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Wet Milling Comparison of Quality Protein Maize and Normal Maize

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Abstract: Quality protein maize (QPM) experimental hybrids and normal maize possessing different physical and chemical properties were studied as the raw material for wet milling. Maize samples were steeped for 36 h in a 600-ml solution containing 15 g kg^{-1} lactic acid and 0·5 g kg^{-1} SO_2 followed by 12 h in a second 600-ml solution containing 5 g kg^{-1} lactic acid and 1 g kg^{-1} SO_2. The steeped grain was then wet milled and the yields and purity of fractions were analysed. Water-soluble solids, kernel size, quality protein, total dietary fibre and ash content were higher in QPM samples than in normal maize. Water-soluble solids were positively correlated to kernel size ($r = 0.97$, $P < 0{\cdot}05$), test weight ($r = 0{\cdot}83$, $P < 0.05$) and density ($r = 0{\cdot}57$, $P < 0{\cdot}05$). Total fraction recovery for the five hybrids tested ranged from 921 to 955 g kg^{-1}, with the highest values corresponding to QPM hybrids. QPM hybrids yielded slightly higher starch content than normal maize. Gluten yields of QPM-HO (high oil) presented the highest values. The lysine contents of kernel, gluten and milling solubles were highest for QPM hybrids. QPM contained more palmitic acid than the other hybrids. The H-137 normal maize and QPM yellow dent-HO contained more oleic and linolenic acids than the other samples, and the QPM white-C (corneous) contained more linoleic acid than QPM-HO and normal maize.

Key words: Wet milling, quality protein maize (high oil), maize/corn, starch, oil, protein, lysine, germ, fibre.

INTRODUCTION

The search for maize genotypes with enhanced nutritional quality led to identification of Opaque-2 as potentially useful mutations for increasing the lysine and tryptophan contents of the grain (Mertz *et al* 1964).

Agricultural scientist from the International Maize and Wheat Improvement Center (CIMMYT) bred modified Opaque-2 into genotypes with a high frequency of 'modifier genes' that confer a normal vitreous phenotype to the endosperm, while maintaining high levels of lysine and tryptophan in the protein (Bjarnason and Vasal 1992).

In developing quality protein maize (QPM) germoplasm with hard endosperm had been involved several phases including development of QPM donor stocks, QPM gene pools. QPM populations and more recently QPM hybrids with high oil contents (Villegas *et al* 1990).

Wet milling of high lysine corn has been conducted by Dimler (1966) and Watson and Yahl (1967). They observed greater loss of solids in the steep and process

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water and higher levels of protein in these fractions. These observations are indicative of oversteeping. The 48-h steeping time used in both studies was too long for the totally soft-endosperm high lysine corn, used by both researches. Reducing steeping time for a soft-endosperm. high lysine corn should lower solubles released while still allowing for sufficiently rapid diffusion of SO_2 into the endosperm for protein matrix dispersion. Fox and Eckhoff (1993) reported that no significant processing differences exist between 8 h and 36 h steeping time for soft endosperm, high-lysine corn. Total oil recovery at steeping time less than 36 was decreased. An 8 h steeping time will yield soluble solids in the range of normal dent corn.

Watson and Yahl (1967) reported that Opaque-2 corns showed acceptable starch yields with significantly higher losses of soluble proteins in the steep-and mill-waters. The starch yield of Opaque-2 corn compared favorably with the values obtained from commercial white corns (Van Twisk *et al* 1976).

Gomez et *al* (1990) determined that QPM yielded similar amounts of the major wet-milling products comparable to feed and food corn hybrids.

There is no current information on the wet milling properties of QPM-HO; therefore, the objective of this study was to compare wet millability of QPM-HO with normal maize possessing different physical and chemical properties.

EXPERIMENTAL

Grain samples

Population 59 (Temp x Trop Yellow Dent, High Oil), and Population 60 (Trop Late White Dent High-Oil). QPM experimental hybrids were grown at Poza Rica (CIMMYT Experimental Station), Veracruz, Mexico, in 1991. H-30 and H-137 (white commercial maize hybrids) developed by INIFAP (National Institute of Research in Agriculture, Forestry and Livestock), were grown at Chapingo, Mexico in 1991.

Wet milling

The steeping procedure used was modified according to the methods of Watson and Hirata (1955) and Krochta *et al* (1981). Approximately 300 g of maize was steeped for 36 h in a 600-ml solution containing 15 g kg^{-1} lactic acid and 0·5 g kg^{-1} SO_2, followed by 12 h in a second 600-ml solution containing 5 g kg^{-1} lactic acid and 1 g kg^{-1} SO_2. The steeped grain was then wet milled using procedures previously reported by Steinke and Johnson (1991). All fractions, except the starch fraction. were dried in a forced-air oven for 24 h at 60°C. After drying, the fractions were weighed for yield and then ground for proximate analysis.

Physical parameters

Kernel density was measured by using a simple device consisting of a suspended wire basket in conjunction with a top loading balance and a water bath. Values were calculated from the following: density = weight in air/(weight in air − weight in water). Hardness values were determined by subjecting kernels to abrasive decortication (Strong-Scott barley pearler) for 10 min, values were reported as a percent of the material removed. The kernel was classified according its sue using round hole sieves of 0·9, 0·8, 0·7, 0.65 cm and bottom. The average kernels weight was determined with a sample of 1000 whole kernels. Test weight of kernels was determined using a Ohaus balance. Water-soluble solids of maize samples were determined by the method of Watson and Yahl (1967). The Brabender viscoamylograph was used to measure viscosity properties of flour (45 g flour at 140 g kg^{-1} moisture basis and 450 ml of water). The colour of kernels was determined with a Hunter Lab reflectance colorimeter.

Chemical analysis

Moisture, protein (N x 6·25), fat (ether extract), starch and ash contents were determined using standard AACC (1986) procedures. insoluble and soluble dietary fibres were determined according to the method of Englyst and Cummings (1988). For Iysine analysis, the method of Spackman et *al* (1958) was used.

Statistical analysis

The data were analysed by using Statistical Analysis System (SAS 1985).

RESULTS AND DISCUSSION

Kernel parameters

The amount of water-soluble solids in ground normal maize was lower than in QPM samples (Table 1). Water-soluble solids were positively correlated to kernel size ($r = 0.97$, $P < 0·05$), test weight ($r = 0·83$, $P < 0·05$) and density ($r = 0·57$, $P < 0.05$) suggesting that QPM samples were higher in water solubility than normal maize. Opaque-2 (a high-lysine maize) had a large amount of water-soluble material probably composed of protein, peptides, amino acids and other simple nitrogenous material as suggested by Watson and Yahl (1967). The test weight was higher in QPM white-C and

TABLE 1
Physical parameters of maize hybrids[a]

	QPM white dent-HO[b]	*QPM yellow dent-HO*[b]	*QPM white-C*[b]	*H-30*[c]	*H-137*[c]
Moisture content (g kg⁻¹)	97b	95b	92c	105a	107a
Test weight (kg hl⁻¹)	74·3c	77·1b	80·8a	73·1d	74·4c
Water soluble solids (g kg⁻¹)	81c	90a	88b	79e	80d
Density (g per 100 cm³)	120b	120b	130a	120b	120b
Hardness (%)[d]	23·3d	29·8b	19·7e	39·7a	28·1c
Weight of 1000 kernels (g)	233d	302c	299c	353b	366a
Size (%)					
> 0·9 cm	23·0c	41·7b	42·6a	8·5e	15·9d
> 0·8 cm	40·9b	37·5c	41·3a	25·0e	34·7d
> 0·7 cm	31·2c	29·3d	15·2e	41·4a	40·4b
> 0·65 cm	3·8c	3·0c	1·4d	14·5a	7·0b
Bottom	1·0c	0·3d	0·2d	10·5a	1·4b
Colour					
L	80·1b	76·1cd	81·9a	75·2d	77·3c
a	−1·0ab	−1·2c	−1·1bc	−0·8a	−1·0bc
b	10·8c	25·3a	9·4d	11·3b	11·2b

[a] Values with the same letter are not significantly different within each line at $P < 0·05$.
[b] Experimental hybrids.
[c] Commercial hybrids.
[d] Percent material removed by abrasion. Kernels that are softer give higher values.

QPM yellow dent-HO samples than in QPM white dent-HO and normal maize and this was attributed to greater kernel size of some QPM hybrids. Abrasive decortication removed 280 and 400 g kg⁻¹ of the normal maize hybrids, indicating that these two hybrids were softer than QPM (white dent-HO and white-C). QPM kernels contained cells tightly packed with relatively few air spaces around the starch granules, resulting in increased hardness (National Research Council 1988). Szaniel *et al* (1984) indicated that kernel hardness was related to differences in horny–floury ratios, pericarp thickness and cell structure. The kernel size of the new QPM hybrids was improved with greater kernel size than normal maize. The colour values of QPM white hybrids were higher in comparison to normal maize.

Steeping solution uptake

When grain was tempered, water was presumably first absorbed by the bran and germ and then diffused into the floury endosperm. QPM and normal maize hybrids showed similar behaviour during steeping-solution uptake (Fig 1). Initially they absorbed steep-water up to approximately 400 g kg⁻¹ in 16 h, an allowed constant solution uptake up to 40 h, and finally absorbed from 440 to 460 g kg⁻¹ steep-water at 50 h. Watson and Hirata (1954) reported that water absorption during maize steeping causes 550 to 650 g kg⁻¹ volume expansion due in part to the disruption of disulphidc bonds. The protein matrix gradually swell, becomes globular and finally disperses during SO_2-steeping (Cox *et al* 1944).

Chemical composition

QPM is significantly superior in protein quality than normal maize. High-lysine maize also stimulates food intake and increases the bioutilisation of other nutrients such as calcium, carotenes and carbohydrates (Bressani 1990). QPM white dent-HO had the highest amount of protein (Table 2). The protein quality of QPM war higher than for normal maize due to a better amino acid balance (Sproule *et al* 1988). Starch is the major component of maize. QPM-HO samples had the lowest amount of starch. Starch content varies inversely with the protein content of endosperm; starch tends to be lower in maize with high oil content (Freeman 1973). QPM-HO hybrids and H-137 normal maize contained a higher amount of oil than QPM white-C and H-30 normal maize; likely due to the high germ/endosperm ratio or kernel size. QPM contained a higher amount of total dietary fibre and ash.

Wet milling

The yields and purity of fractions obtained by wet-milling process of QPM and normal maize are shown in Tables 3 and 4. Total fraction recovery for the five hybrids tested ranged from 921 to 955 g kg⁻¹, with

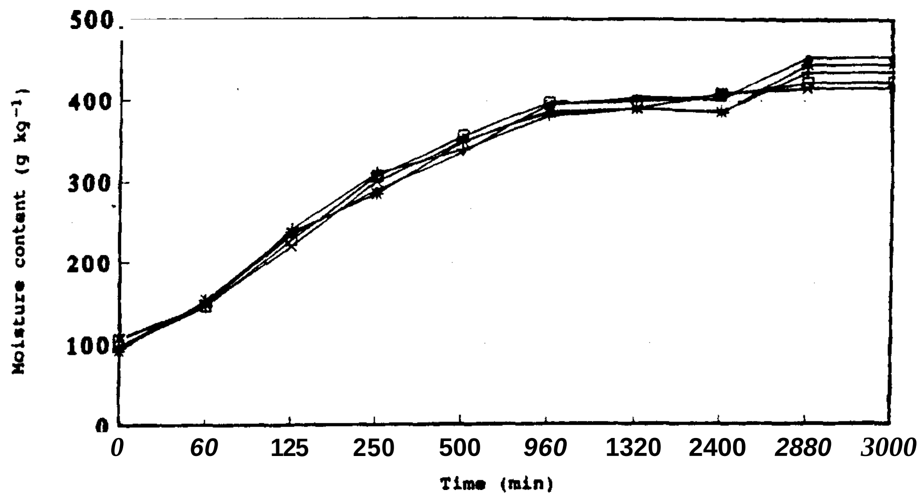

Fig 1. Steeping solution uptake of QPM and normal corns. —□—, QPM White-HO; —+—, QPM Yellow-HO; —*—, QPM White-C; —□—, H-30; and — x —, H-137.

better values for QPM samples. QPM hybrids yielded higher starch content than normal maize. QPM-HO presented the highest gluten yields. QPM bound yield was lower than those of normal maize. QPM gluten is an excellent source of energy and contains a large amount of quality protein that would be an economic asset to swine and poultry producers. The bound layer is an off-white coloured interphase composed of protein-bound starch and its yield is a sensitive indicator of starch–gluten separation, since poor starch

TABLE 2
Proximate composition of maize hybrids[a]

Corn sample	QPM white dent-HO[b]	QPM yellow dent-HO[b]	QPM white-C[b]	H-30[c]	H-137[c]
Protein content (g kg⁻¹)	110a	105b	104b	92c	105b
Starch (g kg⁻¹)	780c	774d	798b	811a	798b
Fat (g kg⁻¹)	71b	83a	S7d	63c	72b
Dietary fibre (g kg⁻¹)	46a	4Sb	46a	37d	39c
Ash (g kg⁻¹)	20a	17b	19a	12c	12c

[a] Values are expressed on dry basis. Values with the same letter are not significantly different within each line at $P < 0.05$.
[b] Experimental hybrids.
[c] Commercial hybrids.

TABLE 3
Wet milling yields of the corn fractions[a]

Fraction yield	QPM white dent-HO[b]	QPM yellow dent-HO[b]	QPM white-C[b]	H-30[c]	H-137[c]
Germ yield (g kg⁻¹ grain)	92a	91b	87d	89c	89c
Fibre yield (g kg⁻¹ grain)	150a	148b	150a	141d	144c
Starch (g kg⁻¹ grain)	564c	569a	566b	550e	558d
Gluten (g kg⁻¹ grain)	48a	47b	36e	38d	4oc
Bound (g kg⁻¹ bound)	12d	13c	11e	16b	17a
Steeping solubles (g kg⁻¹ steep-soluble)	67a	6Sb	61d	65b	62c
Milling solubles (g kg⁻¹ mill-soluble)	21b	21b	2oc	22a	19d
Recovery (total dry matter g kg⁻¹)	955a	954a	933b	921d	929c

[a] Values with the same letter are not significantly different within each line at $P < 0.05$.
[b] Experimental hybrids.
[c] Commercial hybrids.

TABLE 4
Concentration of total protein in wet-milled fractions[a]

Component (g kg⁻²)	QPM white dent-HO[b]	QPM yellow dent-HO[b]	QPM white-C[b]	H-30[c]	H-137[c]
Germ	166a	165a	164a	105c	148b
Bran	106a	106a	106a	76c	80b
Gluten	150d	150d	153c	219a	187b
Fine Fraction	98a	96b	97ab	66c	96b
Steeping soluble	210a	210a	213a	133c	187b
Milling soluble[d]	163a	163a	163a	105b	102c
NC[e]	107d	108c	108c	293a	190b

[a] Values with the same letter are not significantly different within each line at $P < 0.05$.
[b] Experimental hybrids.
[c] Commercial hybrids.
[d] Milling solubles includes solids from steeping and milling liquors.
[e] Not considered: it includes the amount of protein in starch, the bound fraction plus losses during processing.

separation produced high bound yield (Watson and Yahl 1967). Apparently, the starch in QPM endosperm was easily released from the protein matrix. This could be an advantage for wet milling. The QPM germ and bran showed the highest amounts of protein after processing.

The germ is superior in protein quality and quantity compared to the other anatomical parts (Mertz et *al* 1966; Paulis and Wall 1969; Bressani 1990). Fibre in bran of QPM is associated with more protein than fibre in bran from normal maize. QPM gluten contained the lowest amount of protein but QPM protein had the better essential amino acid balance. QPM steep- and mill-water had the highest amount of protein due to the increased amount of soluble proteins (albumins and globulins).

Lysine content

The lysine content of kernel, gluten and milling soluble was highest for QPM (Table 5). Gluten is the prime byproduct of the wet milling industry. Almost all the maize gluten produced by wet-milling is utilised in animal feeds. A gluten with a higher lysine content can be beneficial in diet formulation for swine and poultry since it can significantly reduce use of expensive protein suppiements.

Free fatty acids

Maize oil is an excellent source of essential polyunsaturated fatty acid, linoleic acid (18:2) important to health. More than 820 g kg⁻¹ of triglyceride composition of all maize oils, are unsaturated fatty acids (oleic and linoleic acids). QPM hybrids contained more palmitic acid than normal maize; the H-137 maize hybrid and QPM yellow dent-HO contained more oleic and linolenic acids than the other samples; and the QPM-C contained more linoleic acid than the QPM-HO samples and commercial hybrids (Table 6). Although high polyunsaturated maize oil is a very stable oil because it contains high levels of natural antioxidants and very little linoleic acid (18 : 3).

TABLE 5
Lysine content in kernel, gluten and milling soluble[a]

Component (g kg⁻²) protein	QPM white dent-HO[b]	QPM yellow dent-HO[b]	QPM white-C[b]	H-30[c]	H-137[c]
Whole kernel	41a	41a	41a	32c	33b
Gluten	31a	31a	30a	12c	13b
Milling soluble	29a	30a	30a	27c	28b

[a] Values with the same letter are not significantly different within each line at $P < 0.05$.
[b] Experimental hybrids.
[c] Commercial hybrids.
[d] Milling solubles includes solids from steeping and milling.

TABLE 6
Concentration of fatty acids in corn oil triglycerides[a]

Component ($g\ kg^{-1}$)	*QPM white dent-HO*[b]	*QPM yellow dent-HO*[b]	*QPM white-C*[b]	*H-30*[c]	*H-137*[c]
Palmitic (16 : 0)	142a	127c	140b	110e	118d
Stearic (18 : 0)	20e	29b	28c	30a	23d
Oleic (18 : 1)	405c	436a	361d	434b	436a
Linoleic (18 : 2)	416d	402e	464a	418b	417c
Linolenic (18 : 3)	7·1b	8·3a	5·7d	6·3c	7·2b

[a] Values with the same letter are not significantly different within each line at $P < 0{\cdot}05$.
[b] Experimental hybrids.
[c] Commercial hybrids.

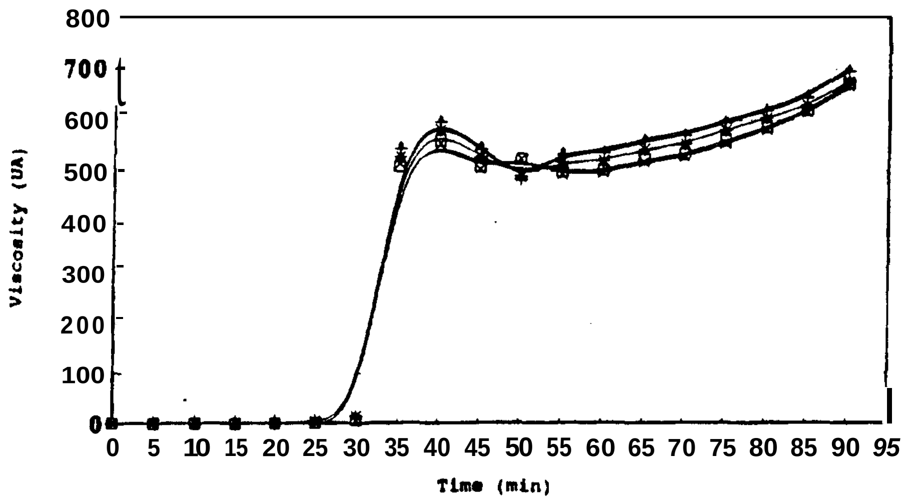

Fig 2. Viscosity of QPM and normal corns. —□—, QPM White-HO; —+—, QPM Yellow-HO; —*—, QPM White-C; —□—, H-30; and —x—, H-137.

Viscosity characteristics

The Viscosity of QPM and normal maize hybrids were similar (Fig 2). All the samples developed the typical pasting properties of normal maize starch (Greenwood 1978).

CONCLUSIONS

Water soluble solids, size kernel, dietary fibre and ash contents of QPM hybrids were higher than normal maize. The QPM hybrids had the best recovery of total dry matter. The lysine content of whole kernel, gluten and milling soluble of QPM hybrids was higher than normal hybrids. QPM hybrids contained more palmitic acid than normal maize. QPM can economically replace normal maize in wet-milling process.

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