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Some Characteristics of Whole Corn: Whole Soybean (70:30) and Rice: Whole Soybean (70:30) Mixtures Processed by Simple Extrusion Cooking

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ABSTRACT

Mixtures of corn or rice with dehulled soybeans (70:30) were extruded at three cone openings. Processing temperatures were inversely correlated with cone opening. As cone opening increased fat retention and nitrogen solubility index increased, while dispersibility, protein nutritive value and acceptability (as "atole") by school children decreased. The PER and NPR of the mixtures were significantly ($P < 0.05$) correlated with processing temperature ($r = 0.90$ for both) and sensory score ($r = 0.83$ and 0.82, respectively). No correlation was observed between protein nutritive value and residual antiphysiological factors of the products. After storage of mixtures for 12 wk at 4° and 25°C, fat acidity values were lower than 2%; those stored at 35°C showed nearly 10%. All samples were equally acceptable.

INTRODUCTION

AS STATED in previous studies (Bressani et al., 1978), there is a need for developing simple and relatively inexpensive technological alternatives in order to promote the establishment of successful food industries in small countries such as those of the Central American area. On the other hand, it has been reported that malnutrition in the Central American countries is mostly prevalent in infants and preschool children, and is due not only to a protein deficiency but also to a calorie deficiency (Viteri and Arroyave, 1973). The need exists then to develop alternatives of food products for children, of a high protein quality, high caloric value, high acceptability and relatively low cost, available to the nutritionally most vulnerable groups, which generally are in the low income bracket.

Previous studies (Bressani et al., 1974; Tejerina et al., 1977) have shown that when a corn:soy or rice:soy mixture is prepared in such a proportion that approximately half of the protein comes from the cereal and the remaining 50% from the soybean, the mixture resulted in a higher protein quality food than each individual component. When whole soybeans are used, the above mixture is attained using approximately seven parts by weight of cereal and three parts by weight of whole soybeans. This mixture (using rice or corn as cereal) resulted in a high protein (around 18%) and calorically improved (around 10% fat) vegetable mixture, that when adequately cooked yields a high protein quality (PER between 2.5 and 2.6) and acceptable food product. In the case of the 70:30 whole corn:whole soybean mixture, it has already been reported (Bressani et al., 1978) that a food product of an improved protein quality could be obtained by simple extrusion cooking using the Brady Crop Cooker extruder. Therefore, the possibility exists of preparing an acceptable product for supplementary child feeding that would be nutritionally adequate (protein and calorie-wise) through a simple and relatively inexpensive technology that could, in turn, be the basis for a community or cooperative agroindustry.

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The present work was undertaken to evaluate the protein quality, the acceptability by children and the storage stability of a 70:30 whole corn:whole soybean mixture and a rice:whole soybean one, processed under different conditions using the Brady Crop Cooker extruder.

MATERIALS & METHODS

THE SOYBEANS and yellow corn used in these studies were grown either at INCAP's experimental farm (1,480m above sea level) or in the lowlands of Guatemala. The rice was obtained in a local rice processing plant and was of third grade (broken rice).

Batches of 200 kg of whole yellow corn and whole soybeans were coarsely ground in a hammer mill equipped with a 3 mesh screen. The broken soybeans were then dehulled by air separation using a Ce-Co-Co air blower (Chuo Boeki Goshi Kaisha, Central Commercial Co., Ibaraki, Osaka, Japan) equipped with a 0.3 hp engine. The broken rice was used as such without any further grinding. The particle size of the three different materials was determined using a set of sieves equivalent to 12, 20, 45 and 60 mesh.

With the coarsely milled corn and the broken rice, 450 kg batches of cereal:dehulled, coarsely milled, whole soybean blends were mixed, using a 70:30 weight ratio. A sample of each was taken for chemical analysis. Three portions of 150 kg each were taken from the two cereal:soybean mixtures, and they were processed in a Brady Crop Cooker extruder model 2160 (Brady, Division of Koehring Co., Appleton, WI), using an engine throwing 100 hp to the axis and a cone opening of 0.6, 1.0 and 1.4 mm for each portion, respectively. Before processing the samples, the cone of the extruder was rebuilt through hard-surface welding and refined to the same dimensions of a new cone. The feeding auger speed in the extruder was kept constant at 32 rpm in all cases. From previous observations on similar corn:soy and rice:soy mixtures, such feeding auger speed assures an average feeding rate of 520 kg/hr. No water was added to any sample before processing and all mixtures had an average 12% moisture content. Each mixture was processed in the extruder for approximately 20 min to attain equilibrium conditions before a sample of approximately 50 kg was taken, and the extrusion temperature at the exit cone and the mass flow data were recorded.

Moisture, crude protein (N x 6.25), and oil content were determined according to the AOAC methods (AOAC, 1980). Trypsin inhibitor activity was determined by the method of Kakade et al. (1969), hemagglutinins according to the method described by Jaffé and Brucher (1972), urease activity according to Caskey and Knapp (1944), and fat acidity according to the AOAC (1980). The nitrogen solubility index (NSI) and the dispersibility index (DI) were determined by the methods described by Smith and Circle (1972). In the case of the DI, the supernatant after centrifugation was evaluated for total solids rather than for nitrogen, as indicated in the method to determine protein dispersibility index (PDI) by Smith and Circle (1972). The total solids thus estimated in the supernatant were then compared with the dry matter content in the sample used for the test to estimate the DI. All determinations were done in duplicate.

The sensory trials were carried out with students (boys and girls) from the third and sixth grades of six public schools, three urban and three rural, of Guatemala. In all cases, the samples were presented as an "atole" prepared by suspending one part of the extruded product in ten parts of boiling tap water and adding 0.5 parts of sugar. The mixture was then boiled for 5 min and the "atole" was served hot, without any flavoring agent. In general, this is the way in which the personnel of such schools usually prepare the corn-soy-milk (CSM), "Incaparina," and similar blends used in the school feeding programs in Guatemala. This prepara-

tion assures at least 20g of dry product per glass of "atole" (240g net weight on the average). Acceptability was evaluated using the consumer preference test described by Kramer and Twigg (1966). numerical values were assigned to the levels of the hedonic scale.

The protein efficiency ratio (PER) was determined by the AOAC (1980) method, using rats of the Wistar strain. The net protein ratio (NPR) was estimated according to the method described by Campbell (1963) using rats of the same strain

For the storage trials, the samples were packed in heat-sealed polyethylene bags which were placed inside a triple paper bag. The product was thus packed when it had cooled to room temperature.

Statistical analyses of the data were carried out by the methods described by Snedecor and Cochran (1967).

RESULTS & DISCUSSION

THE PARTICLE SIZE distribution of the ground, dehulled soybeans, ground whole corn and broken rice utilized are summarized in Table 1. Both the ground whole corn and broken rice presented a particle size distribution similar to that defined as coarse in a previous work (Bressani et al., 1978), where it was stated that for extrusion purposes the use of an intermediately or coarsely ground corn is preferable to a finely ground material.

The temperature recorded at the exit cone and the mass flow data obtained at each of the cone openings evaluated for the two cereal:whole soybean mixtures studied are presented in Table 2. The exit cone temperature attained in each of the two mixtures increased as the cone opening of the extruder was reduced, because the Brady Crop Cooker is a thermodynamically autogenous extruder cooker according to the classification of Rossen and Miller (1973). A slight drop in the mass flow rate was observed when the cone opening was reduced.

The protein and fat content of the raw materials and of the extruded products are presented in Table 3. The NSI and DI values obtained for the extruded products are also included. Whole corn flour had a higher oil and protein content than broken rice. Since the whole corn:whole soybean mixture had a higher oil content than the broken rice:whole soybean mixture, this could explain why the temperature attained at the exit cone was relatively lower when processing the former mixture (Table 2), especially considering that, in a thermodynamically autogenous extruder cooker (as the Brady Crop Cooker), the oil of the raw material serves as a lubricant for the operation (Molina et al., 1978). The fact that as the cone opening was reduced, the oil content of any of the mixtures tended to decrease, suggests that as the processing conditions are adjusted to attain a higher extrusion temperaure, some of the oil is expelled out of the material (probably aided by a partial protein coagulation caused by the higher processing temperature) and it is not recovered in the final product. It was noted that the product processed at the higher temperature (narrower cone opening) was quite oily to the touch as compared with that obtained at a lower temperature (wider cone opening). It is considered that the slight decrease in the percent of fat observed in the products processed at the narrower cone opening caused the slight rise in protein content percentage basis of the same products (Table 3).

It is of interest to note that although the NSI of the extruded product tended to decrease as the exit cone opening was reduced, the DI values tended to increase. A lowering in the NSI values in similar mixtures through an increase in the extrusion temperature has been reported by other workers (Harper et al., 1980; Maga, 1976) using the Brady Crop Cooker or similar simple extruders. This decrease in NSI values indicates a higher degree of cooking, suggesting a higher protein digestibility for the mixtures containing whole soybeans extruded at higher temperatures which may be due to more efficient inactivation of the antiphysiological factors contained in soybeans. Harper et al. (1977) reported a slight protein quality improvement when whole corn:dehulled soybean (70:30) mixture was extruded at 148°C rather than at 132°C. Similar results were reported by Lorenz et al. (1980) with higher PER values for full-fat soybeans evaluated after processing at 143 and 149°C. The increase in the DI values through a decrease in the exit cone opening may be due to an increase in the damaged starch content, causing a decrease in the maximum amylographic viscosity (at 95°C) of the product, as reported by other authors (Anderson et al., 1969, 1970; Molina et al., 1978).

According to the school teachers, each child consumes on the average three glasses (approximately 240 g net weight) of "atole" per day. Each glass, as prepared, contained approximately 209g of water, 10g of sugar and 21g of product, supplying an average of 3.4g of protein. Therefore, the three glasses of "atole" consumed per child per day represented an average protein ingestion of 10 g/child/day, equivalent to 25–30% of the total protein requirement of school boys.

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Table 1—Particle size distribution of ground corn and soybeans and broken rice (g/100 g)[a]

Particle size mesh	Ground corn	Broken rice	Ground soybeans
12	85.02	61.08	23.17
20	9.87	19.39	50.28
45	2.83	10.01	13.08
60	1.68	5.18	7.28
80	0.45	3.27	2.81
Pan	0.15	1.07	2.38

[a] Percent retained of each fraction.

Table 2—Processing temperature and mass flow rate attained for the corn:soy and rice:soy (70:30) mixtures when extruded at the cone opening studied

Mixture	Extruding conditions[a]		
	Cone opening (mm)	Exit cone temp (°C)	Mass flow rate (kg/hr)
Corn:soy	0.6	153	509
	1.0	143	511
	1.4	118	516
Rice:soy	0.6	161	506
	1.0	148	509
	1.4	129	513

[a] The feeding auger speed was kept constant at 32 rpm.

Table 3—Some chemical characteristics of the raw materials and of the corn:soy and rice:soy (70:30) mixtures extruded at different cone openings (dry basis)

Material	Extruder cone opening (mm)	Chemical characteristics (%)			
		Protein (N x 6.25)	Ether extract	Nitrogen solubility index	Dispersibility
Corn	—	10.3	3.6	—	—
Rice	—	8.5	0.5	—	—
Dehulled soybeans	—	35.7	26.1	—	—
Corn:soy	0.6	17.8	8.9	32.8	77.1
Corn:soy	1.0	17.1	11.2	40.9	75.0
Corn:soy	1.4	17.0	11.6	48.0	70.6
Rice:soy	0.6	15.1	8.7	25.8	78.1
Rice:soy	1.0	14.9	9.3	29.8	74.8
Rice:soy	1.4	14.8	9.3	35.4	71.9

The nutritional characteristics of the whole corn:whole soybean (70:30) and broken rice:whole soybeans (70:30) extruded products are presented in Table 4. An increase in the extrusion temperature caused a significant ($p < 0.05$) improvement in the nutritive value of the protein of both mixtures, as indicated by the NPR and PER indices. Although the improvement in NPR and PER values as the extrusion temperature increased agreed with the findings of other authors for corn:soybean mixtures (Harper et al., 1977) or whole soybean alone (Lorenz et al., 1980), in the present case it did not correlate with a decrease in trypsin inhibitors, hemagglutinins or urease activity. Furthermore, the values obtained for these antinutritional factors were low enough in all cases (Table 4) to assure a good protein quality in all samples. The significant ($p < 0.05$) improvement in protein nutritive value observed as the cone opening was reduced cannot be explained with the available data. However, since animals fed the diets prepared with products processed at higher extrusion temperatures showed a higher intake, it is possible that palatability may be a factor favoring these products. It is also possible that the products processed at the higher temperatures may have a higher damaged starch content which would be more digestible. These points should be investigated further. It should be mentioned, however, that a significant ($P < 0.05$) positive correlation was found between the NPR and PER values of the products and their corresponding processing temperature ($r = 0.90$ and 0.91, respectively).

The sensory scores obtained in the different schools is presented in Table 5. An increase in processing temperature exerted a positive effect on the acceptability of the products. Analysis of the data showed that the effect of temperature was statistically significant ($P<0.05$). Furthermore, a significant ($P<0.05$) positive correlation was found between the NPR and PER values of the products and their corresponding average (from all schools) sensory score ($r = 0.82$ and 0.83, respectively). No significant difference was found between the average sensory score of the corn:soybean and that of the rice:soybean mixture extruded at the narrower cone opening (0.6 mm).

The higher degree of preference for products processed at the higher temperatures appears to be due to an improvement in their palatability. Such improvement was identified by the school children as a "better" or "nicer" corn flavor; in some cases even a flavor similar to the highly acceptable "immature corn atole" was reported for the beverages obtained from the products processed at the higher extrusion temperatures. The products processed at lower temperatures were identified as having a "beany-like" or "soybean-like" flavor. The above observations were corroborated by a sensory test carried out at our laboratories with 20 semi-trained panel members. Further, it was reported by our panel members that the sugar (at the concentration used) did not enhance and/or mask the flavor of the mixtures. Therefore, the flavor characteristics reported are thought to be due to the processing temperature.

The fat acidity values of the extruded whole corn:whole soybean and rice:whole soybean mixtures stored for up to 12 wk at different temperatures are presented in Fig. 1 and 2. Both mixtures (whole corn:soybean or rice:soybean) presented the same pattern of behavior. Although the processing temperature or the extruder's cone opening proved not to have any significant effect on the development of fat acidity at any particular storage temperature, it is of interest to note that the lower values were consistently present in mixtures processed at a higher temperature or narrower cone opening.

The storage temperature exerted a significant ($P<0.05$) effect on the increase in fat acidity values of the extruded mixtures. While the samples stored at 4 or 25°C did not have more than 2% fat acidity during the 12 wk of storage,

Table 4—Some nutritional characteristics of the corn:soy and rice:soy (70:30) mixtures extruded at different cone openings

Mixture	Extruder cone opening (mm)	Net protein ratio	Protein efficiency ratio	Trypsin inhibitors (TUI/mg)[a]	Hemagglutinins[b]	Urease activity[b]
Corn:soybean	0.6	3.22	2.13	5.7	0	0.0
Corn:soybean	1.6	2.87	1.85	4.8	0	0.0
Corn:soybean	1.4	2.75	1.68	3.5	1	0.0
Rice:soybean	0.6	3.31	2.21	4.8	0	0.0
Rice:soybean	1.0	3.05	2.05	4.5	0	0.0
Rice:soybean	1.4	2.63	1.54	4.6	1	0.0
Casein stad. diet	–	3.49	2.38	–	–	–

[a] TUI = Trypsin Units Inhibited.
[b] Hemagglutinin data as highest dilution giving positive test. Urease activity expressed as the change observed in pH units.

Table 5—Sensory score of gruels (atoles) prepared from corn:soy (70:30) and rice:soy (70:30) mixtures extruded at different cone openings and evaluated by grammar school students[a]

Product	Cone opening (mm)	Temp (°C)	Number of students/school[b] 54	67	66	64	57	40	Avg score 348 total students
			Sensory score						
Corn:soy	0.6	153	9.0 ± 0.0[c]	7.6 ± 1.9	8.8 ± 0.5	5.8 ± 1.0	7.0 ± 1.8	6.4 ± 2.0	7.4 ± 1.8
	1.0	143	9.0 ± 0.0	6.8 ± 2.5	8.7 ± 0.7	5.8 ± 1.0	6.9 ± 2.2	5.5 ± 1.5	7.2 ± 2.0
	1.4	118	8.8 ± 1.0	7.1 ± 2.2	8.2 ± 0.9	6.6 ± 1.0	6.5 ± 2.0	4.3 ± 2.3	6.9 ± 2.0
Rice:soy	0.6	161	9.0 ± 0.0	7.2 ± 2.3	8.9 ± 0.4	5.9 ± 1.0	8.1 ± 1.5	5.9 ± 1.3	7.5 ± 1.8
	1.0	148	8.8 ± 0.7	6.8 ± 2.3	8.6 ± 0.7	5.6 ± 0.9	6.4 ± 2.4	4.2 ± 2.1	6.8 ± 2.2
	1.4	129	8.9 ± 0.6	6.2 ± 2.5	5.6 ± 3.1	5.2 ± 0.6	6.1 ± 3.3	2.3 ± 1.5	5.8 ± 2.6

[a] Based on a hedonic scale of 1, 3, 5, 7 and 9 according to increased level of acceptance.
[b] Students from the third and sixth grade of the same school.
[c] Figures after ± sign are standard deviation of the mean.

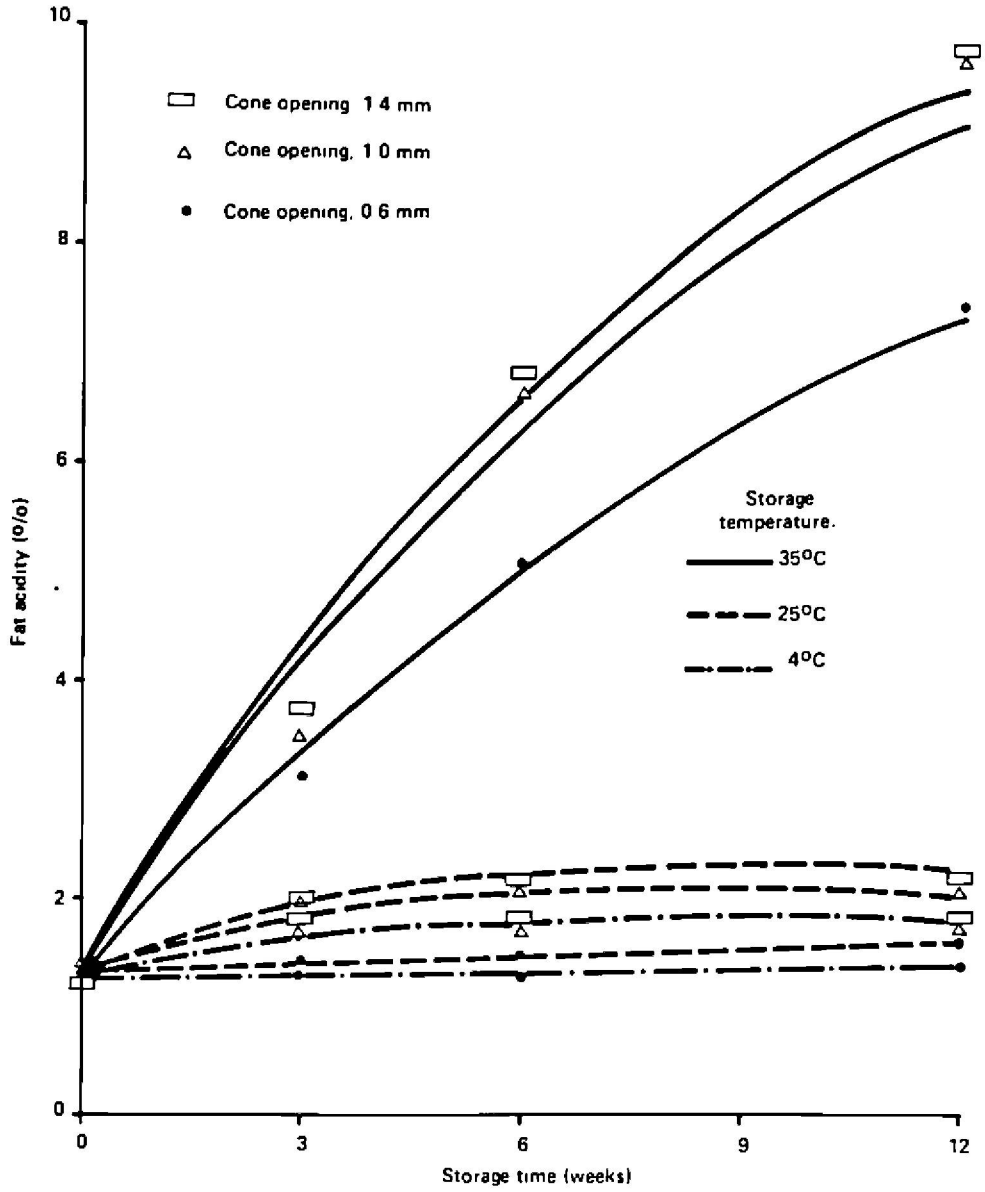

Fig. 1—Fat acidity of the corn:soy (70:30) mixture extruded using different cone openings and stored at three different temperatures.

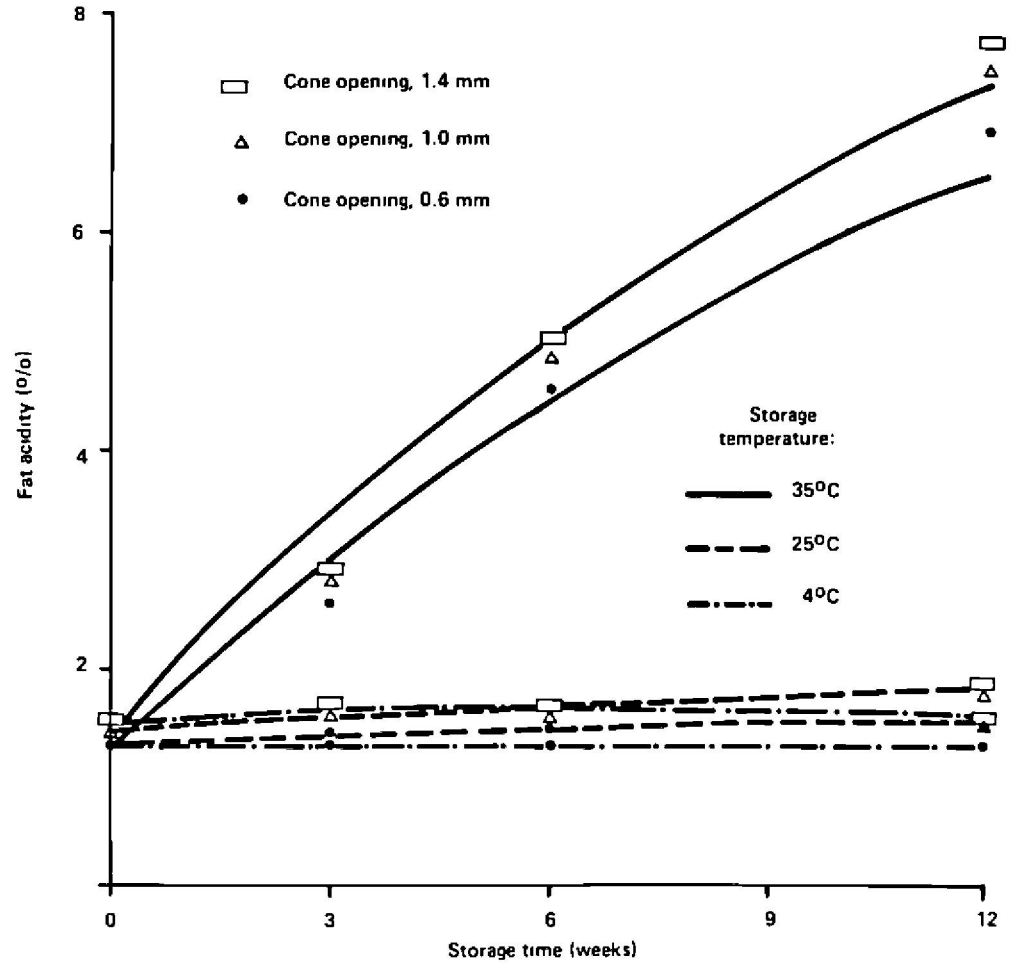

Fig. 2—Fat acidity of the rice:soy (70:30) mixture extruded using different cone openings and stored at three different temperatures.

those stored at 35°C rose over 2% after the first 3 wk and reached a fat acidity between 7 and 10% after 12 wk of storage. Through another acceptability test run with the same school children it was found, however, that all samples remained acceptable after the 12 wk of storage.

Considering the relatively low processing costs (an average of $0.07 per kg) estimated at a pilot level (500 kg/hr) for the production of an extruded cooked product such as the whole corn:whole soybean or rice:whole soy mixture evaluated here, and considering the high acceptability of the evaluated mixtures, their relatively high caloric density and high protein nutritive value, these products represent viable alternatives as low cost complementary food itmes for infant and child feeding, not only for the Central American area but also on a worldwide basis, as previously stated by other authors (Jansen and Harper, 1980a, b). These extruded products can be consumed in an atole, gruel, or puree form and can be flavored according to taste.

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