SO: Quality Protein Maize (by Mertz, E.T.)

THE ALKALINE PROCESSING PROPERTIES OF QUALITY PROTEIN MAIZE

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INTRODUCTION

Maize (corn) is the staple food for millions of people around the world. This cereal is especially important in Central America, Mexico, and some countries of Africa and Asia where it is the main source of energy and protein among the general population. Corn is consumed in different ways throughout the world, ranging from immature grain on the cob to products processed by different traditional technologies, i.e., nixtamalization or alkaline-cooking for tortilla production, fermentation for ogi production, dry milling for thin or thick porridges. Corn, like most cereals, has relatively low protein content and has limiting amounts of two essential amino acids, lysine and tryptophan. This amino acid imbalance is relevant in maize-consuming countries because the basic diet fails to provide sufficient essential amino acids. Agricultural scientists have worked extensively to improve the quality of maize protein. These efforts have resulted in the development of high lysine or *opaque-2* maize

(Mertz et al., 1964). CIMMYT (International Maize and Wheat Improvement Center) transformed *opaque-2* corn into nutritionally improved harder kernel types called quality protein maize (QPM) (Vasal et al., 1980). QPM varieties and lines with white or yellow endosperm and with yield potential equal to commercial corn lines or varieties have been released in Guatemala, Paraguay, Ecuador, Brazil, China, and Africa. Recently, collaborative efforts among CIMMYT, South Africa and Texas A&M University have resulted in the experimental production of QPM hybrids with grain yields sufficiently high to successfully compete for USA food corn markets (Bockholt, 1990).

Corn is consumed as tortillas by a large group of people in Latin America. Tortillas are made by cooking the grain in water:lime solution. Cooked corn is steeped overnight and washed to produce nixtamal, which is ground into masa. Masa is shaped into thin circles and baked into tortillas (Serna-Saldivar et al., 1990).

This article reviews current information on the alkaline-cooking properties of QPM. In addition, pilot plant trials to evaluate the alkaline processing properties of yellow and white QPM hybrids compared to a commercial food grade corn hybrid are reported here.

<u>Alkaline-cooking properties of QPM</u>. One of the first studies on the use of QPM in tortilla processing was conducted in Guatemala in 1976 (Valverde et al., 1983). QPM production (soft and hard endosperm maizes), storage conditions, tortilla production by housewives, nutritional evaluation, and acceptability by families were evaluated. Among the conclusions, the agronomic data indicated that with conventional cultural practices, QPM yields were as high as those of local cultivars. QPM tortillas had

acceptability similar to those prepared from normal corn. The replacement of normal corn by a high-protein-quality maize, i.e. QPM, resulted in an improvement in children's growth rates.

Ortega et al. (1986) compared protein differences (lysine and tryptophan) between QPM and its normal maize counterpart during the different stages in tortilla processing. The study reported that QPM had 80% more tryptophan and 64% more lysine than its normal counterpart. Loss of total lysine during processing was minimal for both genotypes, however, processing reduced the tryptophan levels by 15% in QPM and 11% in normal corn. Similar changes in the solubility of the protein fractions (albumins and globulins, true zein, zein like, glutelin like, and true glutelins) occurred during tortilla processing for both maizes. During processing, chemical changes (hydrophobic interactions, cross-linking, and denaturation) occurred in the proteins which changed the native solubility and reduced their *in-vitro* pepsin digestibility. Processing had no major effect on the content of the amino acids.

The characteristics of alkaline processing and nutritional quality of tortillas and tortilla chips made from a QPM hybrid and a food grade corn were evaluated by Sproule et al. (1988). QPM required longer cooking time because it had a greater amount of corneous endosperm than the food grade corn. However, QPM had a lower dry matter loss because the pericarp was not completely removed during cooking and steeping. Tortillas from both QPM and food grade corn were flexible, with good overall appearance. The protein content of both products was similar. QPM had more than twice the level of the albumin/globulin fraction than did food grade corn. Lysine was the first limiting amino acid of both corn products (Table I), QPM and food grade corn products provided about 70% and 50% of the lysine requirement.

Nutritional value of QPM tortillas. The average feed intake and average daily gain of rats fed QPM products were significantly higher than for rats fed food grade corn products. Both corn lines had similar dry matter, protein and energy digestibilities (Table 1), which indicated that the increased lysine levels in QPM were responsible for the improved rat performance. In both maize types, processing grain into tortillas and tortilla chips slightly decreased protein digestibility and rat performance.

TABLE 1
Nutritional values of Asgrow 404Y and QPM

	Asgrow 404Y			QPM		
Value	Grain	Tort.	Chip	Grain	Tort.	Chip
	Amino Acid Composition (g/16 g N)					
Lysine	2.8	2.8	2.6	4.2	3.8	3.8
Trypt.	0.6	0.5	---	1.0	0.9	---
AA Score [%]	51	50	48	77	70	70
	Apparent Digestibility [%]					
Energy	92.9	94.3	94.7	90.8	94.0	94.4
Protein	86.1	83.8	82.1	85.5	80.9	81.9

Taken from Sproule et al., 1988.

Effect of processing on protein fractionation. Vivas et al. (1990) reported changes in protein fractions, electrophoretic patterns and protein digestibility of a QPM hybrid and a food grade maize hybrid during tortilla and tortilla chip production. QPM had a larger albumin/globulin fraction than food grade corn (Table 2). Processing raw grains into tortillas and tortilla chips reduced the solubility of the albumin/globulin, prolamin, and glutelin fractions in both grains. Cross-linked prolamins and residue proteins increased in both corns after processing.

Table 2
Protein Solubility Distribution of QPM and Food Grade Corn (FGC) Processed into Tortillas and Tortilla Chips[a].

Sample	N (%)	F[b]I (%)	FII (%)	FIII (%)	FIV (%)	Res (%)
QPM						
Raw	1.79	38.8	12.3	25.8	19.1	4.6
Tortilla	1.75	12.6	12.0	27.6	17.2	17.6
Chip	1.78	11.2	10.3	27.6	10.8	28.8
FGC						
Raw	1.60	30.4	28.0	21.7	21.0	2.7
Tortilla	1.62	8.5	9.2	42.7	8.7	21.0
Chip	1.70	8.0	7.0	44.6	4.9	30.9
LSD (P<.01)		0.89	1.1	1.26	0.92	1.26

(a) Modified from Vivas-Rodriguez et al. (1990)
(b) FI: albumins/globulins; FII: prolamins; FIII: cross-linked prolamins; FIV: glutelins; and Res: residue.

The number and intensity of protein bands in electrophoretic patterns decreased after processing for both hybrids. *In-vitro* pepsin digestibility also decreased after processing for both grains. However, QPM contained more albumins and globulins, and less prolamins which accounts for the improved protein quality of QPM products.

Effect of processing on Ca availability. Serna-Saldivar et al (1991, 1992) evaluated the effect of lime treatment on the availability of calcium in diets of tortillas and beans. In this study, QPM, regular corn and sorghum were processed into tortillas. Weanling rats were fed raw grain or tortilla-based diets supplemented with dry, cooked pinto beans and a Ca-free or Ca-rich mineral premix. Rats consuming Ca-supplemented QPM products consumed more feed and gained more weight but had conversion ratios similar to those of their counterparts fed regular corn and sorghum. Among rats fed tortillas, QPM produced denser, stronger, longer, and thicker bones with more ash and Ca. Also, rats fed Ca-supplemented QPM products had the highest serum albumin levels, probably because of the improved dietary protein quality.

Commercial production of QPM tortillas. In 1986, a field study was conducted in a commercial plant in Mexico to compare the processing properties of a white QPM hybrid with a commercial Mexican corn [1]. White QPM and Mexican corn were cooked in 1% lime:water solution (based on corn weight) for 33 min and 40 min, respectively. Both cooked corns were steeped for 12 hours. Nixtamal was ground in a stone-grinder and then masa was extruded into thin discs in a "Celorio" sheeter. Masa discs were baked into tortillas in a triple pass gas-fired oven. The study concluded that QPM was easily cooked in alkali and processed into tortillas. The cooking characteristics were similar to available commercial Mexican corn

[1] Tellez-Giron, A. and Rooney, L.W. 1986. Unpublished data

varieties. QPM tortilla color, taste, flexibility, and other properties were similar or better than those found in Mexican corn tortillas.

Bressani et al.(1991) compared changes of major nutrients during village processing of QPM and regular corn cultivars. The changes in total protein, lipid, total dietary fiber, and ash contents from raw maize to tortilla were similar to those for regular maize previously reported by other workers. Rats fed diets made from raw grain, masa and tortilla made from QPM showed a weight gain, food intake and PER significantly greater than animals fed diets from regular corn and its processed products. Comparing different corn products, animals that consumed diets from masa and tortillas had a weight gain and PER significantly greater than animals fed raw corn diets. Concerning food intake, rats fed tortilla diets showed an intake significantly greater than those fed raw maize diets.

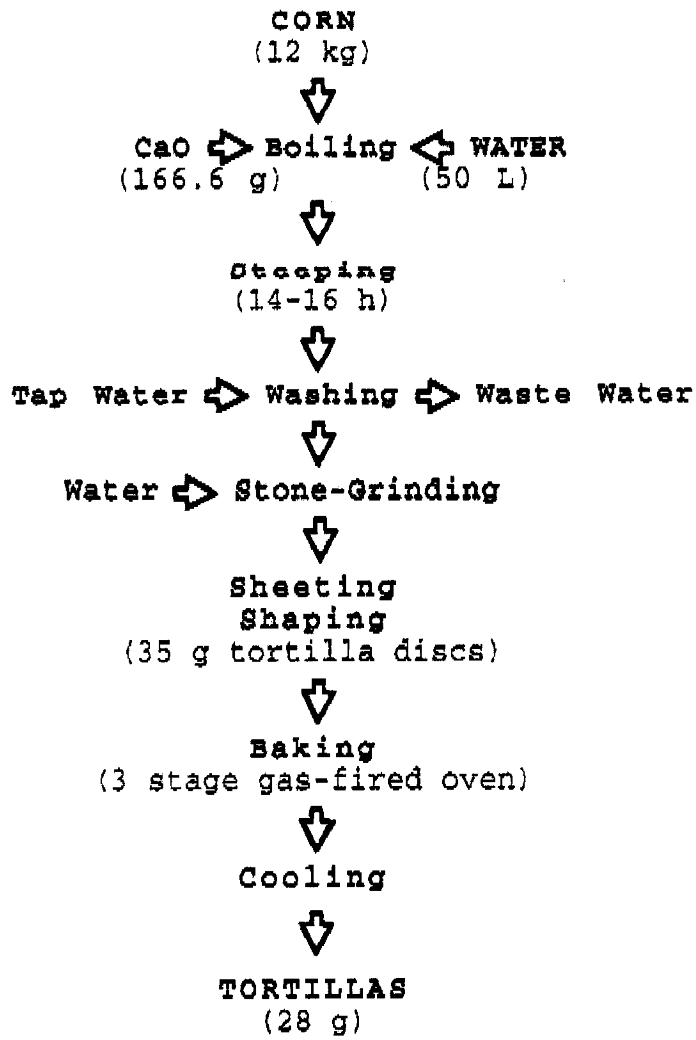
In 1990, the Cereal Quality Lab implemented a project to compare the processing properties of white and yellow QPM hybrids grown at Uvalde, Texas with a very good commercial yellow food-grade corn hybrid. These studies are reported below.

MATERIAL AND METHODS

Sample preparation. Three maize cultivars were used in this study: Asgrow 404Y, a commercial yellow food-grade corn with outstanding alkaline-cooking properties; a yellow quality protein maize (YQPM), which was a composite of grains from two experimental hybrids, F387 and 238 x 380; and white quality protein maize (WQPM), a composite of grains from three experimental white hybrids, 157 x 232, 176 x 230, and 173 x 232. The grain was grown at Uvalde, Texas in a replicated performance test under irrigation. The grain was air dried after harvesting, cleaned and stored in a freezer prior to processing.

Tortilla preparation and evaluation (pilot scale). Four kilograms of each corn variety were processed into tortillas (Fig.1). Grains were placed in perforated nylon bags and boiled with 50-L water and 166.6 g of lime in a steam kettle for the predetermined optimum cooking times. Optimum cooking time was determined in preliminary cooking trials described later. After boiling, steam was cut off, and the grain was steeped for 16 hr. The cooking liquor was discarded, and the grains were washed with running tap water to remove excess lime and pericarp tissue. Nixtamal was stone-ground (12in.-diameter lava stones) using a 20-hp commercial grinder (model CG, Casa Herrera Inc., Los Angeles, CA). Water was added during grinding at the rate of 0.6 L/min which increased masa moisture content to 55-56%. For all runs, the gap between the stone was adjusted to the same setting to produce a fine masa suitable for table tortillas. The masa was sheeted continuously and formed with a commercial sheeter/former (model CH4-STM, Superior Food Machinery, Inc., Pico Rivera, CA) into tortilla disks. Tortilla thickness was indirectly controlled by adjusting the sheeter to produce 35 ± 1 g masa disks, which were continuously baked into tortillas in a gas-fired oven with a three-tiers moving belt (model C0440), Superior Food Machinery). Tortillas were baked for 58 sec with an average temperature of 320, 290, and 370°C for the top, middle, and bottom tiers, respectively. Then tortillas were conveyed onto a three-stage cooling rack (model 3106-INF, Superior Food Machinery) with an average residence time of 60 sec.

Figure 1
Production of Table Tortilla



Tortillas were equilibrated at room temperature for about 10 min, weighed, and packed in low-density polyethylene bags.

Yields of nixtamal, masa, and tortillas for each hybrid were determined.

<u>Physical characteristics</u>. A 1000 kernel weight was counted with a semi-automatic batch type seed counter (Seedburo Equipment Co., Chicago, IL), and weighed.

Test weight or bulk density was determined with a Winchester bushel meter and expressed as pounds per bushel (or kg/hl).

Grain density was determined using a nitrogen comparison multipycnometer (model MUP-1S/N232, Quantachrome Corp., Syosset, NY) with a large cell.

Grain hardness (grams of matter removed per 100 g of whole grain) was measured by 10-min decortication of 40-g samples with a Tangential Abrasive Dehulling Device (TADD) equipped with an aluminum oxide abrasive disk and 8-hole base.

Objective color of masa and tortillas was determined using a HunterLab Tristimulus color meter (Model D25M-9; Hunter Ass.Lab. Inc., Reston, VA) (standard tiles: L= 76.21, a= -0.61, and b= 22.78). Color was expressed as a color solid according to the Hunter L a b system, where L is lightness (100) or darkness (0); +a is redness, -a is greenness; +b is yellowness, and -b is blueness.

Pericarp removal was evaluated subjectively after staining the lime-cooked kernels with eosine Y and methylene blue and washing with methanol as described by Serna-Saldivar et al.(1991).

Tortilla texture was determined subjectively by rolling a 1-in.wide tortilla strip around a 1 in-diameter dowel and grading on a five-point scale (1= immediate complete breakage and 5= no breakage during rolling).

Masa particle size was determined by suspending 5 g of masa in 20-ml distilled water and sieving through a set of 850 (US standard sieve No 20), 250 (No 60), and 150 (No 100) µm-sieves (Gomez, 1988). Fractions retained on each sieve were dried and weighed.

Chemical composition. Moisture content was determined by drying to a constant weight in a forced air oven at 105°C (AACC 1986). Protein (%N x 6.25) was analyzed by Kjeldahl digestion (AACC 1986) and an automated colorimetric assay for ammonia (Technicon 1978). Crude fat in the samples was measured by ether extraction using Goldfish apparatus and evaporation of the solvent (AACC 1986). Ash in the samples was determined after incinerating at 500°C (AACC 1986). Total dietary fiber was determined by a gravimetric, enzymatic method which includes starch gelatinization and digestion by alpha amylase, pepsin and pancreatin (Asp et al., 1983)

Determination of dry matter losses, nixtamal water uptake and optimum-cooking time. Corn (100 g) placed in a perforated nylon bag was boiled in water:lime solution for 0, 15, 30, and 45 min and steeped for 16 hr. Water (50 L) and lime (166.6 g) were brought to boil in a 120-L steam kettle (model TDC/2-20, Groen Div., Dover Corp., Elk Grove Village, IL) and bags of corn were added. The temperature of cooking was kept at 97-98°C. During steeping the temperature decreased at a rate of 0.15°C/min. Moisture content of nixtamal was determined according to Serna-Saldivar (1988a). The bags were opened, and nixtamal was washed for 30 sec, drained, weighed after 10 min of air exposure, returned to the bags for drying in a convection oven at 100°C for 48 hr.; cooled in a dessicator, and reweighed. Moisture content (MC), dry matter losses (DML), and water uptake (WU) were calculated. The time required to cause the nixtamal to reach 50% moisture (cooking time) was calculated using linear regression equations determined for each sample of corn. This moisture level provided acceptable handling properties during grinding of nixtamal, sheeting, and baking of masa.

RESULTS AND DISCUSSION

<u>Properties of corn</u>. QPM samples had lower test weight, reduced kernel weight and were softer than the hard, yellow, commercial food corn hybrid (Table 3).

The QPM kernels were significantly smaller than the Asgrow 404Y grains. WQPM had lower density than the other two cultivars. We believe the optimum properties for alkaline processing of Texas grown corn are test weight of at least 60 lbs/bu, minimum density of 1.30 g/cc, 1,000 kernel weight of at least 300 g and hardness of 40. Grains with these properties have more tolerance to mishandling and overcooking and tend to have reduced dry matter losses during cooking. Alkaline-cooking and steeping removed most of the pericarp of Asgrow 404Y, 75% of YQPM and 50% of WQPM (Table 3). Thus, the two QPM samples did not meet all of the requirements for an ideal Texas food corn; but with the exception of kernel weight and pericarp removal they were very close. Asgrow 404Y grain has outstanding pericarp removal and other alkaline-cooking properties. Other commercial food corns used for alkaline processings do not meet all the criteria either, i.e. Pioneer 3192 has very poor pericarp removal. Thus, the QPM samples can be processed into good table tortillas by altering the cooking conditions since they are significantly smaller than usual food corns. Ultimately, types with more easily removed pericarp can be obtained through breeding and selection of QPM hybrids.

Table 3
Physical Properties of Grains

Property	Asgrow 404	YQPM	WQPM	LSD[a]
Test Weight lb/bu (kg/hl)	61.5 (79.2)	60.0 (77.3)	60.0 (77.3)	0.5 (0.6)
Density g/cc	1.33	1.33	1.31	0.001
1000 Kernel weight (g)	336	284	288	7.4
Hardness (% Removal)[b]	37.1	42.4	41.8	0.3
Pericarp Removal[c]	1.0	2.0	3.0	0.3

(a) Least significant difference ($P<0.05$)
(b) Amount of material mechanically removed in a TADD mill after 10 min milling. Higher values indicate softer kernels.
(c) Pericarp removal was subjectively rated as 1 = all pericarp removed, and 5 = all pericarp present. This was using a standard cooking time of 20 min for all the samples.

The reduced kernel size of QPM shortens its optimum cooking time, however this tends to cause greater retention of pericarp in the nixtamal. Pericarp remnants are not a real problem for table tortilla production because the retained pericarp is a source of gums which probably prevent or retard staling of the tortilla. For chip production, complete removal of pericarp is required to avoid problems in sheeting and forming of chips. Thus, longer cooking times for QPM will be required to remove most of the pericarp, which will increase dry matter losses during processing.

<u>Chemical composition</u>. The protein content did not change during alkaline processing into tortillas (Table 4).

Table 4
Chemical Composition of Grains and Tortillas[a]

Product	Prot. (Nx6.25)	Fat (%)	Ash (%)	TDF[b] (%)	COH[c] (%)
Asgrow 404					
Grain	9.8 a	4.9 a	1.2 b	12.1 a	72.0 b
Tortilla	9.9 a	4.2 b	1.4 a	10.5 b	74.0 a
YQPM					
Grain	9.5 a	4.8 a	1.5 b	13.5 a	70.7 b
Tortilla	9.8 a	3.4 b	1.6 a	12.4 b	72.8 a
WQPM					
Grain	10.4 a	4.3 a	1.6 b	13.8 a	69.5 b
Tortilla	10.3 a	3.2 b	1.7 a	13.0 b	71.5 a

(a) All values are expressed on oven dry matter basis. Means with different letter within column and grains are statistically different at P<0.05.
(b) Total dietary fiber (determined according to Asp et al., 1983).
(c) Total carbohydrate content determined by difference.

While, fat content decreased slightly, suggesting that some fat-rich tissues (i.e. germ) were removed during processing.

Tortillas had more ash or mineral content due to the calcium uptake during alkaline-cooking. Total dietary fiber decreased from grain to tortilla in all cultivars. Some of the pericarp was peeled away by the action of lime during cooking and steeping (Gomez et al., 1989). Most of the undigestible carbohydrates, i.e., cellulose, hemicellulose, and lignins are located in the pericarp (Bressani 1990) so retention of pericarp causes enhanced levels of total dietary fiber. Thus, the fiber content of the QPM tortillas was higher than that of the Asgrow 404Y tortillas.

Lime-cooking trials. QPM grains absorbed more water more rapidly than Asgrow 404Y during lime-cooking and steeping (Table 5). Dry matter losses were similar for the three cultivars at equivalent cooking times. However, Asgrow 404Y required a much longer cooking time (26.3 min) to reach 50% nixtamal moisture content. Serna-Saldivar et al.(1991) reported that nixtamal with 50% moisture content had adequate machinability and produced good quality tortillas. The smaller, slightly softer QPM kernels required less than 4 min cooking to reach the optimum nixtamal moisture. The short cooking time and only 50 to 75% pericarp removal reduced the dry matter losses of QPM grains compared to Asgrow 404Y. The differences in cooking requirements between QPM and Asgrow 404Y were mainly due to reduced kernel size and to a lesser extent the slightly softer endosperm texture of the QPM grains. Grain, nixtamal, masa, and tortillas contained similar moisture contents (Table 6).

Table 5
Effect of Lime-Cooking on Nixtamal Moisture and Dry Matter Losses of Asgrow 404Y, Yellow QPM and White QPM.

Cooking Time	Asgrow 404	YQPM	WQPM	LSD[a]
0 min				
Moisture (%)	45.2	49.9	49.4	1.4
DML (%)	8.3	8.7	8.9	0.8
15 min				
Moisture (%)	47.2	51.9	52.9	4.3
DML (%)	9.1	9.0	10.6	1.2
30 min				
Moisture (%)	49.9	54.5	55.8	2.8
DML (%)	9.2	9.6	11.3	0.9
45 min				
Moisture (%)	54.6	58.8	58.6	3.8
DML (%)	11.5	10.8	11.5	1.4
Optimum Cooking Time (min)	26.3	3.2	2.0	--
DML at Optimum Cook. Time (%)	9.4	8.6	8.3	--

(a) Least significant difference ($P<0.05$)

Thus, similar yields of nixtamal, masa, and tortillas were obtained (Table 7). Nixtamals were stone-ground into fine masa suitable for table tortillas. The three corns have similar masa fractionation values (Table 8) and excellent masa machinability. The most important fraction is the one that passes through the 150 µm screen because it is mainly composed of free native, annealed, and partially gelatinized starch granules which are required to produce desirable properties of masa.

Table 6
Moisture Contents of Asgrow 404Y and QPM grains.

Product	Asgrow 404	YQPM	WQPM
Raw Grain	12.3±0.2	11.4±0.0	11.8±0.0
Nixtamal	51.4±0.4	53.2±0.2	52.7±0.4
Masa	57.2±0.3	57.2±0.5	58.7±0.4
Tortilla	46.2±0.5	46.0±0.3	46.8±0.6

Values are means ± standard deviation

Table 7
Yields of Nixtamal, Masa, and Tortilla from Asgrow 404Y, and QPM grains.

Yield	Asgrow 404	YQPM	WQPM	LSD[a]
Nixtamal/Grain	1.86	1.95	2.02	NS
Masa/Nixtamal	2.12	2.18	2.29	NS
Tortilla/Grain	1.66	1.72	1.78	NS
Tortilla/Masa	0.78	0.78	0.78	NS
N° Tortilla / Kg Grain	63.0	64.0	65.0	NS

[a] NS: No significant difference ($P<0.05$).

As expected, WQPM masa and tortilla was lighter in color than the products from

Asgrow 404Y and YQPM (Table 9a and 9b). The overall color index, E, is similar among masas and among tortillas.

All fresh tortillas had excellent rollability, taste and flavor. Tortillas still had acceptable rollability even after three days of storage at room temperature in sealed polyethylene bags.

Table 8
Masa Fractionation[(a)]

Fraction	Asgrow 404Y	YQPM	WQPM
Coarse (>250 µm)	22.2±1.0	19.9±1.2	18.0±1.4
Interm. (>150 µm)	3.8±0.2	2.7±0.3	3.3±0.3
Fine (<150 µm)	58.6±2.2	59.2±1.7	57.5±2.2
Soluble Solids	7.7±0.2	7.0±0.5	7.4±0.4

(a)Values are means ± standard deviation.

Table 9 a
Color (L, a, b, and E values) of Masa[(a)]

Color Value	Asgrow 404Y	YQPM	WQPM
L	70.3±0.2	72.5±0.3	74.9±0.1
a	2.34±0.02	0.36±0.02	-0.65±0.0
b	29.2±0.3	28.0±0.2	17.5±0.3
E	76.2±0.3	77.7±0.2	77.0±0.2

Values are means ± standard deviation.
(a) L= lightness (100= white, 0= black); a= red (+100), -a= green (-80); b= yellow (+70), -b= blue (-80); E= color index= $(L^2 + a^2 + b^2)^{1/2}$

Table 9 b
Color (L, a, b, and E values) of Tortilla[a]

CV[b]	Asgrow 404Y	YQPM	WQPM
L	65.6±0.3	63.6±0.2	67.9±0.2
a	1.63±0.01	0.41±0.01	-1.09±0.01
b	26.5±0.2	26.5±0.2	18.0±0.2
E	70.7±0.2	68.9±0.3	70.3±0.3

Values are means ± standard deviation.
(a) L= lightness; a= red (+100), -a= green (-80); b= yellow (+70), -b= blue (-80), E color index= $(L^2 + a^2 + b^2)^{1/2}$
(b) Color Values

CONCLUSIONS

WQPM and YQPM required shorter cooking times than the food grade corn because of their smaller kernel size and slightly softer endosperm texture. The characteristics of products from QPM were similar to corresponding products from the food grade corn. QPM produced highly acceptable tortillas with excellent flavor, rollability and color. In addition, the QPM tortillas retained greater amounts of dietary fiber because the pericarp was not completely removed. For production of chips, a longer cooking time may be required to remove the pericarp completely and greater dry matter losses could be expected. However, tortilla chips fried from QPM had excellent color, flavor and aroma with a shelf life equivalent to regular corn tortilla chips. We have never observed any off odors or flavors with fresh QPM tortillas or tortilla chips. QPM can be used to produce good quality alkaline cooked products, but processing conditions must be adjusted because of its smaller kernel size.

ACKNOWLEDGEMENT

We acknowledge partial support for this research from the Snack Foods Association, Alexandria, VA.

Contribution TA 30298 from the Texas Agricultural Experiment Station, Texas A&M University, College Station, TX 77843-2474.

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