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Characterization and proposal of potential use in foods of coproducts from waxy maize wet milling

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Abstract

The aim of this study was to characterize the corn gluten feed and corn gluten meal originated from waxy maize wet milling industry, in relation to its microbiological risk and physical, chemical and functional properties. The wet residues showed microbiological standards for human consumption. Maize gluten meal was characterized by having high protein content (32 g 100 g^{-1}), lipids (16 g 100 g^{-1}) and carbohydrates (45 g 100 g^{-1}), whereas the maize gluten feed contains high content of dietary fiber (44 g 100 g^{-1}). The maize gluten feed and maize gluten meal have high potential for application as food ingredient. The high dietary fiber, suggests its use as a promising ingredient to increase the availability of fibers, thereby increasing attractiveness and nutritional quality of food. Furthermore, the use of this coproduct of waxy starch may be an alternative to traditional fibers used in the production of bakery products already before with claimed functional and health properties.

Keywords: waxy maize coproduct; microbiological risk; proximal composition; food ingredient.

Practical Application: Use the coproduct as an ingredient in food industry.

1 Introduction

Maize (*Zea mays* L.) is a cereal grain mainly used as human food, followed by its use in animal feeding and ethanol production. The main maize grain structure consists of the pericarp (seed coat), endosperm and embryo (germ) (Singh et al., 2014). Grinding removes some of the outer layers of maize, which is the coproduct. The coproduct is generally used as animal feed, resulting in loss of most vitamins and minerals (Ranum et al., 2014). The most coproducts of maize processing are high in lipids and proteins. Moreover, the maize gluten feed is recognized as a fiber source (Robin et al., 2012).

The most used processing of maize is wet milling. The germ is separated for the production of oil, generating as residue maize germ bran (Barnwal et al., 2013). In wet milling, maize grains are fractionated in different components, resulting in many residues (Rausch & Belyea, 2006). These residues are typically recombined to produce proteinaceous maize bran (maize gluten feed) used mostly as animal feed (Schroeder, 2003; Malumba et al., 2015). Physicochemical profile of these residues is already well defined (Malumba et al., 2015). The much of the grain nutrients is retained in the residues obtained from starch extraction, and still carries intrinsic nutritional characteristics of maize as a source of protein, lipid and fiber (Rose et al., 2010; Robin et al., 2012; Singh et al., 2012). Consequently they still have favorable functional properties little explored for human consumption.

In this study, the waxy maize wet milling is from whole grains (without degermination stage). Two wet residues are obtained in large volume with low commercial value, and have not yet been evaluated their potential for use as human food. This large volume of residue coupled with the difficulty of flow, limits the industry's production capacity. However, little is known about the residues obtained from the wet extraction of waxy maize starch. Waxy starches are defined as having an exceptionally high amylopectin content.

The characterization of these residues is critical for their exploration and to check their potential for use in human food. After characterization, it is necessary to transform these residues into raw materials for use in the preparation of food that will, in addition to sustainability for the manufacturing industry, bring new opportunities for the food industry. This study is part of a Research Network for Agroindustrial Waste linked to the Research Foundation of the State of Goiás (FAPEG), which aims to develop technological research for the business environment of Goiás, Brazil. Therefore, the aim of this study was to characterize the corn gluten feed and corn gluten meal originated from waxy maize wet milling industry, in relation to its microbiological risk and physical, chemical and functional properties.

2 Materials and methods

2.1 Obtaining residues

Residues were collected directly from the production line and donated by the company Febela Agroindustrial, located on Piracanjuba Farm, municipality of Bela Vista de Goiás, Goiás, Brazil. The residues were packed in sterile polyethylene bags and

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transported under refrigeration for immediate microbiological analysis and drying of the residue.

The residues were obtained during the production of waxy maize starch that occurs from the grain milling, i.e., without prior removal of the germ. The steps used in the industry are: receiving and cleaning the grain, maceration, grinding, sieving, centrifugation and then separation of the starch (Figure 1).

2.2 Obtaining coproducts

The residues were dried in convective dryer tray with air temperature of 65 °C for 12 hours and 70 °C for a further 12 hours. The dryer trays were a distance of 150 mm from each other (TE, 394/4, Tecnal, Piracicaba).

Coproducts were ground in cyclone rotor mill (TE, 651/2/4, Tecnal, Piracicaba). Coproduct of each residue were packed separately in low density polyethylene bags and stored in a horizontal freezer and kept at -10 °C until the completion of the analysis.

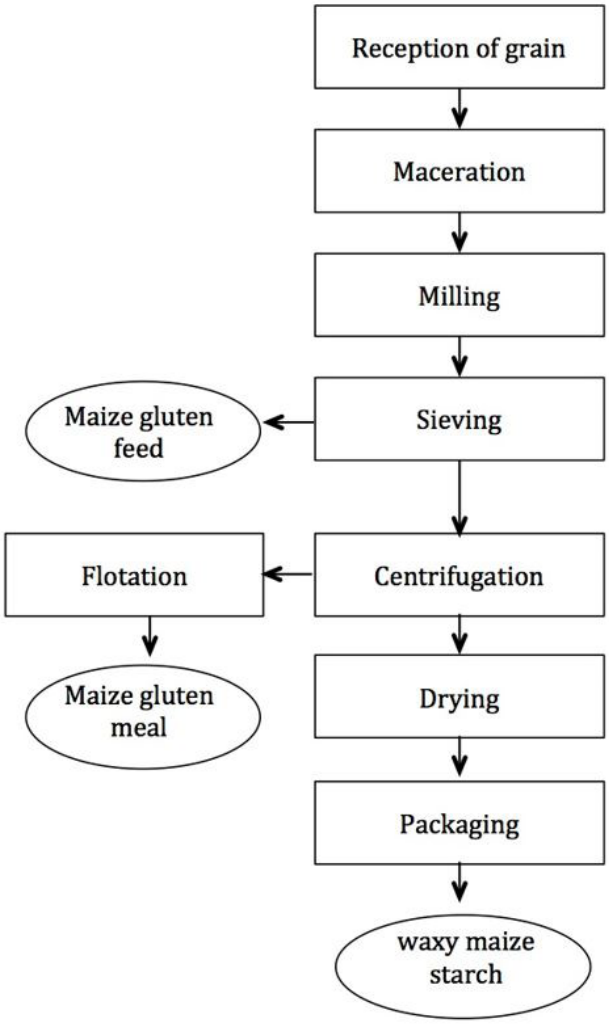

Figure 1. Flow chart of the steps for obtaining a wet waxy maize starch, and respective stages of separation of the wet maize gluten feed and wet maize gluten meal.

2.3 Microbiological risk

Microbiological analyzes of residues and their coproducts were carried out considering the standards set the Brazilian health legislation (RDC 12 in Brasil, 2001) using the microbiological standards (*Bacillus cereus*, coliforms at 45 °C and *Salmonella sp*) for food, specifically item 10 for brans and flours (Brasil, 2001). In the residues, the counting of molds and yeasts also was performed, and *Staphylococcus aureus* as well. Analyzes were performed according to the techniques described in the American Public Health Association (Downes & Ito, 2001) and Food and Drug Administration (2002).

2.4 Physicochemical analyzes

For the granulometric classification, 100 g of maize gluten feed and maize gluten meal were sieved through a set of five rounded screens grid using an electromagnetic stirrer (Bertel, 09/14, Caieiras, Brazil) for 10 min at maximum speed. Then, the amounts retained on each sieve were weighed and the percentage of particles retained on each sieve was obtained. The coproducts were separated in six fractions with particle size larger than 1 mm, between 1 mm and 0.71 mm, between 0.71 mm and 0.5 mm, between 0.5 mm and 0.25 mm; between 0.25 mm and 0.15 mm; and smaller than 0.15 mm.

Instrumental color of maize gluten feed and maize gluten meal were evaluated by CIELab coordinate system, using a spectrophotometer (Konica Minolta, BC-10, Tokyo, Japan). It was obtained values of L* (lightness), a * (green - / red +), and b * (blue - /yellow +). Hue angle (H°) and Chroma (C) values were calculated (Equations 1 and 2, respectively) (Kang, 2006).

$$H° = tan^{-1}\left[b^* / a^*\right] \quad (1)$$

$$C = \left[\left(a^*\right)^2 + \left(b^*\right)^2\right]^{1/2} \quad (2)$$

The moisture content of the sample was determined by weight loss, after heated at 105 °C to constant weight; the ash content through carbonization by complete incineration in a muffle furnace at 550 °C; total nitrogen by the Kjeldahl method, multiplying by 6.25 to estimate the crude protein content; lipids, after extraction with petroleum ether in a Soxhlet extractor; and the total dietary fiber by enzymatic-gravimetric method; all recommended by Association of Official Analytical Chemists (2010), methods 925.10, 923.03, 31.108, 920.39C and 985.29, respectively. Carbohydrates were calculated by subtracting the moisture, ash, protein, lipids and total dietary fiber from one hundred.

Water solubility index (WSI) and water absorption index (WAI) were performed according to the methodology proposed by Schoch (1964). All analyzes were performed in a triplicate.

2.5 Data analysis

Complete randomized design with three replications was used. The means of moisture, protein, fat, ash, total dietary fiber, WSI, WSI, and L*, a *, b *, H° and C were subjected to multiple comparison test of Scott-Knott at 5% significance

level. Statistical analyzes was supported by R-project computer application (R Development Core Team, 2018).

3 Results and discussion

3.1 Microbiological risk

Maize gluten feed and maize gluten meal were obtained from waxy maize processing after artificial drying can be defined as brans, according to Brazilian health legislation published as RDC 263 (Brasil, 2005). This food group includes products derived from cereal grains and / or leguminous processing, mainly made up of hull and / or germ, and may contain parts of the endosperm. Microbiological analysis of the wet coproducts was performed to verify the possible need for treatment to control the population of microorganisms (Table 1).

Both residues showed values for *Bacillus cereus*, coliforms at 45 °C and *Salmonella sp*. below the limits set by the regulation (Brasil, 2001). These results showed that the residues obtained from waxy maize processing showed microbiological standards for human consumption, allowing drying it directly without treatment to reduce the microbial load. Wet maize gluten meal had count of *Staphylococcus aureus*, *Bacillus cereus*, and Coliforms at 45 °C lower than the wet maize gluten feed (Table 1). This may be due to the high temperature (75 °C) used during the decantation process of Maize gluten meal. Moreover, there was an increase in yeasts and molds counts and sporulation of *Clostridium* sulphite reductors in the maize gluten meal compared to the maize gluten feed. These variations can also be justified by the high temperature conditions subjected for the maize gluten meal only.

Brazilian law does not determine the amount of total fungi allowed in brans, or in similar products. However, hygiene standards must be established in the industry for drying, and also during storage of wet coproducts, when necessary. This occurs because the coproducts obtained from waxy maize starch processing have factors that potentially favor the proliferation of fungi and yeast, i.e., conditions of high moisture (78.12 ± 0.18 g 100 g^{-1} and 55.65 ± 0.21 g 100 g^{-1}, respectively) and temperatures (about 40 and 75 °C, respectively).

After drying the residues (65 °C until 70 °C), the coproducts remained within the microbiological specifications for foods (Brasil, 2001). Microbiological evaluation of the brans presented values below 100 CFU g^{-1} for *Bacillus cereus*, Coliform at 45 °C, and absence of *Salmonella sp*.

The coproducts had moisture contents of 4.27 ± 0.16 g 100 g^{-1} and 4.71 ± 0.03 g 100 g^{-1}, respectively. Both below the maximum moisture limit set by law for brans, which is 15 g 100 g^{-1} (Brasil, 2005). In addition to meeting the maximum moisture, the conditions of low moisture content of the brans were also useful to facilitate the grinding process.

3.2 Coproducts processing

Due to the high fat content, the maize gluten meal showed a long period of retention in the mill chamber with 0.5 mm sieve retention, and it was necessary to use a retaining sieve with hole diameter of 0.75 mm. The coproducts showed differing granulometric characteristics (Table 2, Figure 2). Maize gluten feed showed easier grinding and 87.8% of the particles passed through a sieve with 0.5 mm aperture. Only 26.6% of maize gluten meal particles passed through the same sieve, suggesting the need to go through a greater number of steps to obtain finer bran.

Table 1. Results of microbiological analyzes of the wet and dry maize gluten feed and maize gluten meal obtained from waxy maize processing.

Microrganism	Maize gluten feed		Maize gluten meal		MAV*
	wet	dry	wet	dry	
Yeasts and molds (CFU g^{-1})	880	absent	4320	absent	NE
Staphylococcus aureus (CFU g^{-1})	960	absent	49	absent	NE
Bacillus cereus (CFU g^{-1})	524	<10	212	<10	$5x10^3$
Heat-resistant coliform (45 °C) (CFU g^{-1})	261	<10	34	<10	$5x10^2$
Sulfite-reducing Clostridia (CFU g^{-1})	absent	absent	2	absent	NE
Salmonella sp. (CFU 25 g^{-1})	absent	absent	absent	absent	absent

*MAV = maximum allowed value as stated by Brazilian health legislation RDC 12 (Brasil, 2001); CFU = colony forming units per gram of sample; NE = limit not established by Anvisa.

Table 2. Characteristics of coproducts grain size obtained from two residues generated from waxy maize starch through wet processing.

Hole sieve (mm)	Percentage of particles retained	
	Maize gluten feed	Maize gluten meal
1.00	0.1	2.8
0.71	1.2	39.4
0.50	11.2	31.8
0.25	41.7	19.3
0.15	32.8	6.5
Less than 0.15*	13.3	0.8

*Background.

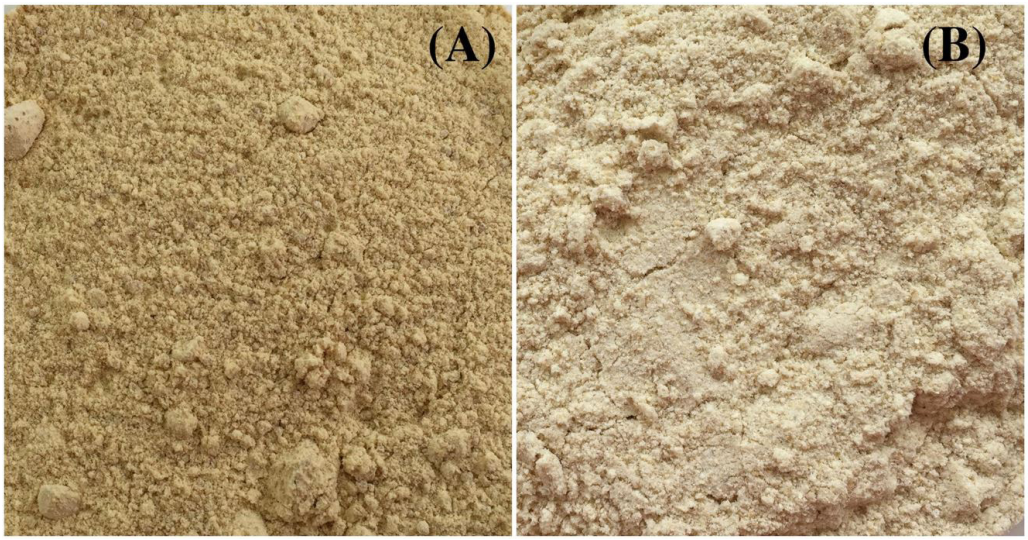

Figure 2. Photos of dry coproducts, maize gluten feed (A) and maize gluten meal (B).

Table 3. Means followed by standard deviation of the physical, chemical and functional properties of coproducts from two residues generated from waxy maize starch wet processing.

Parameter[1]	Maize gluten feed	Maize gluten meal
Luminosity	79.54a ± 1.00	69.30b ± 1.03
a*	2.08b ± 1.04	4.18a ± 1.02
b*	26.14b ± 0.90	35.71a ± 0.85
Hue angle (H°)	26.24b ± 0.96	35.97a ± 0.95
Chroma (C)	1.49a ± 0.04	1.46a ± 0.03
Ash[2]	0.74a ± 0.01	0.74a ± 0.01
Protein[2]	10.08b ± 0.13	32.50a ± 0.31
Lipid[2]	5.53b ± 0.31	16.72a ± 0.29
Carbohydrates[2,6]	39.53	45.39
Dietary fiber[2]	44.12a ± 0.62	4.65b ± 0.80
Soluble dietary fiber[2,7]	36.02	ND[5]
Water solubility index[3]	3.68a ± 0.18	2.11b ± 0.14
Water absorption index[4]	3.22a ± 0.23	1.79b ± 0.11

[1]Means with different letters in the same row are statistically different by the Scott-Knott test ($p \leq 0.05$); [2]g 100 g^{-1} (dry basis); [3]%; [4]g gel g sample (dry basis)$^{-1}$; [5]Not determined; [6]Exclude fibers; [7]Part of the total fibers.

3.3 Physical, chemical and functional properties

The values of a* (green - / red +) and b* (blue - /yellow +) of both coproducts are positive values (Table 3), characterizing maize gluten feed with red and yellow pigmentation, and maize gluten meal showing significantly higher averages in relation to maize gluten feed. The most yellowish pigmentation of the maize gluten feed can be seen in the Figure 2B and Figure 3B. The hue angle (H°) allows the distinction in relation to these colors. The maize gluten meal showed higher mean H°, i.e., greater inclination for coordinate b* (yellow) in relation to coordinate a* (red), with lower average for luminosity. Then, according to the parameters of the Cielab system, maize gluten meal is more yellow and darker than the maize gluten feed. The values of C (chrome) were no significant differences. Maize gluten feed and maize gluten meal had different colors but with the same saturation or color's intensity.

The levels of proteins, lipids and carbohydrates were higher in maize gluten meal (Figure 2B), whereas maize gluten feed (Figure 2A) had higher total dietary fiber content (Table 3). Maize gluten feed is the first to be separated from waxy maize starch extraction process and is characterized by high content of dietary fiber (44.12 g 100 g^{-1}), which is largely soluble (36.02 g 100 g^{-1}).

Fiber content in the maize gluten feed was higher than that found in the germ fraction with maize pericarp processed by Castro et al. (2011) and in the defatted maize germ with pericarp processed by Froes et al. (2012). In addition to protein, lipids and carbohydrates being similar to the defatted maize germ with pericarp, maize gluten feed showed functional properties, a

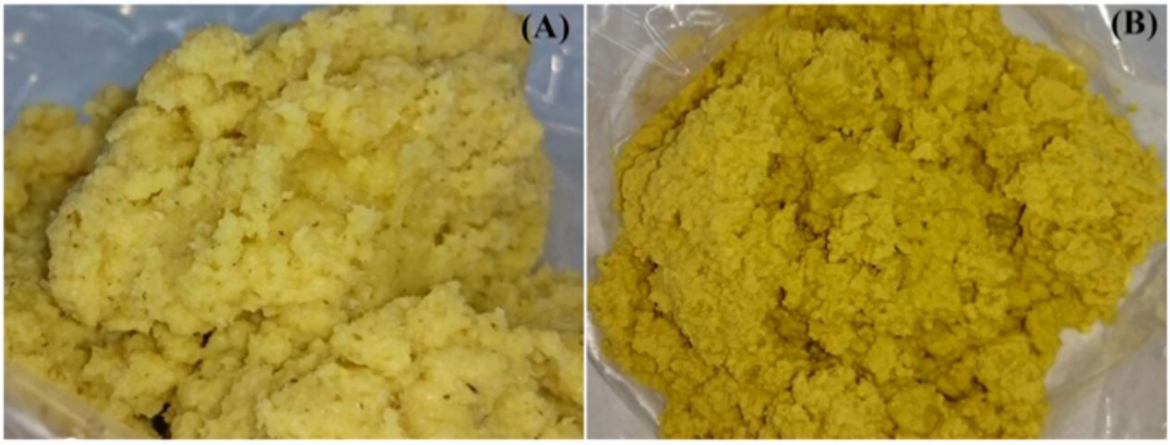

Figure 3. Photos of the wet maize gluten feed (A), and wet maize gluten meal (B).

claim allowed on foods with high fiber content (Food and Drug Administration, 2013).

Ten maize gluten feed from different starch industries located in China were a evaluated by Wang et al. (2014). The mean protein content was twice as high (21.8 g 100 g^{-1}) to found in waxy maize gluten feed (10.08 g 100 g^{-1}). Lipid content was similar (4.2 g 100 g^{-1}) to that found in waxy maize gluten feed (5.53 g 100 g^{-1}).

Researches of the maize gluten meal showed low fiber (0.8-2.4 g 100 g^{-1}), high protein content (65-71 g 100 g^{-1}) and low lipid (2.5-4.1 g 100 g^{-1}) (Neumann et al., 1984; Rausch & Belyea, 2006; Shukla & Cheryan, 2012, respectively). In relation to these values, waxy maize gluten meal showed lower protein content and higher lipid content, due presence of the germ during the process. It was expected to find higher protein content in both coproducts. This suggests losses of this nutrient in the process of recovery of residues.

There is evidence of the increasing importance of fiber rich food to health, due to the relationship of this component with decreased blood cholesterol, cancer protection, increased intestinal transit, intervention in the metabolism of lipids and carbohydrates and in the physiology of gastrointestinal tract (Ozen et al., 2012; Bigliardi & Galati, 2013). Therefore, the use of the maize gluten feed as raw materials may become a promising alternative to increase the availability of fiber in food products, thereby increasing its attractiveness and nutritional quality.

Maize gluten meal showed most of the energetic components (protein, lipid and carbohydrate) compared to maize gluten feed. The maize gluten meal can be considered as a potential source of high protein value. Fiber content of the maize gluten meal was 4.65 ± 0.80 g 100 g^{-1}, less than that found in maize gluten feed. Maize gluten meal, when used in the preparation of food products, will not add enough fibers to enable functional property claims to the final product.

Water solubility and water absorption of maize gluten feed were significantly higher than the maize gluten meal (Table 3). The main maize proteins are primarily defined by their solubility in selected solvents. Zein and glutenin fractions are the most abundant in maize grain representing approximately 80%, while globulins and albumins represent approximately 20%. The albumins exhibit high solubility in water (Anderson & Lamsal, 2011; Shukla & Cheryan, 2012). Given the above, smaller amounts of water-soluble molecules in the maize gluten meal was probably due to the high content of lipids, proteins with poor solubility in water and low fiber content.

Absorption capacity water retention and gel formation were higher for the maize gluten feed (Table 3), probably due to high fiber content. Since the particle size reduction increases significantly maize bran hydration capacity (Shevkani et al., 2014), the profile of smaller particles of the maize gluten feed (Table 3) was also a factor that caused greater water solubility and absorption. Paucean & Man (2013) observed that the increase in the capacity of water absorption was due to a replacement of the wheat corproduct mixture by defatted maize pericarp germ meal. The authors attributed the increase in water absorption because of the high fiber and protein in defatted maize pericarp germ meal. Gupta & Eggum (1998) and Hussein et al. (2013) reported that the wheat coproduct mixture with different types of coproduct rich in protein and crude fiber also increased water absorption index. The results showed here had some disagreement with the results of these authors. The highest rate of water absorption was greater with the maize gluten feed with high fiber content, however, with low protein content. This can be justified because of a high hydrophobicity of most maize proteins.

4 Conclusions

The wet coproducts obtained from waxy maize wet milling show adequate microbiological standards for human consumption, allowing the direct drying without a treatment to reduce the microbial load. The coproducts obtained from both residues have high potential for application as food ingredient. Maize gluten feed is characterized by high content of dietary fiber, which suggests its use as a promising raw material to increase the availability of fiber in food products. Maize gluten meal is characterized by high content of protein and lipid, i.e., a potential food source with high energy content. Maize

gluten feed has higher values of water solubility and absorption compared to maize gluten meal. The coproducts have red and yellow pigmentation, and maize gluten meal is more yellow and darker compared to maize gluten feed.

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