Effect of Soybean and Sesame Addition on the Nutritional Value of Maize and Decorticated Sorghum Tortillas Produced by Extrusion Cooking[1]

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ABSTRACT

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The effects of defatted soybean meal, full-fat sesame, and a mixture of soybean and sesame on the nutritional value of tortillas of maize (75%) and decorticated sorghum (25%) produced by extrusion cooking was studied. Decorticated red sorghum in raw and tortilla form had the best protein digestibility but the worst protein quality because of its poor essential amino acid pattern. Maize plus decorticated sorghum tortillas fortified with 8% soybean or 8% soybean and 4% sesame had protein digestibility similar to unfortified tortillas but higher amounts of lysine and, therefore, better chemical score, biological value, net protein utilization, and protein efficiency ratio. Addition of sesame (8%) did not increase protein quality ($P < 0.05$) or rat performance, but it did slightly increase gross energy. In vitro protein digestibility and calculated protein efficiency ratio techniques were highly correlated with in vivo data. These assays can be used to predict the nutritional value of tortilla products.

Maize constitutes the main staple food for large groups of people in Latin America, where it is generally consumed in the form of tortillas. Most of the tortillas are produced by the traditional process which consists of cooking the grain in excess water with lime, allowing the cooked grain to steep for 12 hr, grinding the resulting *nixtamal* in stone grinders to form a dough or masa, and baking disk-shaped tortillas on a gas-fired oven or hot griddle. According to Paredes and Saharopulos (1983) the annual per capita consumption of tortillas in Mexico is 120 kg. In fact, in some rural areas of Mexico and Central America, the consumption of maize tortillas provides about 70% of the calories and one half of the proteins in the daily diet. Recently, sorghum has been considered as an alternative for tortilla production due to its drought resistance and lower price. However, sorghum use for tortilla is limited, because it produces off-color tortillas and social and psychological factors limit its acceptance. The use of white genotypes or decorticated sorghum has partly overcome the problem due to improved appearance and overall acceptability (Khan et al 1980, Choto et al 1985).

The feasibility of using extrusion cooking to produce shelf-stable instant flours for tortilla production has been studied (Bazua et al 1979, Bedolla 1983, Almeida 1984). Extrusion cooking offers the advantage of producing instant flours with lower use of water and lime. It also saves 10–15% of the dry matter commonly lost when compared to traditional nixtamalization.

Protein malnutrition is a serious problem in Latin American countries where a growing population and lack of agricultural development results in a limited supply of high-quality protein to the general population. The strategic use of inexpensive high-protein resources that complement the amino acid composition of tortillas is, therefore, highly recommended to upgrade the nutritional status of many people. Previous reports have noted the beneficial effect of soybean and sesame additions on the nutritional value of corn tortillas (Bressani et al 1974, 1979; Del Valle and Perez Villasenor 1974; Almeida 1984). The objectives of the present study were 1) to evaluate the effect of extrusion cooking and tortilla baking on the nutritional value of maize and decorticated sorghum; 2) to study the effect of defatted soybean, full-fat sesame, and a mixture of soybean and sesame addition on the nutritional value of maize-decorticated sorghum tortillas; and 3) to predict protein digestibilities and protein efficiency ratios (PER) via in vitro assays.

MATERIALS AND METHODS

Raw Materials

Tortilla mixtures were produced using the following ingredients: 1) commercial white maize with intermediate endosperm grown in Chihuahua, Mexico; 2) commercial yellow sorghum with heteroyellow endosperm, red pericarp, and without a pigmented testa, decorticated using an International Development Research Corporation (IDRC) abrasive mill (Reichert 1982) to remove approximately 18% of its original weight (mainly pericarp and germ tissue); 3) solvent-extracted commercial soybean meal obtained from a commercial plant located in Hermosillo, Sonora, Mexico; and 4) sesame that was decorticated with a dilute sodium hydroxide solution in a commercial plant located in Hermosillo.

Treatments

The experiment consisted of the evaluation of three groups of treatments. The first group contained raw grains of 1) maize and 2) decorticated sorghum. The second group consisted of the unfortified tortilla products obtained after baking the water-reconstituted extruded flours: 3) maize tortilla, 4) 75% maize/25% decorticated sorghum tortilla, and 5) decorticated sorghum tortilla. The last group was designed to study the effect of fortification on the optimized 75% maize/25% decorticated sorghum tortilla with 6) 8% defatted soybean meal, 7) 8% sesame, and 8) a mixture of 8% defatted soybean meal and 4% sesame. The maize and decorticated sorghum mixture produced tortillas with properties (color, texture, and flavor) similar to maize tortillas. Bressani et al (1974, 1979) and Almeida (1984) indicated that fortification of tortillas with 8% whole soybeans or 8% defatted sesame did not affect tortilla organoleptic quality but significantly improved nutritional value.

Extrusion Cooking and Tortilla Baking

Figure 1 shows the flowchart of the extrusion cooking and tortilla baking procedure. For the production of the six different tortilla mixtures (treatments 3–8), raw materials were lime-cooked in a Wenger X-5 extruder (Wenger Mfg. Co., Sabetha, KS). To avoid over gelatinization, the die was removed; therefore, the extruder was used as a continuous cooker.

Chemical Composition

The amino acid composition of raw grains and tortillas was determined after 24 hr of hydrolysis in 6*N* HCl. The hydrolysate was quantitated by ion-exchange chromatography in a Beckman 120C amino acid analyzer according to Spackman et al (1958). Tryptophan was quantitated by the growth of *Leuconostoc mesenteroides* ATCC 8014 in a medium that contained the digested protein material (Ford 1962, 1964; Ford et al 1969). Calcium was obtained after the samples were wet-ashed with nitric and perchloric acids. The oxidized solution was diluted with

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distilled deionized water in the presence of lanthanum oxide and quantified by atomic absorption spectrophotometry (Perkin-Elmer; model 2380) (Anonymous 1976). Gross energy was obtained after burning the samples in a bomb calorimeter according to the method of Raymond et al (1957). Starch was analyzed by an enzymatic procedure in which the polymer was hydrolyzed with glucoamylase (Technicon 1978). The resulting glucose was colorimetrically assayed in a Technicon automated system (model AA-II).

Metabolic Study

Four weanling Sprague-Dawley rats per treatment (two males and two females) were individually housed in metabolic cages for 16 days. The 28-day-old weanling rats had an initial weight of 84 g. The experimental diets consisted of the test materials supplemented with 4% minerals and 1% vitamins. The control casein diet contained 10% protein, 2% crude fiber, 8% fat, and the same amounts of supplemented minerals and vitamins. The rats had a two-day diet and cage adaptation period. Feces and urine were collected daily for 14 days and stored in the freezer. During the collection period, feed intake was carefully monitored. Urine nitrogen losses were further prevented by adding 1 ml/day of HCl (1:1) to the collection containers. Feces were dried in an oven at 50–55° C for 12 hr, left on the counter for moisture equilibration, weighed, and assayed for moisture, nitrogen, and gross energy. Moisture and nitrogen were determined according to standard AOAC (1984) methods. Diets were assayed for the same chemical components, whereas urine was only tested for nitrogen. Data were utilized to calculate dry matter, energy, and apparent protein digestibilities, biological value (BV), and net protein utilization (NPU). Protein digestibilities were calculated by subtracting the amount of protein present in feces from the protein intake and dividing the result by the protein intake. The BV was calculated by subtracting the nitrogen excreted in urine and feces from the nitrogen intake and dividing the result by the difference between nitrogen intake and nitrogen in feces. The NPU was obtained by multiplying the BV times the apparent protein digestibility.

Protein Efficiency Ratio Study

Six growing rats (three males and three females) per treatment were individually housed in stainless steel wire cages for 28 days. Sprague-Dawley rats of approximately 21 days of age with an initial weight of 53 g were blocked by weight and sex. Rats were fed isonitrogenous diets (10% protein) that were prepared according to standard AOAC (1984) procedures. Because some of the materials contained less than 10% crude protein, the nonessential amino acid glycine was supplemented to reach the 10% protein level (Table I). The control diet was formulated to contain the same amounts of fat, fiber, and protein as the experimental diets and had casein as the sole source of protein. Feed and water were provided ad libitum. Rats were weighed weekly, so the final protein efficiency ratio (PER) was the average of four weekly observations. The final PER was adjusted according to the PER of the control casein group.

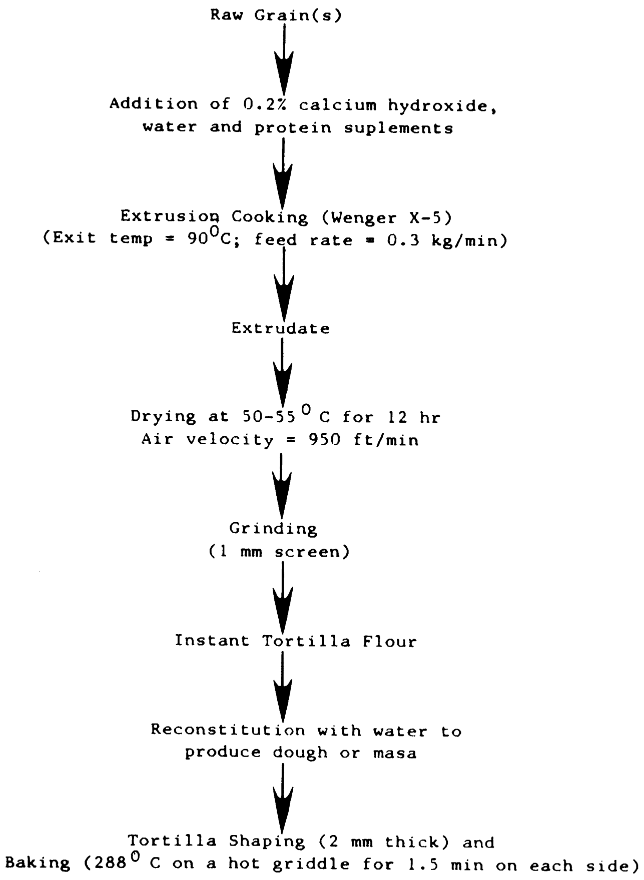

Fig. 1. Steps for the production of tortillas via extrusion cooking.

TABLE I
Composition of Diets Fed During Protein Efficiency Ratio Study[a]

	Treatments[b]								
Ingredient	RM	RS	MT	ST	MST	MSTSOY	MSTSE	MSTSS	Control
Ground	88.4	88.7	85.5	82.7	85.4	87.9	92.4	83.3	···
Starch[c]	···	···	···	···	···	···	···	···	68.7
Casein[d]	···	···	···	···	···	···	···	···	11.3
Corn oil[e]	3.8	6.2	5.9	7.8	5.8	5.6	1.9	4.6	8.0
Cellulose[f]	1.0	1.7	1.4	1.8	1.5	1.4	0.8	1.3	2.0
Sucrose	···	···	···	···	···	···	···	···	5.0
Minerals[g]	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Vitamins[h]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Glycine	1.8	2.4	2.2	2.7	2.3	0.1	1.0	···	···
Total	100	100	100	100	100	100	100	100	100

[a] As fed basis.

[b] RM = Raw maize; RS = raw decorticated sorghum; MT = maize tortilla; ST = decorticated sorghum tortilla; MST = 75% maize/25% decorticated sorghum tortilla; MSTSOY = MST supplemented with 8% defatted soybean meal; MSTSE = MST supplemented with 8% sesame; MSTSS = MST supplemented with 8% defatted soybean meal and 4% sesame.

[c] American Institute of Nutrition (AIN) starch.

[d] American Nutritional Research Center casein.

[e] Mazola corn oil.

[f] Cellulofil.

[g] AIN mineral premix.

[h] AIN vitamin premix.

In Vitro Assays

Protein digestibility. In vitro protein digestibilities were determined according to the procedure suggested by Hsu et al (1977). The test sample was incubated with trypsin, chymotrypsin, and amino peptidase. The degree of protein digestion was directly proportional to the pH drop during 10 min of incubation at 37° C.

Calculated protein efficiency ratio (CPER). The CPER was calculated using the protein digestibility (Hsu et al 1977) and essential amino acid pattern of the test material in the set of equations proposed by Satterlee et al (1982).

Statistical Analyses

Nutrient digestibilities, BVs, NPUs, and PERs were statistically analyzed using analysis of variance and correlation procedures. Duncan's tests were chosen to compare treatment means at the $P = 0.05$ level (Steel and Torrie 1980). The statistical package of an Apple II microcomputer was utilized for all analyses.

RESULTS AND DISCUSSION

Chemical Composition

Decorticated sorghum contained the lowest amount of crude fiber, ether extract, ash, and calcium (Table II). This was attributable to the partial loss of pericarp, aleurone, and germ tissue during decortication. Consequently, sorghum contained the greatest amounts of starch and nitrogen-free extract. In addition, decorticated sorghum contained about one-half of the lysine content of maize (Table II). Raw grains contained less ash and approximately 1/20 of the calcium value of their respective tortilla products. Similar calcium values were reported by Bressani et al (1958) and Serna-Saldivar et al (1987b) in tortillas that were prepared by the traditional method. Addition of defatted soybean meal to the maize-sorghum tortilla increased protein content about 3%. Tortillas fortified with 8% soybean meal and 8% soybean/4% sesame contained twice as much lysine as the unfortified maize-decorticated sorghum tortillas (Table II). Addition of full-fat sesame seed increased protein, energy, and fat content. However, the improvement in protein was not reflected in the amount of lysine, so sesame did not contain the expected amount of this important amino acid.

Lysine was the first limiting amino acid for all experimental treatments (Table III). Chemical scores were not different between raw grains and their respective tortilla products. Decorticated sorghum products (raw and tortilla) had the lowest chemical scores due to the lower lysine level. Decortication removed part of the germ and aleurone and consequently lysine content was reduced. Addition of soybean meal to the maize plus decorticated sorghum tortilla improved the chemical score by 30 units. Tortillas fortified with sesame had almost the same chemical scores as the unfortified tortillas, indicating that sesame addition did not improve the amino acid balance (Table III).

Metabolic Study

Results of the metabolic study are summarized in Table IV. Among the experimental treatments, decorticated sorghum products had the highest dry matter and energy digestibilities that were similar to the control diet because of pericarp removal during decortication. Addition of soybean or sesame, or both, did not influence dry matter and energy digestibilities. The tortillas had a significantly lower protein digestibility ($P<0.05$) than their respective raw grains, indicating that extrusion cooking and tortilla baking decreased protein digestibility. Several authors

TABLE II
Chemical Composition of Raw Grains and Tortillas[a]

	Treatments[b]							
Component	RM	RS	MT	ST	MST	MSTSOY	MSTSE	MSTSS
Protein, %	9.6	9.4	9.7	9.2	9.5	12.5	10.6	13.1
Fat, %	4.2	1.1	3.9	1.1	2.6	2.7	6.7	4.1
Crude fiber, %	2.1	0.4	1.9	0.3	1.5	1.6	2.3	1.7
Ash, %	1.5	0.5	1.6	1.0	1.4	1.6	1.8	2.0
NFE,[c] %	82.6	88.6	82.9	88.4	85.0	81.6	78.6	79.1
Starch, %	···	···	74.6	85.5	77.3	72.0	68.4	67.1
Lysine, %	0.31	0.17	0.30	0.16	0.26	0.52	0.30	0.52
Ca, mg/g	0.07	0.04	1.42	1.38	1.39	1.36	1.58	1.61
Energy,[d] cal/g	4,490	4,387	4,529	4,463	4,521	4,551	4,781	4,696

[a] All values are expressed on dry matter basis.
[b] RM = Raw maize; RS = raw decorticated sorghum; MT = maize tortilla; ST = decorticated sorghum tortilla; MST = 75% maize/25% decorticated sorghum tortilla; MSTSOY = MST supplemented with 8% defatted soybean meal; MSTSE = MST supplemented with 8% sesame; MSTSS = MST supplemented with 8% defatted soybean meal and 4% sesame.
[c] NFE = Nitrogen-free extract.
[d] Determined in an adiabatic bomb according to Raymond et al (1957).

TABLE III
Chemical Scores of Raw Grains and Tortillas[a]

	% FAO/WHO Requirement[b]								
Amino Acid	RM	RS	MT	ST	MST	MSTSOY	MSTSE	MSTSS	Control
Lysine	60	33	57	32	50	76	52	73	147
Methionine + Cysteine[c]	92	108	91	121	116	93	104	97	102
Threonine	89	77	88	82	89	96	90	92	109
Leucine	178	202	188	212	195	171	175	162	132
Isoleucine	94	95	95	112	100	107	99	110	91
Valine	101	100	100	107	103	106	104	104	139
Phenylalanine + Tyrosine	148	160	155	169	159	162	158	154	182
Tryptophan[d]	109	109	109	109	109	123	113	117	113

[a] For all experimental treatments, the first limiting amino acid was lysine; isoleucine was the first limiting amino acid for the control casein diet.
[b] RM = Raw maize; RS = raw decorticated sorghum; MT = maize tortilla; ST = decorticated sorghum tortilla; MST = 75% maize/25% decorticated sorghum tortilla; MSTSOY = MST supplemented with 8% defatted soybean meal; MSTSE = MST supplemented with 8% sesame; MSTSS = MST supplemented with 8% defatted soybean meal and 4% sesame.
[c] Cysteine values were obtained from tables of the average amino acid composition of each product.
[d] Tryptophan was quantified using a microbiological technique suggested by Ford (1964) and Ford et al (1969).

(DeGroot and Slump 1969, Chu et al 1976, DeGroot et al 1976, Finley et al 1978, Robbins et al 1980) reported that alkali cooking has a detrimental effect on protein quality because of amino acid degradation, racemization, and formation of lysinoalanine. Serna-Saldivar et al (1987a), working with ileum-cannulated swine, found that lysine digestibility at the terminal ileum in pigs fed lime-cooked maize and sorghum was about 5% lower than in pigs fed water-cooked grains. This could explain why tortillas had lower BVs and NPUs (Table IV). Serna-Saldivar et al (1987a) fed raw grains, *nixtamal*, or lime-cooked grains and tortillas to rats and also found that *nixtamals* and tortillas had lower protein digestibilities than their respective raw grains. Thus, it seems that extrusion cooking has the same detrimental effect on protein digestibility as the traditional cooking procedure. Fortification of the maize-sorghum tortilla with either soybean or sesame did not significantly ($P > 0.05$) affect protein digestibility, indicating that the soybean was properly treated to destroy trypsin inhibitor. As expected, the control casein diet had the highest protein digestibility; the value was similar to the ones reported by Hsu et al (1977) and Serna-Saldivar et al (1987a).

Chemical scores were closely correlated with BV ($r = 0.93$) and NPU ($r = 0.92$). Despite the high protein digestibility, decorticated sorghum (raw and tortilla) had the lowest BV and NPU because of its low lysine content or chemical score (Tables II and III). The low nitrogen retention values mean that most of the absorbed amino acids were catabolized to urea due to the poor amino acid balance. The BVs of raw maize and maize tortilla were similar ($P > 0.05$) and about 20 units higher than decorticated sorghum. The NPU of raw maize was significantly greater ($P < 0.05$) than maize tortilla due to its higher protein digestibility. The addition of soybean meal improved the BV of the maize-sorghum tortillas, making them similar ($P > 0.05$) to the control casein group. However, the control group had a significantly higher ($P < 0.05$) NPU because of its higher protein digestibility. Addition of sesame did not improve the chemical score (Table III) or the BV and NPU (Table IV) of the maize-sorghum tortilla.

Results of rat performance during the metabolic (Table IV) and PER (Table V) studies indicated that nitrogen retention and chemical scores were closely related to average daily gains, feed/gain ratios, and PERs. Rats fed tortillas fortified with soybean meal showed comparable feed/gain ratios (Table IV) and slightly lower ($P > 0.05$) PERs (Table V) than rats fed the control casein diet. The better feed conversion and PER was the result of adequate nutrient digestibilities and, especially, improved amino acid balance.

In vitro protein digestibilities were correlated with in vivo values ($r = 0.81$; standard error = 1.74) (Table IV). Therefore, the in vitro technique can be used as a fast, inexpensive indicator of apparent protein digestibilities.

PER Study

Feed intake was related to lysine content ($r = 0.65$; standard error = 1.46). Rats under experimental treatments with acceptable chemical scores consumed more feed than rats fed treatments with poor chemical scores. This confirms that protein quality partially governs feed intake, so when a poor diet is offered the organism generally shows apathy for feed. Rats fed decorticated sorghum (raw and tortilla) had the worst PERs, and the values were about one-half of the PERs of maize treatments. Rats fed maize-sorghum tortillas had slightly lower PERs ($P < 0.05$) than rats fed maize tortillas, indicating that the 25% sorghum replacement was enough to detect differences in PER. Rats fed maize tortillas had a significantly lower ($P < 0.05$) PER than rats fed raw maize. The difference is caused by the lower protein digestibility and by the detrimental effect of lime cooking on protein quality (Bressani et al 1958, Serna-Saldivar et al 1987a). The PER of rats fed maize-sorghum tortillas fortified with soybean almost doubled when compared with the PER of rats fed the unfortified tortillas. Similar results were obtained by Bressani et al (1974, 1979) when corn tortillas were fortified with whole soybeans. Rats fed tortillas fortified with sesame had similar weight gains and PERs ($P > 0.05$) to rats fed unfortified tortillas. Tortilla fortification with full-fat sesame at the level of 8% is, therefore, not recommended.

The calculated PER closely predicted the in vivo PER values ($r = 0.98$; standard error = 0.12) indicating that this assay can be used as a fast, accurate indicator of protein quality (Table V).

CONCLUSIONS

Soybean-fortified tortillas had the advantage of increased protein quality and calcium content. The dramatic improvement in the nutritional value appears to be worth the small increase in production cost. Also, soybean meal can be incorporated into the much-needed human nutritional programs in developing countries instead of being fed to animals. The low-cost tortilla mix with similar protein quality to casein and with adequate amounts of calcium, therefore, can be oriented to childhood nutrition.

It seems that commercial red sorghum decorticated to remove the outer layers has the potential of being substituted for up to 25% of the maize in tortilla production. From a nutritional standpoint, it would not be recommended to decorticate sorghum, because important nutrients (i.e., protein, lysine, minerals, fiber, fat) are removed. It would probably be better to incorporate white sorghum genotypes (food grade) with good agronomic properties or to decorticate commercial sorghums to a lesser extent. If sorghum could be successfully incorporated into tortillas, its low price would probably compensate for the price of soybean meal, so the more nutritious tortilla would have a comparable cost to maize tortillas.

TABLE IV

Metabolic Performance and In Vitro Protein Digestibilities of Maize-Sorghum Tortillas Fortified with Defatted Soybean Meal and Sesame[a,b]

	Digestibility (%)						
	In Vivo						
Treatment[b]	Dry Matter	Energy	Protein	In Vitro Protein[c]	Biological Value (%)	Net Protein Utilization (%)	Feed/Gain Ratio
RM	90.7 cd	91.6 bc	86.0 bc	83.3	59.5 ab	51.2 bc	6.5 a
RS	96.0 a	96.5 a	86.9 b	84.3	42.3 de	36.8 de	56.5 b
MT	90.0 de	90.9 cd	83.6 d	81.1	59.1 abc	49.4 bc	6.4 a
ST	95.4 a	95.9 a	84.6 cd	81.0	37.0 e	31.3 e	67.3 c
MST	91.4 b	92.0 bc	82.5 d	81.2	52.9 cd	43.6 cd	10.4 a
MSTSOY	89.5 e	90.4 d	83.0 d	84.5	66.2 ab	55.0 b	3.8 a
MSTSE	90.6 d	91.6 bc	83.2 d	84.2	57.5 bc	47.8 bc	6.3 a
MSTSS	89.6 e	91.0 bc	83.1 d	83.5	62.7 abc	52.1 b	3.8 a
Control	95.5 a	96.1 a	93.0 a	90.3	69.4 a	64.5 a	3.2 a

[a] Means are average of four observations. Means within the same column followed by different letters are statistically different ($P < 0.05$).

[b] RM = Raw maize; RS = raw decorticated sorghum; MT = maize tortilla; ST = decorticated sorghum tortilla; MST = 75% maize/25% decorticated sorghum tortilla; MSTSOY = MST supplemented with 8% defatted soybean meal; MSTSE = MST supplemented with 8% sesame; MSTSS = MST supplemented with 8% defatted soybean meal and 4% sesame.

[c] Estimated according to the technique of Hsu et al (1977).

TABLE V
In Vivo and Calculated Protein Efficiency Ratios of Tortillas Fortified with Defatted Soybean Meal and Sesame[a]

Treatment[b]	Feed Intake (g/day)	Average Daily Gain (g/day)	Protein Efficiency Ratios[c]	
			In Vivo	Calculated
RM	9.42 de	1.50	1.38 d	1.23
RS	5.51 f	0.26	0.41 f	0.51
MT	9.62 de	1.33	1.13 e	1.12
ST[d]	6.52 f	0.28	0.38 f	...
MST	8.69 e	0.93	1.02 e	0.85
MSTSOY	14.06 a	3.33	2.25 b	1.96
MSTSE	10.83 cd	1.45	1.15 e	1.06
MSTSS	13.44 ab	3.12	1.93 c	1.71
Control	12.02 bc	3.60	2.50 c	2.50

[a] Each value is the average of six observations. Means followed by different letters within the same column are statistically different ($P < 0.05$).

[b] RM = Raw maize; RS = raw decorticated sorghum; MT = maize tortilla; ST = decorticated sorghum tortilla; MST = 75% maize/25% decorticated sorghum tortilla; MSTSOY = MST supplemented with 8% defatted soybean meal; MSTSE = MST supplemented with 8% sesame; MSTSS = MST supplemented with 8% defatted soybean meal and 4% sesame.

[c] Protein efficiency ratio (PER) = g gain/g protein; corrected PER = PER test protein × PER casein.

[d] The computer program could not predict the calculated protein efficiency ratio because it was designed to calculate values greater than 0.5.

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