs. These raw materials may be able to solve one of the greatest problems of frozen dough technology, which are the longer proofing times.

Table 3
Results of physical measurements of fermented doughs of French-type bread and French-type bread.

Parameters[1]	Doughs[2]			Bread[3]		
	WFD	EWD	PGD	WFB	EWB	PGB
Differential scanning calorimetry						
Crystallization of unfreezable water						
Tp (°C)	−19.65 ± 1.62 ns	−18.86 ± 0.94 ns	−19.62 ± 1.28 ns	–	–	–
ΔH (J/g)	45.64 ± 2.23 ns	45.09 ± 4.5 ns	43.16 ± 2.8 ns	–	–	–
UW (g/g)	0.30 ± 0.01 ns	0.29 ± 0.01 ns	0.29 ± 0.00 ns			
Melting of ice						
Tp (°C)	−5.58 ± 0.58ab	−5.89 ± 0.22a	−5.05 ± 0.55b	–	–	–
ΔH (J/g)	52.45 ± 2.92 ns	51.79 ± 5.29 ns	50.93 ± 4.08 ns	–	–	–
Proofing time (min)	83 ± 0.05a	48 ± 0.05 b	40 ± 0.03c	–	–	–
Baking time (min)	–	–	–	25 ± 0.05a	12 ± 0.05b	24 ± 0.05a
Height (mm)	43.39 ± 3.39b	38.60 ± 2.13c	50.65 ± 3.96a	50.97 ± 1.76ab	53.23 ± 2.49a	49.31 ± 1.26b
Length (mm)	117.13 ± 6.49ab	111.09 ± 6.02b	120.84 ± 9.51a	117.05 ± 2.80 ns	115.23 ± 4.10 ns	111.88 ± 6.38 ns
Width (mm)	72.06 ± 3.56 ns	73.91 ± 3.64 ns	74.94 ± 5.11 ns	73.60 ± 3.83a	69.17 ± 3.40b	68.32 ± 3.15b
Surface cut height (mm)	–	–	–	8.36 ± 1.91 b	15.28 ± 2.70a	9.64 ± 1.63b
Ovenspring (mm)	–	–	–	7.58 ± 4.59b	14.63 ± 3.46a	0.93 ± 1.17 c
Volume (cm^3)	–	–	–	254.13 ± 21.18a	144.92 ± 9.38c	209.36 ± 21.54b
Weight (g)	–	–	–	51.97 ± 2.36ab	53.82 ± 2.47a	50.67 ± 3.14b
Specific volume (cm^3/g)	–	–	–	4.89 ± 0.43a	2.86 ± 0.36c	3.89 ± 0.39b
Firmness (N)	–	–	–	2.02 ± 0.14b	2.81 ± 0.29a	2.83 ± 0.29a
Crumb color						
L^*	–	–	–	74.50 ± 1.06 ns	75.56 ± 0.81 ns	74.66 ± 0.99 ns
a^*	–	–	–	0.99 ± 0.11 ns	1.22 ± 0.19 ns	1.00 ± 0.09 ns
b^*	–	–	–	19.27 ± 0.18 ns	20.12 ± 0.49 ns	19.55 ± 0.32 ns
ΔE*	–	–	–	–	1.32 ± 0.21 ns	0.67 ± 0.03 ns

Different letters in the lines indicate significant differences ($P \leq 0.05$).
ns = not significant.
[1] UW = unfreezable water; L^* = lightness; a^* and b^* chromaticity coordinates ($+a^*$ = red, and $-a^*$ = green; $+b^*$ = yellow, and $-b^*$ = blue); ΔE* = color difference; Tp = peak temperature; ΔE = enthalpy change.
[2] WFD = frozen bread dough consisting of wheat flour; EWD = frozen bread dough consisting of 95% wheat flour + 5% extruded wheat flour; PGD = frozen bread dough consisting of 95% wheat flour + 5% pre-gelatinized cassava starch.
[3] WFB = bread consisting of 95% wheat flour; EWB = bread consisting of 95% wheat flour + 5% extruded wheat flour; PGB = bread consisting of 95% wheat flour + 5% pre-gelatinized cassava starch.

This decrease of proofing time probably occurred because of the presence of gelatinized and damaged starch in EWF and PGS, facilitating the access of enzymes produced by yeast during proofing (Aschieri, Carvalho, & Modesta, 2007). Also, the presence of low molecular weight carbohydrates and pre-gelatinized starch in these raw materials would lead to a cryoprotective effect, which can increase the number of viable yeast cells.

Cryoprotectants are substances that have the ability to protect cells from chemical changes and loss of functionality during freezing and thawing and, thus, improve the quality and prolong the shelf-life of frozen food (Giannou & Tzia, 2007).

These results are in agreement with our prospection, since in Fig. 2, a higher presence of low molecular weight sugars available for fermentation is verified, indicating that EWF and PGS have the two effects: cryoprotective of yeast and facilitator of fermentation.

3.2.3. Baking and bread quality

The baking time for EWB had a mean decrease of 49% over WFB, enabling an economy in energy consumption. This benefit, coupled with the reduction of proofing time (Table 3) should be considered in the calculation of process costs, once freezing increases the processing costs of French-type bread elaborated from frozen dough. The baking time for dough elaborated with EWF was also lower than the baking time for dough elaborated with PGS. This greater reduction can be due to the fact that EWF, in addition to glucose liberation, also supplies denatured proteins, which could be more available than native proteins for the Maillard reaction (color development).

EWF, at 5% level of substitution, showed an increase in oven spring, an improvement in shape, and increase in surface cut height of breads; while PGS, at 5% level of substitution, only improved the shape of breads. However, these raw materials contributed to decrease the specific volume and to increase crumb firmness.

The breads elaborated with CWF (WFB) presented the highest specific volumes, although their doughs (WFD) did not present the highest oven spring (increase of height during baking). The higher specific volume of WFB was caused by the expansion of its dough (WFD) to the sides, that is, there was an increase of its width.

It was observed that EWF and PGS increased gas production in the dough, by increasing the amount of available glucose and through a possible cryoprotective effect on yeast cells. However, these raw materials did not contribute to increase the gas retention capacity of the gluten network and also diluted the amount of gluten forming proteins. Therefore, EWF and PGS affected the balance of gas production x gas retention found in the dough produced with CWF, leading to a reduction of bread specific volume. The presence of a compact structure in breads with lower specific volume, led to higher firmness of breads elaborated with the blends.

Crumb color (Table 3) showed no significant differences in the parameters L^*, a^*,b^* and ΔE^*, indicating that wheat flour substitution by 5% EWF or PGS in the development of French-type bread from frozen dough, did not affect the final product crumb color. Comparing the data obtained in this work regarding French-type bread made from frozen dough with the results obtained by Oliveira, Pirozi, and Borges (2007), who evaluated French bread obtained by the conventional process (without freezing, frozen storage and thawing steps), it can be verified that the results of weight and specific volume of bread made from control frozen dough were similar to those reported by these authors (weight = 52.1 g and specific volume = 5.31 cm^3/g); however, for bread prepared with blends, the results were lower. In general, the results obtained in this study suggest that the freezing process is viable for production of French-type bread and the blends did not significantly contribute to improve the quality characteristics of breads elaborated from frozen dough, but they behaved as good process improvers by decreasing proofing and baking times. The loss of quality characteristics of French-type bread caused by the incorporation of EWF and PGS could be contoured by the use of vital gluten, additives and/or technological aids. Further studies will be necessary to optimize the quantity of these raw materials (EWF and PGS) and gluten, additives and/or technological aids.

4. Conclusions

The replacement of wheat flour by extruded wheat flour or pre-gelatinized cassava starch at 5% level can be considered a technological alternative in the processing of French-type bread from frozen dough, expanding the possibilities of the use of pre-gelatinized/damaged starches derived from various sources in bread preparation, as well as enabling the feasibility of using regional products.

EWF and PGS showed a great potential to aid the processing of bread elaborated from frozen dough. These raw materials may contour one of the biggest problems of frozen dough technology, which is the longer proofing time. EWF and PGS showed decreases up to 52% in proofing time and also decreased baking time. Therefore, EWF and PGS can lead to a great economy gain due to decreases in labor, bakery plant area, and energy consumption and increases in bread production. The aspect of responsible energy consumption is highly valued by companies worldwide; in many countries this is a highly valued indicator by consumers in a product purchase decision.

Some characteristics of bread quality were impaired by use of these raw materials at 5% substitution and can be contoured through studies of optimization of amount of these raw materials in the formulation and the application of vital gluten, additives and other processing aids.

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