Changes in Selected Nutrient Contents and in Protein Quality of Common and Quality-Protein Maize During Rural Tortilla Preparation

R. BRESSANI,[1] V. BENAVIDES,[2] E. ACEVEDO,[2] and M. A. ORTIZ[2]

Cereal Chem. 67(6):515–518

ABSTRACT

A total of eleven common maize cultivars and one variety of quality-protein maize (QPM) called "Nutricta" were processed into cooked maize and tortillas by the method used in rural areas. Samples of raw and cooked maize and their respective tortillas were analyzed for major nutrient components, as well as for total dietary fiber, calcium, magnesium, sodium, and potassium. Four of the common maize samples, the QPM, and their processing products were analyzed for fatty acid content, and were also evaluated for protein quality. For both common maize and QPM the results showed increases in Ca and Mg from raw maize to tortilla and a small decreases in Na and K. Total dietary fiber decreased from raw maize to masa, and then it increased in tortillas. Fatty acid composition was similar among the maize samples and distribution was not affected by the lime cooking process. Protein quality was significantly higher ($P < 0.03$) in tortillas than in raw maize. In this respect QPM as a raw grain and as tortillas was statistically significantly superior to common maize.

The populations of many Latin American countries consume relatively large amounts of maize, processed by lime cooking and made into tortillas (Bressani 1972). In Guatemala, intake has been reported to be as high as 560 g per day for adults, and as high as 150 g daily for children (Bressani 1972, Garcia and Urrutia 1983). Furthermore, maize either as lime-cooked dough or as tortillas is often used as a weaning food with an intake of 40–60 g daily (Urrutia and Garcia 1983). Since the amounts of other foods consumed are relatively small, nutrient intake from tortillas becomes important. The nutritional quality of maize proteins is low but can be significantly improved by lysine and tryptophan supplementation (Rosenberg et al 1960). Due to the nutritional importance of maize, significant efforts have been made to improve its protein quality. This was achieved through the finding that the *opaque-2* gene increases lysine and tryptophan content in maize protein. In recent years, breeders have been able to develop maize varieties containing the *opaque-2* gene that are similar in yield and many physical properties to common maize but which have a higher nutritive value. These are known as quality-protein maize (QPM) (NRC 1988). One of these varieties was developed by the Institute of Agricultural Science and Technology (ICTA) in Guatemala (NRC 1988), and attempts are being made to introduce it into commercial production. Seed is available from ICTA as well as from commercial seed companies; however, its use by farmers is still low. Compositional studies on the effects of the lime-cooking process on common maize and QPM have been reported by various workers (Bressani and Scrimshaw 1958, Bressani et al 1958, Ortega et al 1986, Sproule et al 1988). Independently of the type of maize used, the alkaline process induces some significant compositional changes, such as increased availability of niacin (Bressani et al 1961), as well as a significant increase in calcium content (Bressani et al 1958, Martínez-Herrera and Lachance 1979, Bedolla and Rooney 1982, Pflugfelder et al 1988, Khan et al 1982), which is over 85% available (Braham and Bressani 1966, NRC 1988, Poneros and Erdman 1988). Thiamin, riboflavin, and niacin contents decrease due to the process (Bressani et al 1958), but only relatively small changes have been reported in essential amino acids (Ortega et al 1986, Bressani and Scrimshaw 1958, Sanderson et al 1978). However, with the exception of Ca, P, and Fe, no information is available with regard to rural processing of this food on other minerals, nor on other nutrients, such as fatty acids, to be affected by the lime-cooking process and short-time high-temperature baking to prepare tortillas. Knowledge of the levels present are of interest because of the high maize consumption by the people. Relatively complete analyses of industrially prepared maize tortillas are available (Bedolla and Rooney 1984, Saldana and Brown 1984, Ranhotra 1985). This paper presents comparative chemical data on selected nutrients and on the changes that occur during processing in both common and QPM, as well as changes in protein quality.

[1]Research coordinator, Institute of Nutrition of Central America and Panama (INCAP), P.O. Box 1188, Guatemala, Guatemala, C.A.
[2]Scientist, Agricultural and Food Science Division, INCAP.

MATERIALS AND METHODS

Eleven samples of common maize produced by high- and lowlands ($n = 8$ and 3, respectively) farmers of Guatemala were obtained. These samples were both white and yellow. The Nutricta variety of QPM was obtained from ICTA. A 5-kg sample of each maize variety was kept raw, and 10 kg of each maize sample was given to the same rural housewife to process the maize into masa and tortillas. This was done by cooking in lime water for 55–60 min, allowing to stand overnight, washing two to three times with water, and converting into masa by grinding in a rotary mill as has been described (Bressani et al 1958, Bressani and Scrimshaw 1958). Of the total masa obtained, 50% was left as masa and 50% was converted into tortillas. These materials were brought to the laboratory and air-dried at 60°C to constant weight then were ground into a flour, as was done with the sample of raw maize. A 200-g subsample of raw maize flour, masa, and tortillas was obtained for chemical analysis, leaving the remainder for protein quality evaluation. All samples were analyzed for moisture, protein, ether extract, and ash content by AOAC procedures (AOAC 1975). These samples were also analyzed for Ca, Mg, Na, and K by atomic absorption and for soluble and insoluble dietary fiber by the method of Asp et al (1983). Three samples of the common highland maize, one of lowland maize, and one of the QPM and their respective tortillas were analyzed for their fatty acid content by gas chromatography. The samples were extracted with di-ethyl ether, which was evaporated to recover the oil. A 400 mg sample of the oil was saponified with 4 ml of a 0.5*N* NaOH solution in methanol. To this, 3.5 ml of trifluoboride (TFB) in methanol was added for ester formation. The methyl esters were extracted with 4 ml of heptane and placed in vials containing small amounts of anydrous Na_2SO_4, then injected into the gas chromatograph. Lysine was determined as available lysine (Conkerton and Frampton 1959), and tryptophan analyses were conducted as suggested by Villegas et al 1982. Only four of the common maize samples (three from the highlands and one from the lowlands) and the QPM raw samples and their respective masa and tortillas were selected for protein quality evaluation. Three diets per maize sample were prepared. Each diet contained 90% raw maize, masa, or tortilla flours. This amount was supplemented with 4% minerals (Hegsted et al 1941), 1% cod liver oil, 5% refined cottonseed oil, and 5 ml/100 g of a complete vitamin mixture (Manna and Hauge 1953). A total of 128 weanling rats of the Wistar strain were distributed by weight among 16 groups of eight rats each, assigning 15 groups to maize diets and one to a casein control at a 10% protein level in the diet. Average initial weight for each group was 42 ± 22 g. The animals were placed in all-wire individual cages with raised bottoms in an animal room held at a constant temperature of 22°C and with a 12-hr light cycle. The diets and water were fed ad libitum for a 28-day experimental period, and weight changes and food consumed were recorded weekly. All diets were analyzed for their protein content by the Kjeldahl method for calculation of protein efficiency ratios.

TABLE I
Partial Chemical Composition of Common and Quality Protein Maize (QPM) and Processing Products (%, w/w)

Processing Stage/ Component	Highland Common Maize[a]	Lowland Common Maize[b]	QPM (Nutricta)
Raw maize			
Dry matter	87.2 ± 0.4	87.3 ± 0.1	87.2
Protein	10.2 ± 1.1	9.4 ± 1.4	10.0
Ether extract	4.7 ± 0.5	4.7 ± 0.7	5.5
Ash	1.1 ± 0.2	1.4 ± 0.2	1.3
Cooked maize			
Dry matter	87.3 ± 0.3	81.2 ± 0.3	86.9
Protein	10.0 ± 1.2	10.3 ± 2.6	10.6
Ether extract	4.6 ± 0.5	4.6 ± 0.7	5.2
Ash	1.2 ± 0.2	1.6 ± 0.2	1.5
Tortillas			
Dry matter	87.4 ± 0.3	87.4 ± 0.3	87.2
Protein	9.7 ± 0.6	11.0 ± 2.7	9.5
Ether extract	2.8 ± 0.3	2.8 ± 0.5	3.1
Ash	1.5 ± 0.1	1.6 ± 0.1	1.5

[a] Average ± SD ($n = 8$).
[b] Average ± SD ($n = 3$).

TABLE II
Calcium, Magnesium, Sodium, and Potassium Content (mg/100 g) of Lime-Treated Maize Dough and Tortillas

Processing Stage/ Nutrient	Common Highland Maize[a]	Common Lowland Maize[b]	QPM[c] (Nutricta)
Raw			
Ca	38.0 ± 15.7	32.0 ± 13.1	23.7
Mg	93.6 ± 23.4	128.4 ± 22.1	104.4
Na	27.5 ± 10.7	22.8 ± 5.5	15.5
K	283.4 ± 47.3	366.9 ± 66.5	361.9
Cooked grain			
Ca	129.1 ± 61.1	144.9 ± 26.5	117.8
Mg	103.0 ± 16.2	137.6 ± 24.0	105.9
Na	25.2 ± 16.4	27.2 ± 16.5	18.7
K	275.7 ± 41.2	246.7 ± 24.9	351.8
Tortilla			
Ca	209.2 ± 57.3	196.1 ± 50.4	210.0
Mg	126.4 ± 17.4	139.2 ± 15.1	129.4
Na	18.2 ± 5.5	20.3 ± 10.5	24.2
K	332.7 ± 50.0	301.8 ± 27.2	291.7

[a] Average ± SD ($n = 8$).
[b] Average ± SD ($n = 3$).
[c] Quality protein maize.

TABLE III
Dietary Fiber (%) in Lime-Treated Maize Dough and Tortillas

Processing Stage/ Fiber[a]	Highland Maize[b]	Lowland Maize[c]	QPM[d] (Nutricta)
Raw			
IDF	10.94 ± 1.26	11.15 ± 1.08	13.77
SDF	1.25 ± 0.41	1.64 ± 0.73	1.14
TDF	12.19 ± 1.30	12.80 ± 1.47	14.91
Dough			
IDF	8.05 ± 1.42	7.92 ± 1.70	10.65
SDF	1.26 ± 0.19	1.64 ± 0.55	1.36
TDF	9.31 ± 1.38	9.56 ± 1.70	12.01
Tortilla			
IDF	9.00 ± 1.14	10.07 ± 1.93	10.35
SDF	1.29 ± 0.21	1.59 ± 0.55	1.87
TDF	10.28 ± 1.00	11.66 ± 1.56	12.22

[a] IDF = Insoluble dietary fiber, SDF = soluble dietary fiber, and TDF = total dietary fiber.
[b] Average ± SD ($n = 8$).
[c] Average ± SD ($n = 3$).
[d] Quality protein maize.

RESULTS AND DISCUSSION

Changes in average dry matter, protein, fat, and ash contents of the maize samples subjected to the lime-cooking process are shown in Table I. Dry matter content was similar in the raw, cooked, and the tortilla samples of all maizes, since all were air-dried under the same conditions. On the other hand, when comparing the three groups of samples, protein content in raw maize varied from 9.4 to 10.2%, in cooked maize from 10.0 to 10.6%, and in tortillas from 9.5 to 11.0%. Average protein content of raw maize was 9.9%, of masa 10.3%, and of tortilla 10.1%. The change in total protein content from raw maize to tortilla is similar to that previously reported by other workers (Bressani et al 1958, Bressani and Scrimshaw 1958, Ortega et al 1986), and it is due to losses of soluble carbohydrates during washing of the cooked maize. Ether extracts among groups of samples varied from 4.7 to 5.5% with an average of 5.0 in raw maize, while in cooked maize the average value was 4.8 with a variation of 4.6 to 5.2%. In tortillas a decrease was found in all maize samples, with a variation of 2.8 to 3.1% and an average value of 2.9%. This change in ether extract has also been reported before (Bressani et al 1958, Pflugfelder et al 1988). The ash content increased from maize to tortilla for all samples, as reported in other studies (Bressani et al 1958, Khan et al 1982); raw maize showed an average of 1.3% ash, cooked maize 1.4%, and tortillas 1.5%. Calcium, magnesium, sodium, and potassium contents are shown in Table II. Average calcium content for all samples increased from 35.0 in raw maize to 206.0 mg/100 g in tortillas and magnesium from 104.0 to 121.0 mg/100 g. The increases result from the use of lime, which probably contains magnesium compounds. On the other hand, sodium and potassium contents decreased from 25 to 19 and from 313 to 276 mg/100 g from maize to tortilla, respectively. Sodium levels in maize are very low, and the decrease may be an experimental error. On the other hand, the loss of potassium could be due to losses of germ where K is found with Mg as salts of phytic acid. Average results on dietary fiber are shown in Table III. While insoluble dietary fiber decreased from maize to tortilla in all cases studied, the soluble fiber was relatively constant, with QPM showing a relatively small increase from the raw state to tortilla. These changes resulted in tortillas having a total dietary fiber content similar to that of raw maize. It is of interest to point out that insoluble dietary fiber decreased from raw to cooked maize, due mainly to the elimination of the seed coat during alkaline cooking. However, there was an increase from cooked maize to tortilla, possibly due to the development of insoluble compounds when the maize dough is placed on the hot plate to bake the tortilla. Using the Van Soest fiber fractionation method, other workers reported similar trends although the values were smaller that the values reported in this paper (Reinhold and García 1979). Others (Sproule et al 1988, Serna-Saldivar et al 1988, Acevedo and Bressani unpublished) also reported similar values for common and QPM tortillas using the method of Asp et al (1983). The relatively high levels of dietary fiber in tortillas are of nutritional significance, particularly for those who consume large amounts of processed maize. On the basis of around 400 g of tortilla per person per day, on a dry weight basis, intake of dietary fiber would be around 40 g, a high level on the basis of present recommendations. Changes that occurred in lysine and tryptophan content—the two most limiting amino acids in maize (Rosenberg et al 1960)—from maize to tortillas, are shown in Table IV. While differences were found in lysine content between maize samples, lysine content did not change significantly due to processing. Differences in tryptophan content were also found with respect to maize cultivars with the QPM. Nutricta containing the highest amount. The process of lime cooking decreased tryptophan content in common maize from an average value of 38 mg/g of nitrogen in raw maize, to 26 mg/g in tortillas. In QPM, tryptophan content also decreased from 57 to 42 mg/g of nitrogen. Ortega et al (1986) reported a reduction of 11% for common maize and of around 15% for QPM; in the present study the QPM Nutricta showed a 26% reduction from raw maize to tortilla. The average change for all samples was around 22% with values ranging from 9 to 37%. The main decrease took place when cooking the masa of the tortilla, but no explanation can be offered for such a significant decrease in tryptophan content. Fatty acid content in raw maize and its tortilla in 5 of the 13 samples is shown in Table V. The fatty acid distribution in raw maize was similar to that reported by others (Jellum 1970, Weber 1987), and the differences are possibly due to both cultural practices and genetic makeup of the samples. The lime cooking process did not induce major changes in the different fatty acids even though total fat content decreased. Fatty acid content in QPM Nutricta was similar to that of other maize samples.

Table VI summarizes the evaluation of the protein quality of three samples of maize grown in the highlands (where maize consumption by humans is greater), one sample from the lowlands, and QPM Nutricta. Table VII summarizes the statistical analysis of the biological data. In this experiment, rats fed the casein diet showed a weight gain, food intake, and protein efficiency ratio (PER) that was significantly ($P < 0.01$) greater than those for rats fed the different diets based on raw and processed maize. Rats fed diets made from QPM Nutricta, either raw or processed as maize dough and tortillas, showed a weight gain, food intake, and PER significantly greater ($P < 0.01$) than animals fed diets made from the common maize samples and respective processing products. Rats fed diets of common maize showed a weight gain, food intake, and PER that did not differ statistically, with the exception of the Santa Apolonia sample, which had a significantly lower PER value than White Tropical.

With respect to processing of the different maize samples, it was observed that animals consuming diets made from maize dough and tortillas showed a weight gain and PER significantly greater ($P < 0.01$) than animals fed raw maize diets. This demonstrates the beneficial effect of lime cooking on nutrient bioavailability, which is in agreement with observations previously made (Bressani et al 1968).

Concerning food intake, it was found that rats fed tortilla diets showed an intake significantly greater ($P < 0.05$) than those fed raw maize diets. However rats fed dough diets showed an intake not significantly different from the intake of diets made from raw maize. In addition, it was observed that animals fed diets based on common raw maize or their respective dough showed a weight gain, food intake, and PER not statistically different

TABLE IV
Lysine and Tryptophan Contents (mg/g of N) in Common and Quality Protein Maize (QPM), and Their Respective Doughs in Tortillas

Maize Sample	Raw	Cooked Maize	Tortilla
Tryptophan			
Common highland maize[a]	32 ± 5	28 ± 4	23 ± 3
Common lowland maize[b]	43 ± 11	37 ± 4	29 ± 3
QPM Nutricta	57	...	42
Lysine			
Common highland maize	158	152	145
Common lowland maize	166	165	175
QPM Nutricta	196	202	196

[a] Average ± SD ($n = 8$).
[b] Average ± SD ($n = 3$).

TABLE V
Fatty Acid Content (%) in Raw Maize and its Tortilla

Cultivar/ Sample	C16:0	C18:0	C18:1	C18:2	C18:3
Quality protein maize[a]					
Raw	15.71	3.12	36.45	43.83	0.42
Tortilla	15.46	3.25	35.84	43.03	0.94
Azotea[b]					
Raw	12.89	2.62	35.63	48.85	...
Tortilla	13.43	2.70	35.73	47.12	1.03
Xetzac[b]					
Raw	11.75	3.54	40.07	44.65	...
Tortilla	11.86	3.50	39.52	44.16	0.97
White Tropical[c]					
Raw	15.49	2.40	34.64	47.47	...
Tortilla	16.56	2.67	35.38	45.39	...
Santa Apolonia[b]					
Raw	11.45	3.12	38.02	47.44	...
Tortilla	12.68	2.92	37.95	46.44	...

[a] Nutricta.
[b] Highland.
[c] Lowland.

TABLE VI
Protein Quality of Maize Cultivars and Their Respective Processing Products

Maize	Average Weight Gain (g) ± SD	Average Food Intake (g) ± SD	Protein Efficiency Ratio (Average ± SD)
Raw			
QPM[a]	60 ± 14	362 ± 49	1.92 ± 0.23
White Tropical[b]	17 ± 6	222 ± 38	0.99 ± 0.25
Xetza[c]	18 ± 4	228 ± 29	0.96 ± 0.19
Azotea[c]	15 ± 5	212 ± 27	1.02 ± 0.19
Santa Apolonia[c]	12 ± 3	218 ± 35	0.71 ± 0.20
Dough			
QPM[a]	67 ± 14	337 ± 49	2.16 ± 0.22
White Tropical[b]	25 ± 4	219 ± 21	1.35 ± 0.09
Xetzac[c]	23 ± 7	212 ± 32	1.10 ± 0.22
Azotea[c]	19 ± 6	212 ± 38	1.15 ± 0.21
Santa Apolonia[c]	18 ± 6	204 ± 32	0.98 ± 0.25
Tortilla			
QPM[a]	66 ± 9	355 ± 43	2.12 ± 0.12
White Tropical[b]	28 ± 4	238 ± 28	1.41 ± 0.11
Xetzac[c]	25 ± 7	250 ± 39	1.12 ± 0.20
Azotea[c]	25 ± 6	247 ± 31	1.41 ± 0.17
Santa Apolonia[c]	18 ± 4	211 ± 17	0.98 ± 0.17
Casein	126 ± 14	392 ± 118	2.63 ± 0.17

[a] Quality protein maize (Nutricta).
[b] Lowland.
[c] Highland.

TABLE VII
Statistical Analysis of the Protein Efficiency Ratio Assay Data

ANOVA Source	Wt Gain Pr > F	Feed Intake Pr > F	Protein Efficiency Ratio Pr > F
Model error total	0.0001**[a]	0.0001**	0.0001**
Orthogonal contrasts			
Casein vs. maize samples	0.0001**	0.0001**	0.0001**
QPM[b] vs. common maize	0.0001**	0.0001**	0.0001**
Common maize	0.05 NS	0.05 NS	0.05 NS
Raw maize vs. tortilla	0.0011**	0.0118*	0.0001**
Raw maize vs. masa	0.0012**	0.1595 NS	0.0001**
Interactions	0.05 NS	0.05 NS	0.05 NS
Scheffé contrasts	SE 40.79	SE 178.33	SE 0.977
Tortilla vs. masa	0.05 NS	NS	NS
Xetzac vs. Sta. Apolonia	0.05 NS	NS	NS
Xetzac vs. Azotea	0.05 NS	NS	NS
Xetzac vs. White Tropical	0.05 NS	NS	NS
Sta. Apolonia vs. Azotea	0.05 NS	NS	NS
Sta. Apolonia vs. White Tropical	0.05 NS	NS	0.05*
Azotea vs. White Tropical	0.05 NS	NS	NS

[a] ** $P < 0.01$, * $P < 0.05$, and NS, not significant.
[b] Quality protein maize.

between them ($P < 0.05$). It is of interest to point out that weight gain, food intake, and PER of QPM Nutricta raw and processed were statistically significantly greater than values observed from common maize. Animals fed on QPM and its processing products showed a significantly higher diet intake, which provided more energy, protein, and other nutrients and which resulted in a higher weight gain than the results from feeding normal maize and products. This important observation is not due to differences in diet protein content, which was 8.8% for QPM diets and 8.4% for normal maize diets, but to the superior essential amino acid pattern in QPM. In all cases, PER of tortillas was higher than PER of raw maize, and it is interesting to note that PER of common maize samples increased more by processing into tortillas than that observed in QPM Nutricta. The observation that PER of tortillas is somewhat higher than PER of maize used to prepare them has previously been made (Bressani et al 1968). It was postulated that a higher rate of amino acid availability from the nonprolamine proteins in maize causes the difference, since solubility of prolamine fractions is severely affected by the lime-cooking process (Bressani and Scrimshaw 1958). Results of other investigators, however, show that protein quality of tortillas is slightly lower than that of raw maize (Serna-Saldivar et al 1987). No explanation can be offered except that the samples in this study were processed under milder conditions; for example, the level of lime used, as compared to industrially produced samples, which may have longer cooking times and higher levels of lime. The difference in protein quality between maize and tortilla may also be partially due to the higher bioavailability of the carbohydrate content in tortilla as compared to raw maize, since animals on the tortilla diets consumed more feed than those on raw maize diets. Varieties of QPM such as Nutricta with yields as high as those commonly grown in Guatemala are already available for commercial production. Efforts to introduce such materials as a means to improve the quality of diets presently consumed by rural populations in maize-consuming countries should continue.

ACKNOWLEDGMENTS

This work was supported by funds from General Foods Fund, Inc. White Plains, New York.

LITERATURE CITED

ASP, N. G., JOHANSSON, C. G., HALLMER, H., and SILJESTROM, M. 1983. Rapid enzymatic assay of insoluble and soluble dietary fiber. J. Agric. Food Chem. 31:476-482.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. 1975. Official Methods of Analysis, 3rd ed. The Association: Washington, DC.

BEDOLLA, S., and ROONEY, L. W. 1982. Cooking maize for masa production. Cereal Foods World 27:219-221.

BEDOLLA, S., and ROONEY, L. W. 1984. Characteristics of U.S. and Mexican instant maize flours for tortilla and snack preparation. Cereal Foods World 29:732-735.

BRAHAM, J. E., and BRESSANI, R. 1966. Utilización del calcio del maíz tratado con cal. Nutr. Bromatol. Toxicol. 5:14-19.

BRESSANI, R. 1972. The importance of maize for human nutrition in Latin America and other countries. Pages 5-29 in: Nutritional Improvement of Maize. R. Bressani, J. E. Braham, and M. Béhar, eds. INCAP: Guatemala City, Guatemala.

BRESSANI, R., and SCRIMSHAW, N. S. 1958. Lime-heat effects on corn nutrients. Effect of lime treatment on *in vitro* availability of essential amino acids and solubility of protein fractions in corn. J. Agric. Food Chem. 6:774-778.

BRESSANI, R., PAZ Y PAZ, R., and SCRIMSHAW, N. S. 1958. Corn nutrient losses. Chemical changes in corn during preparation of tortillas. J. Agric. Food Chem. 6:770-774.

BRESSANI, R., GOMEZ-BRENES, R., and SCRIMSHAW, N. S. 1961. Effect of processing on distribution and *in vitro* availability of niacin of corn (*Zea mays*). Food Technol. 15:450-454.

BRESSANI, R., ELIAS, L. G., and BRAHAM, J. E. 1968. Suplementación, con aminoácidos, del maíz y de la tortilla. Arch. Latinoam. Nutr. 18:123-134.

CONKERTON, E. J., and FRAMPTON, V. L. 1959. Reaction of gossypol with free E-amino groups of lysine in proteins. Arch. Biochem. Biophys. 81:130-134.

GARCIA, B., and URRUTIA, J. J. 1983. Descripciones de las condiciones socio-económicas de la comunidad de Santa María Cauqué. Pages 116-132 in: Memorias de la Conferencia Interacción entre Producción Agricola, Tecnología de Alimentos y Nutrición. Archivos Latinoamericanos de Nutrición: Guatemala City.

HEGSTED, D. M., MILLS, R. C., ELVEHJEM, C. A., and HART, E. B. 1941. Choline in the nutrition of chicks. J. Biol. Chem. 138:459-466.

JELLUM, M. D. 1970. Plant introductions of maize as a source of oil with unusual fatty acid composition. J. Agric. Food Chem. 18:365-370.

KHAN, M. N., DES ROISIERS, M. C., ROONEY, L. W., MORGAN, R. G., and SWEAT, V. E. 1982. Corn tortillas: Evaluation of corn cooking procedures. Cereal Chem. 59:279-284.

MANNA, L., and HAUGE, S. M. 1953. A possible relationship of vitamin B13 to orotic acid. J. Biol. Chem. 202:91-96.

MARTINEZ-HERRERA, M. L., and LACHANCE, P. A. 1979. Corn (*Zea mays*) kernel hardness as an index of the alkaline cooking time for tortilla preparation. J. Food Sci. 44:377-380.

NATIONAL RESEARCH COUNCIL. 1988. Quality Protein Maize. National Academy of Sciences: Washington, DC.

ORTEGA, E. I., VILLEGAS, E., and VASAL, S. K. 1986. A comparative study of protein changes in normal and quality protein maize during tortilla making. Cereal Chem. 63:446-451.

PFLUGFELDER, R. L., ROONEY, L. W., and WANISKA, R. D. 1988. Dry matter losses in commercial corn masa production. Cereal Chem. 65:127-132.

PONEROS, A. G., and ERDMAN, J. W., JR. 1988. Bioavailability of calcium from tofu, tortillas, nonfat dry milk and mozzarella cheese in rats: Effect of supplemental ascorbic acid. J. Food Sci. 53:208-210.

RANHOTRA, G. S. 1985. Nutritional profile of corn and flour tortillas. Cereal Foods World 30:703-704.

REINHOLD, J. G., and GARCIA, J. S. 1979. Fiber of the maize tortilla. Am. J. Clin. Nutr. 32:1326-1329.

ROSENBERG, H. R., ROHDENBURG, E. L., and ECKERT, R. E. 1960. Multiple amino acid supplementation of white corn meal. J. Nutr. 72:415-422.

SALDANA, G., and BROWN, H. E. 1984. Nutritional composition of corn and flour tortillas. J. Food Sci. 49:1202-1205.

SANDERSON, J., WALL, J. S., DONALDSON, G. L., and CAVINS, J. F. 1978. Effect of alkaline processing of corn on its amino acids. Cereal Chem. 55:204-213.

SERNA-SALDIVAR, S. O., KNABE, D. A., ROONEY, L. W., and TANKSLEY, T. D., JR. 1987. Effects of lime cooking on energy and protein digestibilities of maize and sorghum. Cereal Chem. 64:247-252.

SERNA-SALDIVAR, S. O., KNABE, D. A., ROONEY, L. W., TANKSLEY, T. D., JR., and SPROULE, A. M. 1988. Nutritional value of sorghum and maize tortillas. J. Cereal Sci. 7:83-94.

SPROULE, A. M., SERNA-SALDIVAR, S. O., BOCKHOLT, A. J., ROONEY, L. W., and KNABE, D. A. 1988. Nutritional evaluation of tortillas and tortilla chips from quality protein maize. Cereal Foods World 33:233-236.

URRUTIA, J. J., and GARCIA, B. 1983. Diagnóstico de la situación de salud de la población de Santa María Cauqué. Pages 133-165 in: Memorias de la Conferencia Interacción entre Producción Agrícola, Tecnología de Alimentos y Nutrición, INCAP, Guatemala City, Nov. 6–9, 1978. Archivos Latinoamericanos de Nutrición: Guatemala City.

VILLEGAS, E., ORTEGA, E. I., and BAUER, R. 1982. Métodos Químicos Usados en CIMMYT para Determinar la Calidad de Proteína de los Cereales. CIMMYT: El Batán, México.

WEBER, E. J. 1987. Lipids of the kernel. Pages 311-349 in: Corn: Chemistry and Technology. S. H. Watson and P. E. Ramstad, eds. Am. Assoc. Cereal Chem.: St. Paul, MN.

[Received July 28, 1989. Accepted March 16, 1990.]