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Nutritional Quality of Blended Foods of Rice, Soy and Lupins, Processed by Extrusion

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ABSTRACT

The nutritional quality of two blends of rice grits, one with soy grits and one with lupin flour, processed by extrusion, was evaluated on the basis of proximate analysis of fat, protein, carbohydrates and certain minerals. The protein content was 12·6% for rice–soy and 15·3% for rice–lupin. The amino acid composition showed that the limiting amino acid in both blends was tryptophan. The chemical scores for rice–soy and rice–lupin were 76 and 72, respectively. Dietary fibre content was 1·4% for the rice–soy blend and 3·5% for the rice–lupin blend. The fatty acid composition of the fat and the content of calcium, magnesium, iron, copper and zinc are also reported. The nutritional density of the blends in relation to the Recommended Daily Allowance for some essential nutrients for children between 1 and 3 years of age was higher than that of raw rice grits.

INTRODUCTION

As in many other developing countries, severe malnutrition, particularly during the weaning period, is common among the children of Ecuador (Mitzner *et al.*, 1984; Grijalva *et al.*, 1986), where infant foods of good nutritional quality are required for supplementary feeding programmes.

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Cereals are one of the most extensively used foods in Ecuador. They can be supplemented with proteins from legumes, like soybean and lupin, which are also good sources of lysine. Soybean contains 34% protein, but, depending on the processing, it may contain as much as 50% protein (of the total solids). Lupin seeds contain 27–44% protein and may contain as much as 60% protein in certain preparations. Blended foods (cereal and oil seeds or cereals and legumes) are generally produced by extrusion of the components separately prior to mixing or extruded after the components have been mixed together. The blend is supplemented with essential vitamins and minerals after grinding it to powder of the required particle size (Jansen *et al.*, 1978; Jansen & Harper, 1980; Mitzner *et al.*, 1984; Harper & Jansen, 1985). A beverage based on rice and soy flour with a nutritional value that was similar to that of milk was developed by Guerra *et al.* (1981). Soy flour was used in Bolivia to increase the nutritional value of certain wheat based foods (Bean & Fellers, 1982). Nyotu *et al.* (1986) studied some Kenyan foods (*Ugali*) based on maize–soy blends. Schoeneberger *et al.* (1982) found that the protein efficiency ratio of some blends of lupin with cereals did not differ significantly from that of casein. Pompei *et al.* (1985) produced pasta products of rice and wheat of acceptable quality and higher protein digestibility with 20% lupin flour.

The present paper deals with the production of blended foods based on rice, soy and lupin, and the estimation of their nutritional quality by chemical analysis.

MATERIALS AND METHODS

Raw materials

Rice grits, from polished rice (8–40 mesh) was purchased from the local market in Quito, Ecuador. Grits of dehulled soya beans (Iniap–Jupiter variety, 10–40 mesh) was supplied by Indugrasa, Guayaquil, Ecuador. Lupin flour (*Lupinus mutabilis*), debittered by extraction at 20°C with isopropanol, was obtained from the Technological Research Institute of the Escuela Politécnica Nacional, Quito, Ecuador. All the chemicals used in this study were of analytical grade.

Extrusion process

The raw materials for the blends (rice:soy 80:20 w/w and rice:lupin 80:20 w/w) were thoroughly mixed and extruded together after adjusting the moisture content in a single screw extruder (Brabender Model 20 DN. 825602) under the processing conditions described in Table 1.

TABLE 1
Process Conditions During Extrusion Cooking of Rice with Soya and Lupin

	Rice–soy (80:20 w/w)	*Rice–lupin (80:20 w/w)*
Feed moisture content (%)	22	22
Screw speed (rpm)	150	180
Temperature at feed section (°C)	75	150
Temperature at compression sections (°C)	150	175
Temperature at metering section (°C)	150	180
Screw compression ratio	1:1	3:1
Die diameter (mm)	4	4

The extruded products were ground in a disc mill to a powder of 60-mesh particle size and stored in nylon–polythene bags at 4°C, until analysed.

Chemical analysis

Nitrogen was assayed by the Kjeldahl method (Kjeltec, Tecator AB Höganäs, Sweden), and the amount of protein calculated as 6·25 × N. Moisture was assayed according to the AOAC (Association of the Official Analytical Chemists, Virginia, USA) method 14004 (1984).

The fat analysis was performed gravimetrically after extraction with petroleum-ether, according to the method described by Croon & Fuchs (1980). Fat was hydrolysed with 3% conc. sulphuric acid in methanol and the methyl esters of the fatty acids were produced with a mixture of 50% dimethyl carbamate in hexane and 1% metallic sodium in methanol. The methyl esters were separated on a gas chromatograph (Varian Model 3700), equipped with a flame-ionisation detector and a fused silica capillary column (30 m × 0·25 mm), having OV-351 as the stationary phase and helium as the carrier gas.

The determination of the quantity of starch and its availability to the digestive enzymes was performed by the enzymatic and colorimetric methods described by Holm *et al.* (1985, 1986). The content of dietary fibre was analysed gravimetrically after solubilisation of the protein and starch with enzymes as described by Asp *et al.* (1983).

Ash was assayed according to the AOAC method 14006 (1984). Minerals (Ca, Mg, Zn, Cu and Fe) were determined by atomic absorption spectrophotometry (Varian Techtron) after wet digestion (Abdulla, 1986).

Amino acids were analysed by ion-exchange chromatography. (Biotronic LC 5001, Instrument AB Lambda, Stockholm, Sweden) after acid hydrolysis (6N HCl, 116°C, 20 h). Cysteine and methionine were determined as cysteic acid and methionine sulphone after performic acid oxidation followed by acid hydrolysis. Tryptophan was analysed spectrofluorimetrically after incubation with papain in urea (Öste *et al.*, 1976). The chemical score was estimated using the FAO/WHO reference protein for calculation. The nutrient density of the blends was calculated according to Hansen (1973) based on the values for the daily allowance of essential nutrients recommended by the Food and Nutrition Board, National Research Council (FNB), (1980), Washington DC, USA. All the analyses were run in duplicate.

RESULTS AND DISCUSSION

The results of the proximate analysis of rice grits and the processed blends of rice with soya and lupin are presented in Table 2.

Due to the heat treatment and dehydration during extrusion, the moisture content of the processed blends is about 50% lower and the contents of protein, ash and total fat are considerably higher than that of rice. The amount of carbohydrates was calculated by difference, and it includes both digestible and non-digestible components. By adding 20% solids from soy and lupin, the content of essential nutrients, such as protein and minerals, could be raised to a level that was almost 100% above that of rice grits.

Table 3 shows the content of dietary fibre and starch in the processed blends, as well as in raw rice grits. A rice–lupin blend contains a relatively higher percentage of dietary fibre, which is mainly due to the higher content of fibre in lupin, as also reported by Batterham (1979). A high level of dietary fibre in weaning foods cannot only cause an increase of bulk, but can also lower the density of calories, affect the digestibility of protein and influence the availability of vitamins and minerals. Irritation of the intestinal mucosa

TABLE 2
Proximate Analysis of Raw Rice Grits and Extruded Blends of Rice Grits with Soy Grits and Lupin Flour (g/100 g sample)

	Rice grits	*Rice–soy (80:20 w/w)*	*Rice–lupin (80:20 w/w)*
Moisture	12·3	5·3	5·4
Protein	6·7	12·6	15·3
Carbohydrates[a]	80·1	75·6	72·1
Ash	0·5	1·0	1·3
Fat	0·4	5·5	6·0

[a] Calculated by difference.

TABLE 3
Starch and Dietary Fibre Content (g/100 g sample) of Rice Grits and Extruded Blends of Rice Grits with Soy Grits and Lupin Flour

	Rice grits	*Rice–soy (80:20 w/w)*	*Rice–lupin (80:20 w/w)*
Starch	69·4	53·6	69·4
Dietary fibre	1·4	1·4	3·5

of infants who are suffering from malnutrition may also result as a consequence of a higher amount of crude fibre in the weaning foods. Considering the above aspects, the Protein Advisory Group (PAG) of the United Nations recommends that the weaning food used for supplementary feeding should contain less than 5% crude fibre. On the other hand, studies carried out on young children using a corn–soy blend with a level of 8% neutral detergent fibre (NDF) did not show any harmful effects (Jansen, 1980).

The starch content of the rice grits and blends of rice with soy and lupin is reported in Table 3. Lupin flour was obtained after extraction with cold isopropanol to remove the alkaloids, which are bitter in taste. Soy grits were obtained from raw, dehulled soybeans. The starch content of the rice–soy blend is 53%. Soybean contains a large amount of soluble carbohydrates (sucrose, raffinose, stachyose, verbascose, etc.), which are determined in the total carbohydrates.

The Recommended Daily Allowances (FNB, 1980) suggested are 1300 kcal for children between one and three years of age. The contributions from carbohydrates in the rice–soy blend and in the rice–lupin blend are 75% and 71%, respectively, of the total energy required.

Figure 1 shows the availability of starch in rice and in the extruded blends.

The rate of hydrolysis of starch in the intestine has important physiological consequences. Earlier studies indicated that the level of glucose in plasma and insulin response in man vary with the type and physical form of the starch products ingested (Jenkins *et al.*, 1981; Collier & O'Dean, 1982; Cheftel, 1986). Carbohydrates that are slowly absorbed are beneficial in the regulation of diabetes, and provide a longer duration of satiety after a meal in healthy individuals. On the other hand, an increased susceptibility of starch to hydrolysis in the presence of α-amylase in the saliva in the oral cavity may also contribute to the development of dental caries (Cheftel, 1986).

The degree of hydrolysis of the starch in the rice–soy blend and the rice–lupin blend was higher than that of the starch in raw rice grits. The

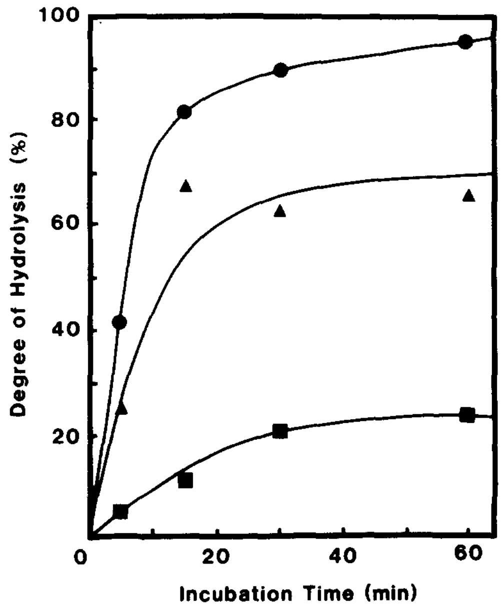

Fig. 1. Availability of starch in rice grits and blends of rice grits with soybean flour and lupin seed flour after extrusion. Starch hydrolysis of wet-homogenized samples with hog pancreatic α-amylase (405 units/g starch) *in vitro*. The percentage of hydrolysis is expressed in terms of maltose equivalents: ■, rice grits; ▲, rice–soy blend; ● and rice–lupin blend.

amount of starch of the rice–soy blend hydrolysed after incubation for 5 min was lower than that of the rice–lupin blend, and both values were significantly higher than that of raw rice grits. A high rate of hydrolysis was seen in the rice–soy blend, but even more in the rice–lupin blend during the first 15 min of incubation. The degree of hydrolysis reached a steady state at a level corresponding to 20%, 65–70% and 90% for raw rice grits, the rice–soy blend and the rice–lupin blend, respectively. Starch from the rice–lupin blend seems to be modified to a greater degree than the rice–soy blend. Cooking and gelatinisation of starch increase the susceptibility to amylase hydrolysis due to the hydration of the starch granules and the partial solubilisation of the starch molecules. It has also been demonstrated that thermal treatment inactivates α-amylase inhibitors present in raw cereals (Granum, 1979). The degree of gelatinisation after extrusion cooking increases as the extrusion temperature increases. An increase in the moisture content of the feed had a positive effect at high temperature. Further, an increase in the screw speed and the die diameter reduces the degree of gelatinisation (Björck, 1984). Mercier & Feillet (1975) reported that the susceptibility of cereal starches to α-amylase hydrolysis increased with increasing extrusion temperature. The formation of crystalline complexes of amylose and polar lipids during the extrusion of cereal starches has certain

TABLE 4
Mineral Content (mg/kg Dry Weight) of the Extruded Blends of Rice Grits with Soy Grits and Lupin Flour

	Rice grits[a]	*Rice–soy (80:20 w/w)*	*Rice–lupin (80:20 w/w)*
Zinc (mg/kg)	14·8	27·4	42·1
Iron (mg/kg)	13·7	17·2	56·8
Calcium (mg/kg)	114	275	129
Magnesium (mg/kg)	399	719	948
Copper (mg/kg)	3·0	10·9	9·2

[a] Values from the literature (The Danish National Food Administration (1983)).

technological advantages (Mercier, 1980). It may improve functional properties: lower stickiness of snacks and biscuits, modified viscosity profiles, etc. From the nutritional and analytical points of view, it is important to know whether the complexes are digested and should be looked upon as starch or non-digestible carbohydrates. However, amylose–polar lipid complexes have been degraded completely with excess amylase and prolonged incubation time (Holm *et al.*, 1983; Schweizer *et al.*, 1986).

Contents of calcium, iron, zinc, copper and magnesium are shown in Table 4.

The amounts of these minerals in the rice blends are increased in relation to the amounts in rice grits.

The amounts of calcium in rice grits, the rice–soy blend and the rice–lupin blend are 114, 275 and 129 mg/kg (dry sample), respectively.

Many dietary factors influence the intestinal absorption of mineral elements. The lactose content and fatty acid composition of infant formula affect calcium absorption in infants. On the other hand, high oxalate and phytate, some forms of fibre and saturated fats have been reported to decrease calcium absorption. Growing children may need two to four times as much calcium as adults (FNB, 1980).

Magnesium is important for maintaining the normal function of the nerves and the membranes of the muscles (FNB, 1980; Flink, 1976). The amounts of magnesium in rice grits, the rice–soy blend and the rice–lupin blend are 399, 719 and 948 mg/kg (dry sample), respectively. The amounts of iron in rice grits, the rice–soy blend and the rice–lupin blend are 13·7, 17·2 and 56·8 mg/kg (dry sample), respectively. Children need iron, not only to maintain haemoglobin concentrations, but also to increase their total iron mass during the period of growth. Iron deficiency results first in reduced haemoglobin concentration. When the haemoglobin concentration falls, breathing is more laboured (dyspnoea), the heart rate increases (tachycardia) and there is general fatigue (McGilvery, 1984; FNB, 1980).

The amounts of zinc in rice grits, rice–soy and rice–lupin are 14·8, 27·4 and 42·1 mg/kg (dry sample), respectively. Zinc deficiency results in loss of appetite, retardation of growth, impaired learning ability, skin changes, impaired regeneration of wounds and decreased taste acuity (Hambidge & Walravens, 1976; FNB, 1980).

The amounts of copper in rice grits, the rice–soy blend and the rice–lupin blend are 3·0, 10·9 and 9·2 mg/kg (dry sample), respectively. Copper deficiency leads to anaemia, skeletal defects and the degeneration of the nervous system, defects in the pigmentation and structure of the hair (Menke's disease), reproductive failure (Wilson's disease) and pronounced cardiovascular lesions. Copper, from some protein and enzymes is essential for the proper utilisation of iron (McGilvery, 1984; FNB, 1980).

The nutrient density of the blends is presented in Table 5. The values are

TABLE 5

Nutrient Density of Extruded Blends of Rice Grits with Soy Grits and Lupin Flour

	RDA, children (1–3 years) (13 kg)	*Nutrient density*[a]		
		Rice grits	*Rice–soy blend*	*Rice–lupin blend*
Energy	1 300 kcal	1·0	1·0	1·0
Protein	23 g	1·1	1·8	2·1
Histidine	19 mg	3·0	3·7	6·8
Isoleucine	28 mg	4·0	4·2	7·1
Leucine	66 mg	2·9	3·8	5·4
Lysine	58 mg	1·5	2·6	4·2
Methionine + Cystine	25 mg	6·3	10·7	10·0
Phenylalanine + Tyrosine	63 mg	3·2	5·1	6·6
Threonine	34 mg	2·2	3·2	4·9
Tryptophan	11 mg	2·6	2·2	2·5
Valine	35 mg	4·3	4·6	5·9
Calcium	800 mg	0·1[b]	0·1	0·1
Magnesium	150 mg	0·9[b]	1·5	1·9
Iron	15 mg	0·3[b]	0·4	1·2
Zinc	10 mg	0·5[b]	0·8	1·3
Copper	1 mg	0·9[b]	3·2	2·7

[a] Calculation based on the data from Table 38 of FAO/WHO/UNU Expert Consultation (1985) and The FNB National Research Council (1980).

[b] Values from the literature (The Danish National Food Administration (1983)).

calculated according to Hansen (1973). The value of 1 represents the content of the analysed nutrient in relation to the amount of energy that is just sufficient to cover the daily requirement for children between 1 and 3 years of age. The rice–soy blend has low amounts of calcium and iron. On the other hand, the rice–lupin blend contains enough iron, but a very low amount of calcium. It is clear from the data that the mineral content is improved considerably by mixing rice with soy and lupin. In the supplementation of weaning food with minerals, some aspects have to be taken into account. Calcium salts reduce expansion and post-extrusion storage qualities. Ferrous sulphate has high solubility and bioavailability, but catalyses lipid oxidation. Data concerning minerals in extruded foods indicate that ferric ions catalyse the destruction of vitamin C (Maga & Sizer, 1978).

Table 6 reports the content of fatty acids in the fat of the rice–soy blend and the rice–lupin blend.

In the rice–soy blend the most abundant unsaturated fatty acid was linoleic acid. The corresponding saturated fatty acid was palmitic acid. The fatty acid pattern of the rice–soy blend if reflected in the data for soybeans reported in the literature (The Swedish National Food Administration, 1986; Mostafa *et al.*, 1987). The major saturated fatty acid present in the rice–lupin blend is stearic acid. Oleic acid and linoleic acid are the most abundant unsaturated fatty acids in the rice–lupin blend. The ratio between total unsaturated fatty acids and total saturated fatty acids was 4·5:1 for the rice–soy blend and 0·5:1 for the rice–lupin blend. A decrease of fat content in food products due to loss during extrusion has been reported. Monoglycerides and free fatty acids form complexes with amylose during extrusion

TABLE 6
Fatty Acid Composition (% of the Total Fat) of the Extruded Blends of Rice Grits with Soy Grits and Lupin Flour

Fatty acids		*Rice–soy (80:20 w/w)*	*Rice–lupin (80:20 w/w)*
Myristic acid	C 14	0·2	0·4
Palmitic acid	C 16	13·1	15·4
Palmitoleic acid	C 16:1	0·1	0·1
Margaric acid	C 17	0·0	0·8
Stearic acid	C 18	3·5	49·2
Oleic acid	C 18:1	24·1	15·0
Linoleic acid	C 18:2	50·9	14·7
Linolenic acid	C 18:3	5·2	0·8
Arachidic acid	C 20	0·4	0·9
Eicosenoic acid	C 20:1	0·3	0·1
Behenic acid	C 22	0·5	0·0

cooking, and it will become difficult to extract them with organic solvents for the determination of fat (Mercier, 1980; Schweizer *et al.*, 1986). However, Holm *et al.* (1983) found that amylose–lipid (amylose–lysolecithin) complexes were almost completely digested and absorbed by rats. Besides a decrease in the fat content of maize with increasing extrusion temperatures, a decrease in the ratio of unsaturated to saturated fatty acids with increasing extrusion temperature and a small increase of *trans* fatty acids have also been reported (Maga, 1978).

The American Academy of Pediatrics (FNB, 1980) recommended 3% of energy as essential fatty acid in infant formulas. The rice–soy blend satisfied the recommended intake with 6·2% of the energy as linoleic acid. The rice–lupin blend had only 2·0% of energy from linoleic acid.

The amino acid contents of the raw materials (rice grits, soy grits and

TABLE 7
Amino Acid Composition (mg/g sample) of the Raw Materials and Processed Blends by Extrusion

	Raw materials			*Processed blends*	
	Rice grits	*Soy grits*	*Lupin flour*	*Rice–soy (80:20 w/w)*	*Rice–lupin (80:20 w/w)*
Cystine	2·7	8·2	11·7	4·0	4·2
Methionine	2·9	6·6	8·5	6·7	5·8
Aspartic acid	6·7	34·1	69·4	12·4	18·0
Threonine	2·6	13·5[a]	26·0	4·4	6·8
Serine	2·8	14·9	36·5	5·7	9·4
Glutamic acid	13·0	50·9	174·8	21·4	40·8
Proline	3·7	14·5	20·5	5·8	7·5
Glycine	3·5	14·2	29·7	5·4	8·0
Alanine	4·3	15·2	25·5	6·1	7·5
Valine	5·3	19·2	26·8	6·6	8·3
Isoleucine	3·9	21·1	44·7	4·7	8·1
Leucine	6·8	29·3	54·7	10·2	14·4
Tyrosine	2·7	13·6	32·3	6·2	8·7
Phenylalanine	4·4	20·3	28·3	6·8	8·0
Lysine	3·0[a]	21·1	41·7	6·1	9·8
Histidine	2·0	10·8	21·6	2·8	5·2
Tryptophan	1·0	4·1	5·0[a]	1·0[a]	1·1[a]
Arginine	6·5	29·7	78·3	8·8	18·2
Total	77·6	341·2	736·1	124·8	189·6
Chemical score	82	87	72	76	72

[a] Limiting amino acid. Values of tryptophan for rice grits and soy grits were obtained from the literature (The Swedish Food Administration (1986)).

debittered lupin flour) and the extruded blends (rice–soy and rice–lupin) are presented in Table 7.

Lysine was the limiting amino acid in raw rice grits. In the extruded rice blends, lysine was contributed by soy and lupin, and tryptophan became the limiting amino acid in both the rice–soy and the rice–lupin blends. The chemical score calculated using FAO reference protein as standard was 76 and 72 for rice–soy and rice–lupin, respectively.

Björck *et al.* (1983) reported a decrease in lysine with increased processing temperature, and the sulphur-containing amino acids, arginine and tryptophan, especially when the moisture of the feed is below 15%. On the other hand, it is reported that these conditions improved the digestibility and bioavailability of limiting sulphur amino acids of oil seeds and legumes. Heat treatment leads to the thermal unfolding of the major seed globulins and the thermal inactivation of trypsin inhibitors and other growth retarding factors (Mustakas *et al.*, 1970; Harper & Jansen, 1985).

The protein quality of the extruded rice blends in relation to the energy content is higher than that of the daily requirement of essential amino acids. In both rice blends the amount of amino acids exceeds the daily dietary requirement. However, the chemical score based on the amino acid determination does not reveal the digestibility of the protein or the availability of the individual amino acids.

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