PREPARATION PREGELATIZED FLOUR BY THERMOPLASTIC EXTRUSION-BASED BAGASSE BARLEY AND CORN GRITS

ELABORAÇÃO DE FARINHAS PRÉGELATINIZADAS POR EXTRUSÃO TERMOPLÁSTICA A BASE BAGAÇO DE CEVADA E GRITS DE MILHO

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Resumo: Considerando o potencial nutritivo e o baixo valor agregado do bagaço de cevada, além da alta produtividade e baixo custo do grits de milho, aliado à aplicabilidade e vantagem da tecnologia de extrusão termoplástica de alimentos, o presente trabalho estudou os efeitos do teor de água na mistura, a temperatura da terceira zona de extrusão de um extrusor Brabender de parafuso único, e concentração de bagaço de cevada com tamanho de 180 µm sobre as propriedades tecnológicas do grits de milho extrudido. Foi empregado um planejamento experimental central composto rotacional 23 usando metodologia de superfície de resposta para avaliar o efeito do teor de água (18-22%), formulação (% de bagaço de cevada, 15-30%) e temperatura da terceira zona de extrusão (120-160 °C) no índice de expansão radial (REI), densidade aparente (BD), índice de absorção de água (WAI), índice de solubilidade em água (WSI) e propriedades de pasta. Os resultados indicaram que o REI diminui com a adição de bagaço de cevada e aumenta com o incremento da temperatura. A temperatura tem efeito negativo sobre a densidade enquanto que WAI foi diretamente proporcional sobre esta variável. O teor de água e a formulação afetaram positivamente o WSI. A formulação foi a variável de maior importância nas propriedades de pasta: a viscosidade inicial foi diretamente proporcional à adição de bagaço de cevada e as viscosidades máxima e final foram inversamente proporcional ao aumento da cevada bagaço.

PALAVRAS-CHAVE: bagaço de cevada, grits de milho, extrusão, metodologia de superfície de resposta.

Abstract: Considering the nutritiootential and low market value of the bagasse barley, and high production, low cost of corn grits coupled with applicability and advantages of thermoplastic food extrusion technology, in the present work was studied the effect of moisture content of mixture, temperature of the third extrusion zone of the extruder of single extruder Brabender and bagasse barley concentration with size of 180 µm on the technological properties of the extruded corn grits. Was applied a central composite rotational design 23 using response surface methodology to evaluate moisture effect (18-22%), formulation (% bagasse barley) (15-30%) and third zone extrusion temperature (120-160°C) on the radial expansion ratio (REI), bulk density (BD), water absorption index (WAI), water solubility index (WSI) and pasting properties. The results indicated that the REI decreased with the addition of bagasse barley and increased with increasing temperature. The temperature has a negative effect on the density while the WAI was directly proportional to this variable. The water content and formulation positively affect the WSI. The formulation was the variable of greatest significance on the pasting properties: the initial viscosity was directly proportional to the addition of bagasse barley and maximum and final viscosity were inversely proportional to the increase of bagasse barley.

KEY WORDS: bagasse barley, corn grits, extrusion-cooking, response surface methodology

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Recebido: 30/05/2016 - Aprovado: 31/10/2016

INTRODUCTION

The bagasse barley is an organic residue from the brewing process, pasty, coarse, non-toxic presenting about 80% of the solid and liquid phase composed primarily of the bark of the barley that is formed by fibers (20%) , and proteins (20%-25%), extractives and ashes, to a lesser extent (CABRAL-FILHO et al. 2007).

Currently, great interest in materials that can be used to enrich foods with fiber and protein combined with increasing restrictions on economic and commercial requirements, new consumer trends and habits specific food causes the dry bagasse of barley is an attractive material for the production of new foods with this profile (BARTOLOMÉ et al., 2002).

The application of bagasse barley, along with other agro-industrial residues such as corn grits, flour for the production of pre-gelatinized using thermoplastic extrusion process emerges as an alternative for the reuse of this material in human food because of the calories to replace carbohydrate foods, and influence on various aspects of digestion, absorption and metabolism.

According to El-Dash (1987), and Fellows (2006), is a thermoplastic extrusion process technology, in which the mechanical frictions was combined with the heat continuously, mix, gelatinize starch and plasticizer, denatured protein materials and inactivate enzymes, restructuring them to create new forms. Moreover, this process is the elimination of antinutritional factors and reduction of microbial load (ALONSO, et al. 2000)

The thermoplastic extrusion allows greater ease in the production of flour and starches, pregelatinized. These products can be used for thickening and water retention without the use of heat, for example, in puddings, milk mixtures and instant foods for breakfast (CLERIC; EL-DASH, 2008).

Technological properties important to be evaluated in extruded products are radial expansion ratio, bulk density, water solubility index, water absorption index and folder properties (CARVALHO et al., 2002). According to Ascheri et al. (2006), through the radial expansion ratio, one can at first observation, predicting the severity of the process.

Bulk density is an indirect way to quantify the efficiency of the extrusion process. Indirectly also lets you objectively evaluate how light or heavy extruded are prepared (VERNAZA et al., 2009). Water solubility index indicates the severity of heat treatment and consequent desintegrate starch structure (CARVALHO et al., 2002).

Water absorption index indicates the amount of water absorbed by starch granules from a given sample subjected to heat treatment (CARVALHO et al., 2002). Since the viscosity parameters allow the determination of pasting study the degree of cooking of the extruded product and allows the evaluation of the behavior of starch in aqueous medium, applying different temperatures during the process (TEBA et al., 2009).

In this context, the present study aimed to obtain and characterize technologically pregelatinized flour-based bagasse barley and dry milled corn grits, extruded thermoplastic, through temperature variation of the third extrusion zone, the moisture of raw material and content of bagasse barley.

MATERIALS AND METHODS

Approximately 170 kg of bagasse barley was supplied by a brewery located in the city of Anapolis, GO, Brazil. After collection, the bagasse barley was quickly transported to Enzymology laboratory, State University of Goias and pressed in order to reduce the water content. Then the material was distributed uniformly placing them on trays in an oven with forced air recirculation (Tecnal) at 105 °C until it reached around 6.0% moisture.

Later, ground the dried residue (BCS) in a macro mill circular rotor with knives fixed and mobile, type "CROTON" (Marconi, model MA 580), using sieves of 1mm diameter. After milled, the material was sieved through sieve with mesh size equal to 180 µm, thus obtaining

doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

the flour with a particle size of 180 µm (BCSM) used in this study.

The corn grits was obtained in sufficient quantities in some supermarkets in Rio de Janeiro city, RJ, Brazil packed in plastic bags under refrigeration below 0°C until their subsequent use in extrusion and analysis.

Analysis was performed of the chemical composition of the dry bagasse barley, barley cakes with a particle size of 180µm and corn grits, using the methods described by Adolfo Lutz Institute (IAL, 2008) to determine the moisture, total ash and ether extract. The methodology used to calculate the crude protein was the Association of Official Analytical Chemists (AOAC, 2007). Crude fiber was determined according to Silva and Queiroz (2005). The total carbohydrates were calculated by difference, subtracting from 100 the values found for moisture, protein, ether extract and ash.

For preparation of formulations of the tests established a full factorial central composite design 23, with three independent variables (moisture content of the mixture (%), temperature of the third zone of the extruder (°C) and content of bagasse barley), totaling 19 trials, eight factorial (combinations of levels -1 and +1), six axial (a ± α level variable and one at level 0) and five central (BOX et al., 1978). The value of α is based on the number of independent variables (n = 3), defined by the equation: α = (2n) 1/4 = (23) 1/4 = 1.68 (BARRO-NETO et al. 2003). The levels of independent variables, both coded as real, are in Table.

Table 1. Levels of the independent variables: X_1 = bagasse Barley (%); X_2 = Moisture of the mixture (%); X_3 = Temperature third zone of the extruder (°C), studied in the extrusion process of corn grits and bagasse barley.

Variables	Levels				
	-α	-1.00	0.00	1.00	+α
X_1	15.00	18.04	22.50	26.96	30.00
X_2	18.00	18.81	20.00	21.19	22.00
X_3	120.00	128.11	140.00	151.89	160.00

Mixtures of bagasse barley flour and corn grits were prepared as set out in experimental design. Later, it was determined the moisture of the mixtures on a dry basis using the moisture balance model MOC-120 h in order to use the value of initial moisture in Equation (1) to calculate the amount of distilled water to be added to the mixtures that they reach the moisture percentage established by experiment.

$$V_w = \left(\frac{M_f - M_i}{100 - M_i}\right) m_s \quad (1)$$

Where:

Vw = Volume of water added (mL);

Mf = final moisture (dry basis) of the sample established by experiment;

Mi = initial moisture (dry basis) of the sample;

ms = mass of sample (g).

Once homogenized, the samples were placed in plastic bags and stored under refrigeration for 16 hours to obtain more uniform distribution and absorption of water.

After conditioning trials, was proceeded to the extrusion. Was used a Brabender extruder (model 20DN) single screw, fitted with 3 mm die, screw compression ratio of 1:3, feed speed 24 rpm, feed rate 5.0 kg h-1 , and the temperatures in Zones 1 and 2 held constant at 80 and 100 °C, respectively. The third zone temperature varied according to the experimental

Revista Agrotecnologia, Ipameri, v.7, n.2, p.27-39, 2016
doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

design proposed, and the screw speed remained constant throughout the process (180 rpm).

The extrusion process was initiated after the feed zone (zone 1), transition (zone 2) and high pressure (zone 3) to reach desired temperatures. The extruded product was collected after reaching equilibrium process, arranged in trays and sent to an oven with air circulation at 60 °C for 2 hours.

Parts of the samples, after reaching room temperature, were placed in plastic bags, sealed and kept at room temperature to then be subjected to tests to determine the technological properties.

The rate of radial expansion (REI) of extruded products was evaluated after cooling the samples, and prior to kiln drying. Was measured the diameter of the extruded with caliper Craftsman model No. 40257. The calculation was obtained by the ratio between the diameter of the extruded material (D) of the matrix and the diameter of the extruder (D0), as shown in Equation 2. The value of this parameter was obtained by the arithmetic mean of six determinations for each treatment.

$$REI = \left[\frac{D}{D_0}\right]^2 \quad (2)$$

The apparent density (DAP) was calculated using Equation 3, following the methodology described by Fan et al. (1996). The value considered was obtained by the arithmetic mean of 10 measurements for each treatment.

$$DAP = \frac{4\,m}{\pi\,D^2\,L} \quad (3)$$

Where: D = diameter of the extruded material (cm) L = sample length (cm) m = sample weight (g).

The determination of the water solubility index (WSI) and water absorption index (WAI) was performed according to the basic principles of the method described by Anderson et al. (1969), modified. Analysis were performed in quadruplicate, for all treatments, with the objective of verifying the absorption and water solubility of the extruded material.

The pasting viscosity (PV) was determined in a RVA (Rapid Visco Analyser, RVA of Newport Scientific, Australia) essentially followed the methodology of materials extruded in the same manual. The ground samples were sieved in sieve shaker RO-TAP, model RX-29-10. The sieve fraction between 106 and 212 µm was analyzed by duplicate. The PV was expressed in cP (centipoise).

For the RVA analysis, 3 g of flour extruded with moisture adjusted to 14% (wet basis) was added distilled water to final weight of 28 g. The initial temperature of 25 °C was increased gradually to 95 °C at a heating rate of 14 °C min-1, remaining constant at this temperature for 3 min. Cooling was done gradually at a rate of 14 °C min-1 until the final temperature of 25 °C.

In interpreting the viscoamilogramas we considered the following parameters:

- Initial Viscosity (Vinic.) folder to 25 °C ("cold"), is the maximum value of the suspension viscosity in cP at the start of the heating cycle.

- Maximum Viscosity (Vmax.) is the dynamic viscosity in cP at the peak of the curve, obtained during the heating cycle maximum viscosity.

- End viscosity (Vend): Value of the viscosity of the analysis cycle cooling at 25 °C.

Was applied the second-order equation as a predictive mathematical model of the response variables Y1 (REI), Y2 (DAP), Y3 (WAI), Y4 (WSI), Y5 (Vinic.), Y6 (Vmáx.) and Y7 (Vmax) whose general equation is (BOX et al., 1978):

$$Y= b_0+b_1X_1+b_2X_2+b_3X_3+b_{11}X^2{}_1+b_{22}X^2{}_2+b_{33}X^2{}_3+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3+\varepsilon$$

Where Y is the generic function, the variable X coded, obtained from the original variable, b represents the coefficients estimated by the method of least squares is the experimental error.

The response surface plots and the coefficients of the mathematical model were obtained through the program Statistica® for Windows® version 8.0 from StatSoft®

RESULTADOS E DISCUSSÃO

The water content values and chemical composition of corn grits, barley dry bagasse (BCS) and bagasse barley dry milled to particle size of 180 µm (BCSM) are in Table 2.

Table 2. Proximal composition (18 g per 100 g) of raw materials, corn grits, bagasse barley dehydrated (BCS), and bagasse barley flour with 180 µm (BCSM).

Material	Corn grits	BCS[3]	BCSM[4]
Moisture[1]	10.94 ± 0.06	5.15 ± 0.12	5.09 ± 0.03
Protein[2]	8.10 ± 0.11	22.85 ± 0.26	25.26 ± 0.18
Fiber Brut[2]	0.15 ± 0.11	19.40 ± 0.31	13.58 ± 0.22
Ether extract [2]	0.48 ± 0.02	6.61 ± 0.13	8.62 ± 0.20
Ash[2]	0.30 ± 0.08	4.25 ± 0.05	3.80 ± 0.006
Carbohydrates*	80.18	64.56	57.23

[1]base wet; [2]base dry; *include a crude fiber residue. Mean ± standard deviation.

It appears from Table 2 that the corn grits is basically a starchy material (80.18 g per 100 g of carbohydrate) close as observed by Peplinski et al. (1992) (76-77%).

The dried residue of barley showed a value of protein content (22.85%) close to those reported by Senthilkumar et al. (2010) (24.34%). The percentage of crude fiber residue was found in 19.4%, presenting therefore differing from the value reported by Vieira (2010) (16.76%).

The value found for ether extract (6.61%) confirms the great variation found in the literature for this bagasse type. Geron et al. (2007) reported value of 8.38%. This variation may be related to the extract ether method of determination could be low precision. The ash content found (4.25%) is similar to the value reported by Vieira (2010) (4.40%).

The barley residue and dry milled to particle size of 180 µm (BCSM) had a higher protein content (25.26%) and ether extract (8.62%) than the dry bagasse barley (BCS). The increase in protein content is probably due to decreased fiber fraction retained during the screening. Since the increase in the value of ether extract can be explained based on the low accuracy of the method of determination of this constituent.

On the other hand, the BCS showed a higher content of crude fiber and ash that the BCSM.

The results of the assessment of physical-chemical characterization of extruded corn grits with bagasse barley as soon as solubility in water (ISA), water absorption index (AAI), radial expansion ratio (REI), density apparent (DAP) and folder properties are in Table 3.

Table 3. Results of experimental characterization: water solubility index (WSI), water absorption index (WAI), radial expansion index (REI), apparent density (DAP), pasting viscosity initial at 25 °C (V_{inic}), maximum pasting viscosity (V_{max}), and final pasting viscosity (V_{end}) of extruded corn grits and bagasse barley, in function of bagasse barley (X_1, %), moisture of mixing ratio (X_2, %), and temperature of the third extrusion zone (X_3, °C).

Trials	X_1	X_2	X_3	WSI	WAI	REI	DAP	$V_{inic.}$	$V_{max.}$	$V_{end.}$
1	18.04	18.81	128.11	1.72	4.66	1.23	1.65	17.0	742.5	1708.0

doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

2	18.04	18.81	151.89	1.93	5.00	1.42	1.52	18.0	644.5	1482.0
3	18.04	21.19	128.11	2.39	5.37	1.17	1.63	13.5	704.5	1559.0
4	18.04	21.19	151.89	1.44	5.23	1.37	1.44	38.0	644.5	1397.0
5	26.96	18.81	128.11	2.26	5.12	1.28	1.54	80.5	231.5	393.5
6	26.96	18.81	151.89	1.98	4.87	1.19	1.62	38.0	280.5	546.5
7	26.96	21.19	128.11	4.45	5.59	1.06	1.71	11.5	398.0	777.0
8	26.96	21.19	151.89	3.27	5.57	1.39	1.26	8.0	260.5	392.5
9	15.00	20.00	140.00	1.54	5.04	1.42	1.41	10.5	613.5	1279.0
10	30.00	20.00	140.00	2.4	5.28	1.19	1.44	13.5	290.5	582.5
11	22.50	18.00	140.00	1.94	4.63	1.35	1.37	17.0	446.5	894.0
12	22.50	22.00	140.00	2.67	5.50	1.23	1.63	0.5	439.0	858.0
13	22.50	20.00	120.00	2.74	5.27	1.17	1.77	40.5	465.5	884.0
14	22.50	20.00	160.00	2.97	5.55	1.44	1.39	0.0	317.0	540.0
15	22.50	20.00	140.00	2.75	5.00	1.25	1.42	15.0	438.0	915.5
16	22.50	20.00	140.00	2.69	5.24	1.21	1.40	0.0	391.5	811.0
17	22.50	20.00	140.00	2.2	4.80	1.17	1.54	0.0	462.0	1039.0
18	22.50	20.00	140.00	1.88	5.15	1.23	1.52	11.5	405.5	811.5
19	22.50	20.00	140.00	1.57	5.83	1.32	1.52	19.0	425.5	832.5

Essa variabilidade, provavelmente, seria detectada com o desenvolvimento da planta Applying the surface response methodology results in Table 3, was obtained correlation coefficients (R2), regression coefficients and their values of the F test applied to their statistical significance, as shown in Tables 4 and 5.

According the processing conditions, the REI of extruded corn grits and bagasse barley flour ranged from 1.06 to 1.44. Table 4 presents the regression coefficients for the response variable REI of extruded. Among the factors that make up the model, there was linear contribution of the percentage of crushed barley at a significance level of 5%. In addition, variable temperature and linear intercept were significant at 1%. The graphic three-dimensional response surface (Figure 1A) represents the effect of variables decoded bagasse barley (%) and temperature of the third extrusion zone (°C), the rate of radial expansion of extruded.

Table 4. F-test and regression coefficients of the parameters of the statistical model of the dependent variables rate of radial expansion (REI), apparent density (DAP), water solubility index (WSI) and water absorption index (WAI) of extruded corn grits and bagasse barley, in function of bagasse barley (X_1, %), moisture of mixing ratio (X_2, %), and temperature of the third extrusion zone (X_3, °C).

Variable[a]	REI		DAP (g cm^{-3})		WSI (%)		WAI (g gel g^{-1} dry basis)	
Intercept	-	1.24**	-	1.48**	-	2,22**	-	5,21**
X_1	6.50*	-0.05*	0.02^{ns}	0.00^{ns}	11,91**	0,43**	1,57^{ns}	0,09^{ns}
X_1^2	0.71^{ns}	0.02^{ns}	0.13^{ns}	-0.01^{ns}	0,39^{ns}	-0,08^{ns}	0,09^{ns}	-0,02^{ns}

Revista Agrotecnologia, Ipameri, v.7, n.2, p.27-39, 2016
doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

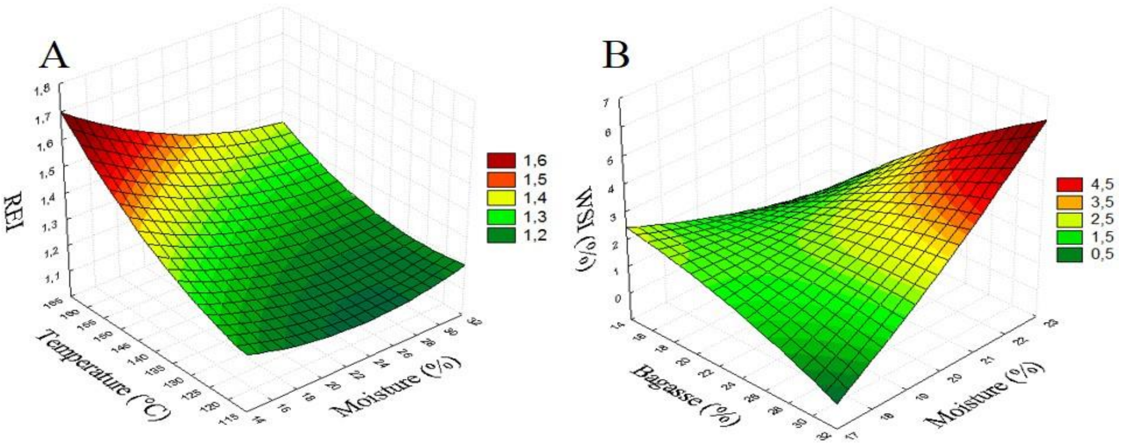
X_2	1.66^{ns}	-0.02^{ns}	0.15^{ns}	0.01^{ns}	8,10*	0,36*	12,00**	0,26**
X_2^2	0.31^{ns}	0.01^{ns}	0.34^{ns}	0.02^{ns}	0,10^{ns}	0,04^{ns}	0,56^{ns}	-0,06^{ns}
X_3	17.72**	0.08**	11.98**	-0.10**	1,11^{ns}	-0,13^{ns}	0,15^{ns}	0,03^{ns}
X_3^2	0.71^{ns}	0.02^{ns}	2.51^{ns}	0.04^{ns}	3,48^{ns}	0,23^{ns}	0,74^{ns}	0,07^{ns}
$X_1 X_2$	0.21^{ns}	0.01^{ns}	0.09^{ns}	-0.01^{ns}	6,30*	0,41*	0,08^{ns}	0,03^{ns}
$X_1 X_3$	0.58^{ns}	-0.02^{ns}	0.03^{ns}	-0.01^{ns}	0,30^{ns}	-0,09^{ns}	0,35^{ns}	-0,06^{ns}
X_2X_3	4.76^{ns}	0.05^{ns}	4.03^{ns}	-0.07^{ns}	2,46^{ns}	-0,26^{ns}	0,10^{ns}	-0,03^{ns}
R^2	0.785		0.683		0.793		0.639	

n.s. = not significant at 5% probability; - = no determinate; ** = significant at 1% probability, * = significant at 5% probability

Table 5. F-test and regression coefficients of the parameters of the statistical model of the dependent variables initial viscosity (V_{inic}), maximum viscosity (V_{max}), and end viscosity (V_{end}) of extruded corn grits and bagasse barley, in function of bagasse barley (X_1, %), moisture of mixing ratio (X_2, %), and temperature of the third extrusion zone (X_3, °C).

Variable[a]	$V_{inic.}$(cP)		$V_{máx.}$ (cP)		V_{end} (cP)	
Intercept	-	7.24^{ns}	-	422.20**	-	874,35**
X_1	1.24^{ns}	4.14^{ns}	53.35**	-154.41**	35,72**	-381,34**
X_1^2	1.51^{ns}	4.57^{ns}	1.12^{ns}	22.39^{ns}	0,85 ^{ns}	58,83 ^{ns}
X_2	4.71^{ns}	-8.07^{ns}	0.11^{ns}	7.02^{ns}	0,01 ^{ns}	-4,76 ^{ns}
X_2^2	0.85^{ns}	3.42^{ns}	0.82^{ns}	19.12^{ns}	0,38 ^{ns}	39,48 ^{ns}
X_3	3.34^{ns}	-6.80^{ns}	2.95^{ns}	-36.34^{ns}	1,89 ^{ns}	-87,72 ^{ns}
X_3^2	3.59^{ns}	7.05^{ns}	0.00^{ns}	0.91^{ns}	0,08 ^{ns}	-18,51 ^{ns}
$X_1 X_2$	8.82*	-14.44*	0.70^{ns}	23.06^{ns}	0,48 ^{ns}	57,94 ^{ns}
$X_1 X_3$	3.38^{ns}	-8.94^{ns}	0.10^{ns}	8.69^{ns}	0,06 ^{ns}	19,56 ^{ns}
X_2X_3	2.58^{ns}	7.81^{ns}	0.45^{ns}	-18.56^{ns}	0,50 ^{ns}	-59,19 ^{ns}
R^2	0.762		0.868		0.816	

n.s. = not significant at 5% probability; - = no determinate; ** = significant at 1% probability, * = significant at 5% probability.



Revista Agrotecnologia, Ipameri, v.7, n.2, p.27-39, 2016
doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

Figure 1. Effect of quantitative variables of the: A) third zone temperature and moisture (%) of extruded in rate of radial expansion (REI), and B) bagasse barley and moisture in water absorption index (WAI) of extruded corn grits and bagasse barley.

The analysis of Figure 1A shows a decline in the radial expansion index due to the addition of bagasse barley. This finding may be related to two factors. The first is the increase of fibrous materials include cellulose, hemicellulose and lignin. These materials tend to remain firm and stable during processing without its small size during extrusion, ie, the physical presence of these materials in the cell walls of air reduces the potential for expansion of the starch mixture.

The second factor is related to the reduction of starch content. The maximum degree of expansion is closely related to starch content, with maximum expansion obtained with pure starches.

In addition to the above observations, analysis of the response surface (Figure 1A) shows that the expansion of the material increases as temperature is increased. According to Ding et al. (2005), it is expected that an increase in temperature reduces the viscosity of the melting material favoring the growth of bubbles leading to production of extruded low-density cell thinner and more crispy.

The apparent density is generally correlated with the REI. Extruded with high rates of radial expansion tend to have lower density, because the formation of air bubbles in the internal structure of the material increases the volume of extruded and consequently reduces its weight, thus increasing the crispness (DING et al., 2005).

The results indicate that the highest and lowest value of DAP (1.40 and 1.77 $g.cm^{-3}$) were obtained at a temperature of 120 °C and 140 °C, respectively, with 20% moisture and 22.5% of bagasse barley in both situations. The results presented are consistent with those reported above for the extruded more DAP showed REI lower (1.17) and lower extruded DAP showed REI equal to 1.21.

The determination coefficient (Table 4) showed a low value (0.683), explaining 68.3% of the total variation of the response variable about the mean and 31.7% attributed to residue, providing evidence that this model is predictive, not justifying the construction of graphs.

The water absorption index is related to the availability of hydrophilic groups (-OH) to bind to water molecules, and the ability of starch molecules to form gels, and only the starch granules, gelatinized, absorb water at room temperature and swell.

According to the results presented in Table 3 shows that the extruded had WAI between 4.63 and 5.83 g gel g^{-1} dry basis. Table 4 shows that only the linear coefficient of variable moisture and intercept is shown to be significant ($p \leq 0.01$), with higher values of WAI were hit with moisture of 20% and the lowest values occurred with moisture of 18 %.

The above observation can be explained based on the fact that in samples with higher moisture content, even at high temperatures, there is less degradation of starch, ie, there is less breakage and therefore there is greater water absorption. On the other hand, considering that the incorporation of materials with high fiber content extruded starch formulas result in a decrease of hydrophilic interaction since the melting process of fibers can be form barriers preventing the same structure formation to higher water absorption degree. In this case the fibers, polymers with high molecular weight are very different connections to those starch structures composed of amylose and amylopectin are not very compatible for good results in the expansion.

The coefficient of determination (R^2) for the model applied was low (0.639), explaining only 63.9% of the total variation of the response variable about the mean and 36.1% is attributed to the residue by providing evidence that the model adopted is invalid for predictive purposes, not thus justifying the presentation of graphics.

The WSI is widely used to measure the solubility of the extruded starch in drinks, soups, flour for solubilization in aqueous media and for the characterization of "snacks" because it is related to the degree of expansion (SILVA, 2010). According to Ascheri et al. (2002), the WSI expresses the percentage of dry raw materials recovered after evaporation of the supernatant of the determination of water absorption and is related to the amount of soluble molecules in the sample and measures the dry dextrinization. This index increases with the severity of the treatment. According to the results presented in Table 3, note that the extruded flour crushed barley and corn grits had index values of solubility in water between 1.54 and 4.45%. For the analysis of Table 4 shows that the linear coefficient of the percentage of bagasse and fatted intercept was highly significant ($p \leq 0.01$) and the linear coefficient of moisture and interaction between the variables percentage of bagasse barley and moisture were significant at 5%.

Figure 1B shows that the higher the moisture and the greater the percentage of bagasse barley, the greater the WSI. The analysis of Table 4 shows that the linear variable percentage of bagasse barley interfered more in the values of the variable linear WSI moisture. High moisture levels cause reduced friction of the screw and the inner wall of the tube extruder on the starch molecules due to the water running as a lubricant in the middle, thus resulting in less degradation of amylose and amylopectin which culminates in lower WSI (CARVALHO et al., 2002).

However, in this case, the increase of bagasse barley may have led to an increase in shear rate and, consequently, a higher level of degradation of starch granules, and higher water solubility index.

The Vinic parameter is related to the gelatinization of starch present in the material and breaks the molecules during the extrusion process indicating the capacity of the extruded flour to absorb water at room temperature to form paste, gel or viscous liquid. According to Teba et al. (2009), the greater the degree of gelatinization, is a consequently higher the initial viscosity.

The initial viscosity values ranged from 0 to 80.5 cP. The low values of this parameter may be due to the high protein content and the presence of bagasse fiber in barley. The increase of this material decreases the proportion of starchy material and, moreover, the fibers do not provide sufficient added viscous material causing the decrease of starch gelatinization, which was also observed by Ascheri et al. (2006) in working with mixed rice flour and bagasse jabuticaba.

Regarding the regression coefficients, Table 5 shows that only the interaction between moisture and formulation was significant at 5% confidence presenting negative effect on pulp viscosity values at 25 °C.

Figure 2A represents the effect of varying percentage of bagasse barley and moisture in the initial viscosity.

For the analysis this figure shows that the highest values of peak viscosity at 25 °C are achieved when the percentage of bagasse barley is their highest levels an concomitantly moisture is at its lowest levels. The reduction in water content coupled with the

increase of bagasse barley may have led to a longer residence time and greater friction in the extruder culminating in greater mechanical degradation of starch granules and, consequently, increased gelatinization of them.

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doi: 10.12971/2179-5959/agrotecnologia.v7n2p27-39

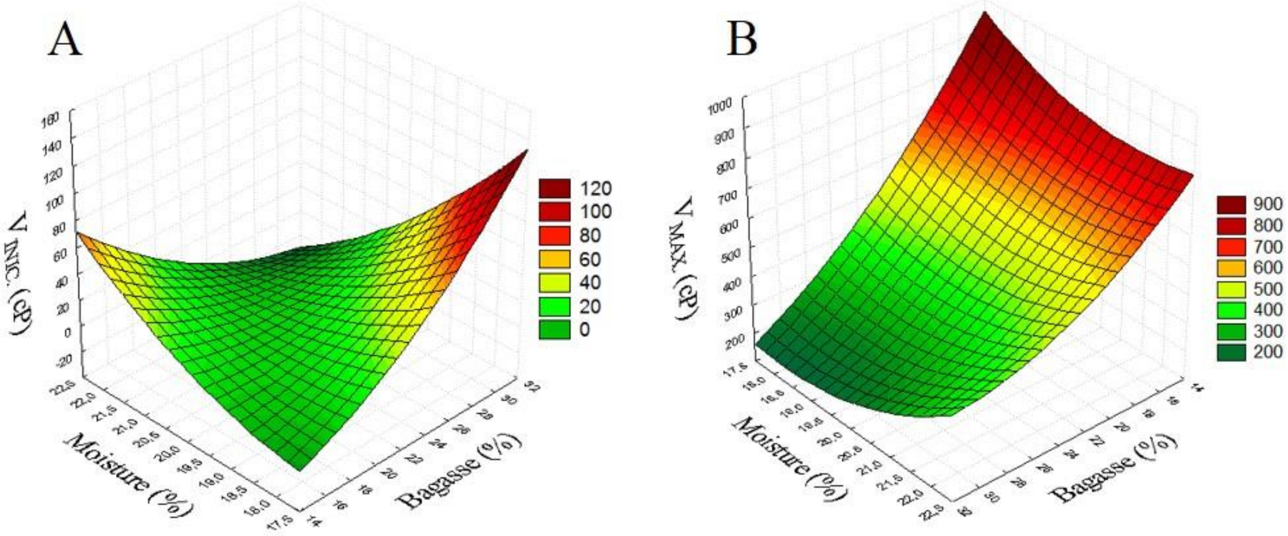

Figure 2. Effect of quantitative variables of the moisture and bagasse barley in: A) initial viscosity (Vinic), and B) maximum viscosity (Vmax) of extruded corn grits and bagasse barley

The resistance of the starch granule to collapse resulting from the action of temperature and mechanical stress in viscoamilograf is measured by the viscosity of paste at 95 °C. At this stage of the heating cycle is swelling and gelatinization of starch granules reaching a viscosity peak.

According to Carvalho et al. (2002) and Teba et al. (2009), the maximum viscosity at 95 °C is intrinsically related to the conditions of the extrusion process, and the severe heat treatment combined with low moisture can lead to destruction of the crystalline structure of starch, so that in the heating cycle, viscoamilogram the present lack of a peak or very low viscosity. The opposite leads to conservation of starch structure culminating in relatively high pasting viscosity values because of the higher number of beads in terms of swelling.

The regression coefficients results for Vmax. are presented in Table 5. It is observed that the linear variable bagasse barley and intercept were highly significant ($p \leq 0.01$). The linear effect of the variable percentage of bagasse barley was negative, indicating that the change in value of maximum viscosity is inversely proportional to the increase of it.

In Figure 2B, it is observed that as moisture is increased, it increases also the Vmax. There is also that the increase in the proportion of bagasse barley led to a reduction of viscosity.

The increase of bagasse barley leads to decreased amount of starch and increased protein content. According to Clerici and El-Dash (2008), the decrease in starch concentration causes a decrease in the number of beads and hence the viscosity in the same temperature as the presence of soluble starch and the interaction between the swollen granules are responsible for the viscosity of a suspension of gelatinized starch.

Furthermore, high moisture levels in the lower friction extruder consequently a smaller amount of starch granules degrades. As mentioned previously, the maximum viscosity is related to the level of degradation suffered by the bead resulting in higher values when preserving the integrity of starchy material, which justifies the above results found.

According to Silva (2010), the end viscosity is a characteristic that is directly related to the composition of the raw material used and the changes that occur in the structures of molecules and the bead during processing by extrusion.

During heating starch products, followed by gelatinization and cooling of starch granules

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is the process of downgrading (BOBBIO; BOBBIO, 2003). In determining the pasting viscosity the cooling cycle usually shows the tendency to retrogradation. According to Silva (2010), this phenomenon is due to the effect of recrystallization of amylose and amylopectin molecules, culminating in the reorganization of molecular structure and, consequently, increasing the final viscosity.

The analysis of the regression coefficients (Table 5) shows that only the intercept and the linear variable percentage of bagasse barley were significant ($p \leq 0.01$).

From Figure 3, shows that the increase in the percentage of bagasse barley culminates in lower final viscosity.

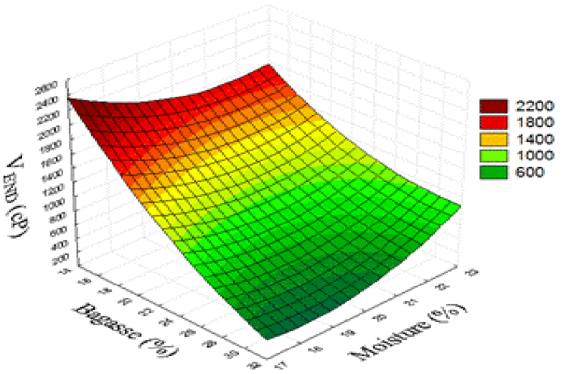

Figure 3. Effect of quantitative variables moisture and bagasse barley in the end viscosity (Vend) of extruded corn gritz and bagasse barley.

The reduction observed can be related to the decrease in starch content due to increased bagasse barley. The high levels of protein, fiber and lipids present in the residue of barley are responsible for the pasting properties presented.

CONCLUSIONS

The results indicated that the rate of radial expansion decreased with the addition of bagasse barley and increased with increasing temperature. The temperature has a negative effect on the density while the water absorption index was directly proportional to this variable. The water content and formulation positively affect the water solubility index. The formulation was the variable of greatest significance on the pasting properties: the initial viscosity was directly proportional to the addition of bagasse barley and maximum and final viscosity were inversely proportional to the increase of bagasse barley.

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