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Properties of High Amylose Maize Varieties for Use in Alkaline-Cooked Foods

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Abstract

The use of high amylose maize varieties significantly affected the alkaline-cooking process and characteristics of alkaline-processed food products, such as masa and tortilla chips. High amylose maize varieties had softer endosperm textures with more tightly attached pericarps than normal maize. Masa prepared from high amylose mutant maize was less cohesive than that of normal maize due to insufficient dispersion of amylopectin and excessive retrogradation of starches. Tortilla chips prepared from amylose-extender dull (*ae du*), amylomaize V, and VII had slightly increased oil absorption, while tortilla chips from dull (*du*) and amylose-extender sugary-2 (*ae su-2*) had oil contents similar to that of control chips. Increased oil absorption of the tortilla chips was due to their increased surface area. Tortilla chips produced from high amylose mutant maize had darker color than control chips, presumably due to the pigmented pericarp tissues, higher levels of reducing sugars, and phenolic compounds present in the kernel.

Key words: high amylose maize, amylose-extender, masa, tortilla chip

INTRODUCTION

Alkaline-cooked products, such as tortillas, tortilla chips, and corn chips, are prepared by a nixtamalization process. This process involves alkaline-cooking and steeping of maize kernels called nixtamals. Nixtamals are washed and stone-ground to form the dough, called masa. The masa is kneaded and molded, then baked to produce tortillas, which are fried for tortilla chips, corn chips, or dried to produce nixtamalized corn flour (1).

The characteristics of alkaline-cooked products are directly determined by the properties of starch used. In general, these starch properties are the result of factors such as gelatinization temperature, the fine structure of polysaccharides, and percentage distribution of amylose and amylopectin. Normal maize starch is composed of approximately 70～80% amylopectin and 20～30% amylose. The ratio of these two molecules in starch can be altered by genetic means. Modulating the expression of the amylose-extender (*ae*) gene plus modifiers can vary amylose content over a range of 50～80%. For example, in amylomaize V and VII, the amylose content is approximately 50～60% and 70～80%, respectively (2,3). Other mutant genes, such as the dull (*du*) and sugary-2 (*su-2*) genes also affect the starch composition (4).

Starch granules from high amylose maize showed a weak B type X-ray diffraction pattern, indicating less crystalline structure compared to those of normal and waxy maize (5). These starches frequently have amorphous extensions that result in granules with irregular shapes (6). High amylose starches form strong films and gels more rapidly than regular starches. The hydrogen bonds between linear amylose chains are responsible for the rigid gels and strong films. However, sufficient moisture and autoclaving are required to gelatinize and disperse amylomaize starches. High amylose starches have been used in extruded products, batters, and breadings to impart crispness and reduced oil content (7). Currently, high amylose starches are primarily used in cereal-based foods as a contributor to the dietary fiber content, since these starches are retrograded rapidly and are difficult to be hydrolyzed by enzymes. However, no published information is available for use of high amylose maize in the production of snack foods. Therefore, the objectives of this research were to examine the effects of high amylose mutant maize varieties on the alkaline-cooking properties and characteristics of tortilla chips.

MATERIALS AND METHODS

Materials

Five varieties of high amylose maize provided by American Maize Products Company (Hammond, IN, USA) were used: Dull (*du*), amylose-extender dull (*ae du*), amylose-

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extender sugary-2 (*ae su-2*), amylomaize V, and amylomaize VII. These samples were categorized into two groups: 1) high amylose maize varieties with gelatinization temperature below 100°C (*du* and *ae du*), 2) high amylose maize varieties with gelatinization temperature above 100°C (amylomaize V, VII, and *ae su-2*). The samples were cleaned using a seed screen and then stored at -4°C prior to experiments. Commercial food-grade yellow dent corn (Asgrow 404) was used as the control normal maize. Proximate composition and starch properties of high amylose maize varieties are shown in Table 1.

Physical properties of grain

Endosperm hardness was measured by a Tangential Abrasive Dehulling Device (TADD, Model 4E-115, Venables Machine Works Ltd., Saskatoon, Canada) (8). The density of maize kernel was determined using a multipycnometer (Model MUP-1/N232, Quantachrome Corp., Syosset, NY, USA) (8). Test weight was determined using cleaned grain and expressed as pounds per Winchester bushel. One hundred kernel weight was determined by counting and weighing 100 whole sound kernels. Pericarp removal was evaluated subjectively after staining the alkaline-cooked kernels with eosine Y and methylene blue (8).

Determination of water uptake and dry matter loss

Water uptake and dry matter loss of *du* and *ae du* during nixtamalization were determined using procedures described by Lee et al. (9). Amylose-extender sugary-2, amylomaize V, and VII were pressure-cooked due to their high gelatinization temperature. Five sets (0, 20, 40, 60, and 80 min) of duplicates of each sample (50±0.2 g) were placed in perforated nylon bags and steeped in 0.3% CaO solution (w/w) overnight at room temperature. Steeped samples were then pressure-cooked using the kitchen type pressure-cooker (Model 5F-502, Sears, IL, USA) and washed with running water, blotted dry, and weighed. Water uptake and dry matter loss were calculated using the following formulas:

Table 1. Proximate chemical composition and starch characteristics of high amylose maize varieties

Maize varieties	Starch[1)] Total starch (%)	Amylose (%)	G.T.[2)] (°C)	Lipid (%)	Protein (%)
du	62	31~35	71~74	5.0	12
ae du	60	45~50	68~72	5.5	14
ae su-2	58	63~68	-	6.0	14
Amylomaize V	65	55~65	-	6.0	12
Amylomaize VII	65	65~70	-	6.0	10

1)Values were reported on a dry basis and provided by American Maize Products Company.
2)G.T. denotes gelatinization temperature of starch.

$$\text{Moisture content } (\%) = \frac{(\text{wt. of wet nixtamal} - \text{wt. of dried nixtamal})}{\text{nixtamal wt.}} \times 100$$

$$\text{Dry matter loss } (\%) = \frac{(\text{dried grain wt.} - \text{dry wt. of nixtamal})}{\text{dried grain wt.}} \times 100$$

Tortilla chip preparation

Optimal tortilla chip processing conditions were determined using the standard normal maize (Asgrow 404) (9). Maize samples were placed in a perforated nylon bag and cooked in a steam kettle (TDC/2-20, Groen Div., Dover Corp., Elk Grove Village, IL, USA) containing a 0.3% CaO solution (w/w) for a predetermined optimal time period. After boiling, nixtamal was quenched to 68°C and steeped overnight. The cooking liquor was discarded, and nixtamals were washed and ground into masa using a commercial stone-grinder (Model CG, Casa Herrera Inc., CA, USA). During the grinding step, water was added at the rate of 850 mL/min to increase the moisture content to 52~54%. Masas were continuously sheeted and shaped into triangular tortilla pieces using a commercial sheeter/former (CH4-STM, Superior Food Machinery Inc., CA, USA), and baked into tortillas in an oven with three moving tiers (C0440, Superior Food Machinery Inc., CA, USA). Tortillas were baked for 50 sec with average temperatures of 343, 222, and 220°C for the first, second, and third tiers, respectively. Baked tortillas were cooled at room temperature, rested for 30 min, and deep-fat fried for 1 min in partially hydrogenated soybean oil at 190~195°C.

Due to the differences in starch characteristics and endosperm properties, the high amylose maize varieties were processed into tortilla chips using the same standard processing procedures except with the following modifications. Dull (*du*) and amylose-extender dull (*ae du*) were alkali-cooked for 27 and 37 min, respectively, and nixtamals were ground into masa without adding water. Amylomaize V, VII, and *ae su-2* were steeped in 0.3% CaO solution for 12 hr at room temperature, and then autoclaved at 20 kg cm^{-2} for 50 min, and nixtamals were ground without adding water.

Analytical methods

Moisture and oil contents were determined using standard AACC methods (10) 44-15A and 30-20, respectively. Colors of tortilla chips were measured with a Hunterlab Tristimulus color meter (Model D25M-9, Hunter Lab. Inc., Reston, VA, USA).

Statistical analysis

Data were analyzed using the SAS software (SAS Institute, Cary, NC, USA). Fisher's least significant difference (LSD) was used to assess significance of differences among means.

RESULTS AND DISCUSSION

Physical grain properties

High amylose maize varieties had lower test weights, 100 kernel weights, densities, and hardness than normal maize (Table 2). In addition, pericarps of high amylose varieties are firmly attached, and not removed during nixtamalization process (Table 2). Amylomaize VII had a relatively harder endosperm texture, while *du* had the softest endosperm texture among maize samples. Kernels of all high amylose maize varieties were much smaller than normal maize, except for the *du* variety. These results indicate that kernel characteristics of high amylose maize varieties are not suitable for the traditional alkaline-cooking process and require modified procedures to produce alkaline-cooked products.

Alkaline-cooking properties

The moisture content of *ae du* reached 55% after steeping overnight without cooking, and then slowly increased to 59% after 80 min cooking (Fig. 1). The moisture content of nixtamal prepared from *du* was lower than that of *ae du* nixtamal during the cooking trials, but *du* showed a similar moisture absorption pattern to that of *ae du*. During cooking and steeping, endosperm components of nixtamal, such as gelatinized starches, protein matrix, cell walls, and germ absorbed water (11). It is evident that most of the water absorbed in nixtamal was retained by the gelatinized starches due to their swelling and hydration capacity. However, *ae du* and *du* absorbed water rapidly during steeping without cooking, indicating that most of the absorbed water was held in the kernel presumably by filling the internal voids and hydrating cell components. Cox et al. (12) reported that corn initially absorbs water at a rapid rate to fill void pericarps through the tip cap by capillary action and enters the endosperm through the crown. Dry matter loss of *du* was lower than that of normal maize during cooking trials, while *ae du* had about the same dry matter losses as those of normal maize except for the 0 min cooking trial (Fig. 2). This was caused by incomplete removal of pericarps during nixtamalization.

Amylomaize V and VII had 56~57% moisture contents after steeping overnight in the lime solution, while *ae su-2* had slightly lower moisture uptake (Fig. 3). Moisture contents of pressure-cooked maize samples increased as pres-

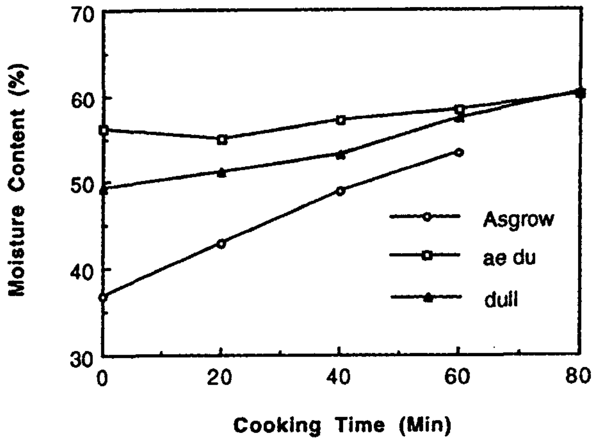

Fig. 1. Effects of alkaline-cooking time on moisture contents of high amylose maize varieties. The least significant difference (LSD, at α = 0.05) was 0.83.

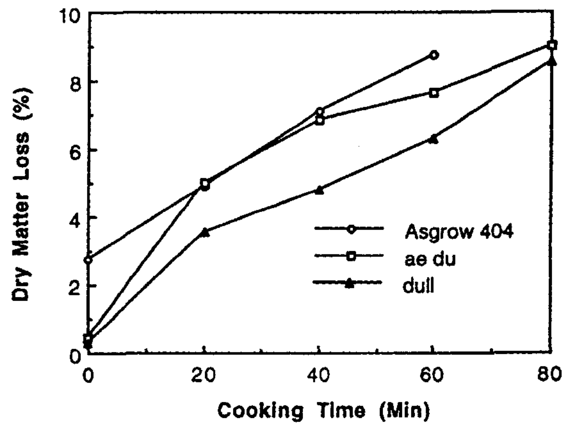

Fig. 2. Effects of alkaline-cooking time on dry matter loss of high amylose maize varieties. The least significant difference (LSD, at α = 0.05) was 1.14.

Table 2. Physical properties of normal and high amylose maize varieties[1)]

Maize varieties	Test wt. (lb/bu)	100 kernel wt. (g)	Density (g/cm^3)	Hardness[2)] (%)	Pericarp removal[3)]
Asgrow 404 (Control)	62.3	33.9	1.32	57.4	2.0
ae du	51.6	23.8	1.28	46.0	5.0
du	60.0	29.5	1.27	40.5	4.5
Amylomaize V	52.0	27.8	1.21	43.9	5.0
Amylomaize VII	52.6	27.0	1.26	53.7	5.0
ae su-2	55.0	28.1	1.25	48.7	5.0
LSD (0.05)[4)]	1.0	2.0	0.01	1.4	.

[1)]Values are means of three observations.
[2)]Calculated as percent material remained using a tangential abrasive dehulling device. Kernels that are harder give higher values.
[3)]Rated on a scale in which 1 represents complete removal and 5 represents no removal.
[4)]LSD (0.05): Least significant difference (α = 0.05).

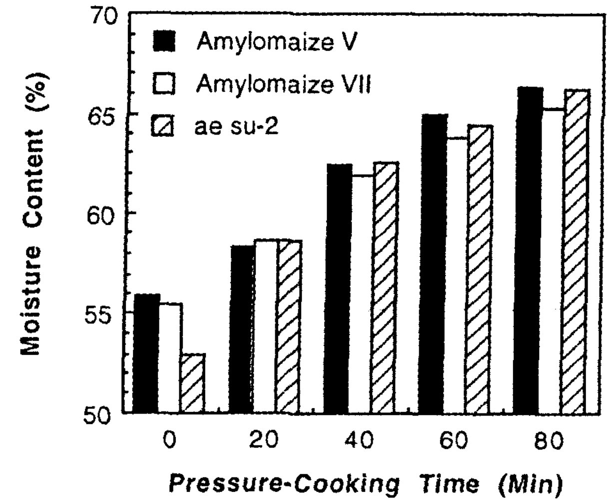

Fig. 3. Effects of pressure-cooking time on moisture contents of high amylose maize varieties. The least significant difference (LSD, at α = 0.05) was 0.80.

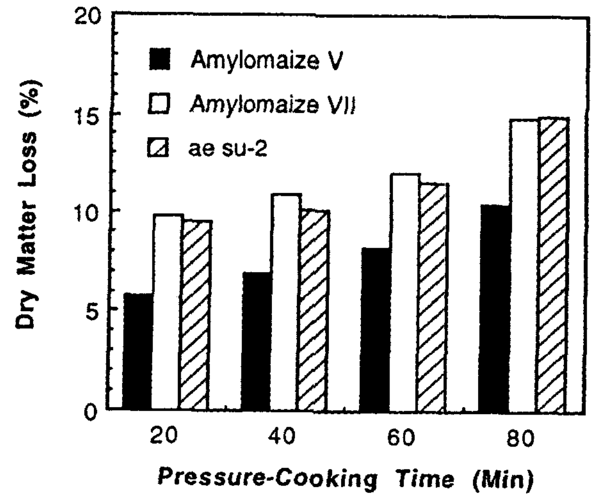

Fig. 4. Effects of pressure-cooking time on dry matter loss of high amylose maize varieties. The least significant difference (LSD, at α = 0.05) was 0.72.

sure-cooking time increased (Fig. 3). Amylomaize VII absorbed water at a slower rate with increasing pressure-cooking time, compared to other maize varieties. These results were due to the harder endosperm texture and higher amylose content of amylomaize VII (Table 2). Amylomaize VII and *ae su-2* lost significant amounts of dry matter during pressure-cooking trials (Fig. 4). The dry matter losses of *ae su-2* were 10% after 20 min pressure-cooking, and increased to 15% after 80 min pressure-cooking. However, relatively low dry matter losses were observed for amylomaize V. Commercial processes for production of corn masa caused losses of 8.5~12.5% of corn dry matter (13). Excessive dry matter losses of amylomaize VII and *ae su-2* were probably due to the over-hydrated kernels which disintegrated easily during washing.

Production of masa from mutant maizes

The moisture contents of nixtamals prepared from *du* and *ae du* were 56.9 and 54.9%, respectively, after optimum cooking and steeping (Table 3). Most pericarps of *du* and *ae du* kernels were still attached after alkaline-cooking and steeping (Table 3). Hence, lower dry matter loss of *du* resulted from the reduction in pericarps removed during cooking and steeping.

Both masas produced from *du* and *ae du* nixtamals had poor sheeting properties due to the crumbly and less cohesive texture of the masa. Excessive retrogradation of the amylose molecules after cooking may explain the reduced cohesiveness in *du* and *ae du* masas. In addition, lower contents of dispersed amylopectin molecules in *du* and *ae du* masa resulted in decreased water holding capacity by the amylopectin molecules; i.e. lack of stickiness in *du* and *ae du* masa. Therefore, masas prepared from *du* and *ae du* resulted in thinner masa pieces after sheeing and forming, even under the same sheeter setting as for the normal maize masa. Masas prepared from *du* and *ae du* nixtamals had darker color with a wet appearance compared to normal maize masa. These mutant maizes had pericarps with red-pink stains that darkened during lime cooking. The poor pericarp removal and colored pericarp tissues produced a darker masa.

Masas prepared from amylomaize V, VII, and *ae su-2* were less cohesive and had a crumbly masa texture, i.e. rheological properties similar to those of *du* and *ae du*

Table 3. Dry matter losses (DML) and moisture content of normal (Asgrow 404), dull, and amylose-extender dull during tortilla chip processing[1)]

	Cooking time (min)	Dry matter loss (%)	Pericarp removal[2)]	Moisture content (%)			
				Nixtamal	Masa	Tortilla	Tortilla chip
Asgrow 404 (Control)	39.2	8.1	1.0	50.5	52.2	27.2	1.2
ae du	27	5.9	5.0	56.9	58.1	31.6	1.5
du	37	5.2	5.0	54.9	57.9	29.1	1.5
LSD (0.05)[3)]	.	1.0	.	1.1	0.5	0.6	0.3

[1)]Values are means of two or three observations.
[2)]Rated on a scale in which 1 represents complete removal and 5 represents no removal of pericarp.
[3)]LSD (0.05): Least significant difference (α = 0.05).

masa. Amylomaize VII, which had the highest amylose content (65~70%), yielded a masa that was much less cohesive than those prepared from other high amylose mutants. Insufficient dispersion of amylopectin and excessive retrogradation of amylose could account for the less cohesive and crumbly masa

Characteristics of tortilla chips

High amylose mutant maize varieties produced tortilla chips with darker color than control chips (Table 4). Several factors may account for the dark color of tortilla chips. These are pigmented pericarps, presence of reducing sugars, and phenolic compounds in the kernel. Pigmented pericarps of high amylose maze varieties were not removed during nixtamalization and tended to darken under alkaline conditions. It is reported that polyphenols in sorghum pericarps resulted in unacceptably dark tortillas (14). Maize mutants with sugary gene (*su*) and high amylose genotype had higher concentrations of sugars in the kernel than normal maize (15). Therefore, dark tortilla chips prepared from high amylose maize varieties were the result of the pigments and phenolic compounds present in the pericarps and the high concentrations of reducing sugars in the kernels.

Although high amylose maize varieties produced tortillas with higher moisture content than that of normal tortillas, moisture content of tortilla chips was similar to that of control chips, indicating that water is evaporated readily during deep fat frying (Table 4). These results implied that water molecules in the masa and tortillas of high amyose maize varieties are more loosely held due to high levels of retrograded amylose molecules and insufficiently dispersed amylopectin molecules.

The oil content of tortilla chips prepared from *du* and *ae su-2* was not significantly different from that of normal tortilla chips. However, tortilla chips prepared from the *ae du*, amylomaize V, and VII varieties had slightly increased oil absorption (Table 4). Masas prepared from high amylose maize had less cohesive textures, resulting in thinner masa pieces after sheeting. Hence, increased surface areas per weight of the masa contributed to the higher oil contents of tortilla chips. Morrison and Milligan (16) reported that the inclusion complexes between amylose and lipid were formed during any wet analytical procedure. However, most of amylose molecules that leached out during nixtamalization and baking retrograded rapidly, prior to deep fat frying. In addition, the increased oil content of tortilla chips prepared from high amylose mutants is much too low, compared to the amylose content of the starch granule. Therefore, higher oil absorption of tortilla chips prepared from *ae du*, amylomaize V, and VII was caused by increased surface areas of the tortilla chips.

Table 4. Characteristics of tortilla chips prepared from control (Asgrow 404) and high amylose maize varieties[1)]

Maize varieties	Moisture content (%)	Oil content (%)	Color		
			L	a	b
Asgrow 404 (Control)	1.2	21.2	62.0	2.0	28.1
ae du	1.5	22.9	53.2	4.2	27.2
du	1.5	21.4	52.0	5.8	25.2
ae su-2	1.3	23.3	50.4	5.8	23.6
Amylomaize V	1.1	24.5	51.7	5.8	24.4
Amylomaize VII	1.4	23.6	52.2	4.4	24.7
LSD (0.05)[2)]	0.3	0.6	1.0	0.4	0.6

[1)]Values are means of three observations.
[2)]LSD (0.05): Least significant difference ($\alpha = 0.05$).

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