NONCONVENTIONAL LEGUME GRAINS AS PROTEIN SOURCES

M.R. MOLINA, R. BRESSANI, and L.G. ELIAS

☐ OF THE APPROXIMATELY 13,000 known species of legume grains, only a relatively small number are used directly as food items. In Latin America, for example, only about 20 species are of relative economic importance as food items, and in Central America and Mexico, the number is even smaller.

The Jack bean *(Canavalia ensiformis)*, the Black-eyed pea *(Vigna sinensis)*, the velvet bean *(Stizolobium deeringianum)*, and the pigeon pea *(Cajanus cajan)* can be counted among the legume seeds which are either not consumed or consumed at very low levels, and only in specific areas. All of them have been reported to be grown relatively easily, with high yields, in regions of low altitude inadequate for the growth of other legume seeds such as common beans *(Phaseolus vulgaris)* (Rachie. 1973). Thus, these legume seeds have a high potential in zones of varying climates and altitudes such as Latin America, where they would not compete with the common bean *(P. vulgaris)* and still could provide an additional protein source.

The fact that the above-mentioned legume grains are not used as a human food can be attributed mainly to regional dietetic habits that do not include them as part of the common diet. Therefore, in order to increase their utilization as a protein source, two main possibilities have been considered: (1) production of protein concentrates and/or isolates from the beans for use in food formulations, and (2) use of the beans or their flour in the formulation of conventional processed food products.

PRODUCTION OF PROTEIN CONCENTRATES

The nitrogen solubility characteristics of different legume seeds have been reported by several authors (Evans and Kerr, 1963; Hang et al., 1970; Molina et al., 1974a; Pant and Tulsiani, 1969; Powrie, 1961; Smith et al., 1959). In general, the nitrogen solubility of legume seeds in aqueous systems has been reported to be favored by the use of an alkaline pH (higher than 9.0), a temperature between 50 and 70°C, and a solvent:meal ratio of 100:4 to 100:6. In the case of the Jack bean and the Black-eyed pea, Molina et al. (1974a; 1976a) have reported that the nitrogen extraction equilibrium is attained after 1 hr. On these bases, Molina et al. (1974a) described a one-stage protein extraction process of 1 hr for the Jack bean, using 70°C, pH 13, and a solvent:meal ratio of 100:6 with continuous agitation as the extracting conditions. Under these conditions, a protein extraction efficiency of 80% was obtained, and after precipitation at the isoelectric point, the protein recovery efficiency reached 55%. Further, with the exception of methionine (the first limiting amino acid), the protein concentrate presented a higher chemical score than the original meal. The essential amino acid content was also higher in the extracted material than in the original Jack bean meal.

Considering that protein and starch represent the two main constituents (25-35% and 55-75%, respectively) of most legume grains (Bressani and Elías, 1974), it has been considered that a combined extraction and recuperation of both components (protein and starch) would be more economically feasible. In this respect, Altschul (1966) and Bhumiratana and Nondasuta (1971) described a simple process for the combined protein and starch isolation from the Mungo bean *(P. mungo)*. Later, Molina and Bressani (1975) and Molina et al. (1976a) described similar simple processes for the protein and starch isolation from the Jack bean and Black-eyed pea, respectively. In general, in such processes, care should be taken to use relatively-mild extracting conditions in order to prevent any possible damage to the starch fraction.

Using a solvent:meal ratio of 100:3, ambient temperature (25°C), and the pH of the aqueous suspension (6.6) as the extracting conditions, Molina and Bressani (1975) reported a protein extraction efficiency of 87% for the Jack bean, using three extraction stages of 1 hr each. Using 40°C as the extracting temperature, only two extraction stages of 1 hr each were necessary to attain a similar (90%) protein extraction efficiency. The protein recuperation efficiency through isoelectric point precipitation (pH 4.9) was found to be very similar in both cases (78 and 81% for the three- and two-stage extraction systems, respectively), and the starch recuperation oscillated between 91 and 95%. The protein concentrates obtained had a higher essential amino acid content and a higher protein score (mainly due to a higher cystine content) than the original material.

Similarly, Molina et al. (1976a) indicated that for the

THE AUTHORS are with the Div. of Agricultural & Food Sciences, Institute of Nutrition of Central America and Panama (INCAP), Carretera Roosevelt, Zona 11, Guatemala City, Guatemala, Central America

Table 1—**SOME FUNCTIONAL PROPERTIES AND COST** *of the protein concentrates obtained from Jack bean and Black-eyed pea through a protein-starch extraction*[a]

Functional property	Protein concentrate: Jack bean	Protein concentrate: Black-eyed pea
Emulsifying capacity (at 25°C)	612 ml/g	665 ml/g
Whippability (at a pH of 9.0)[b]	9.3 ml/g	5.0 ml/g
Water absorption at 25°C and:		
62% relative humidity	18.5%	21.9%
83% relative humidity	21.8%	25.1%
97% relative humidity	39.7%	52.5%
Gelation (in a 10% suspension)	Negative	Negative
Nitrogen solubility index (at a pH of 7.00)	13.1%	17.5%
Cost/lb of product[c]	$0.27	$0.31
Cost/lb of protein	$0.36	$0.43

[a]A two-stage aqueous (pH 6.6) extraction process for the Jack bean and a one-stage (pH 9.0) extraction process for the Black-eyed pea. Both extractions were carried out at 25°C, and both protein concentrates were dried at 60°C
[b]As ml of foam
[c]Calculated for a production rate of 340 lb of dry product/day. Starch production cost = $0.20/lb

Table 2—**PROTEIN QUALITY** *of different mixtures containing Black-eyed pea submitted to extrusion cooking*[a]

Mixture	Average weight gain (g)	Protein efficiency ratio (PER)[b]
Corn:Black-eyed pea, 72:28	61 ± 4.1	1.9
Cassava:Black-eyed pea, 81:19	50 ± 3.7	1.6
Corn:Black-eyed pea, 72:28, plus 0.3% DL-methionine	98 ± 3.5	2.6
Cassava:Black-eyed pea, 81:19, plus 0.3% DL-methionine	92 ± 2.8	2.6
Cottonseed flour:Black-eyed pea:corn, 17:36:47	86 ± 3.1	2.0

[a]Processed through the Brady Crop Cooker Extruder
[b]The casein standard protein value was 2.8

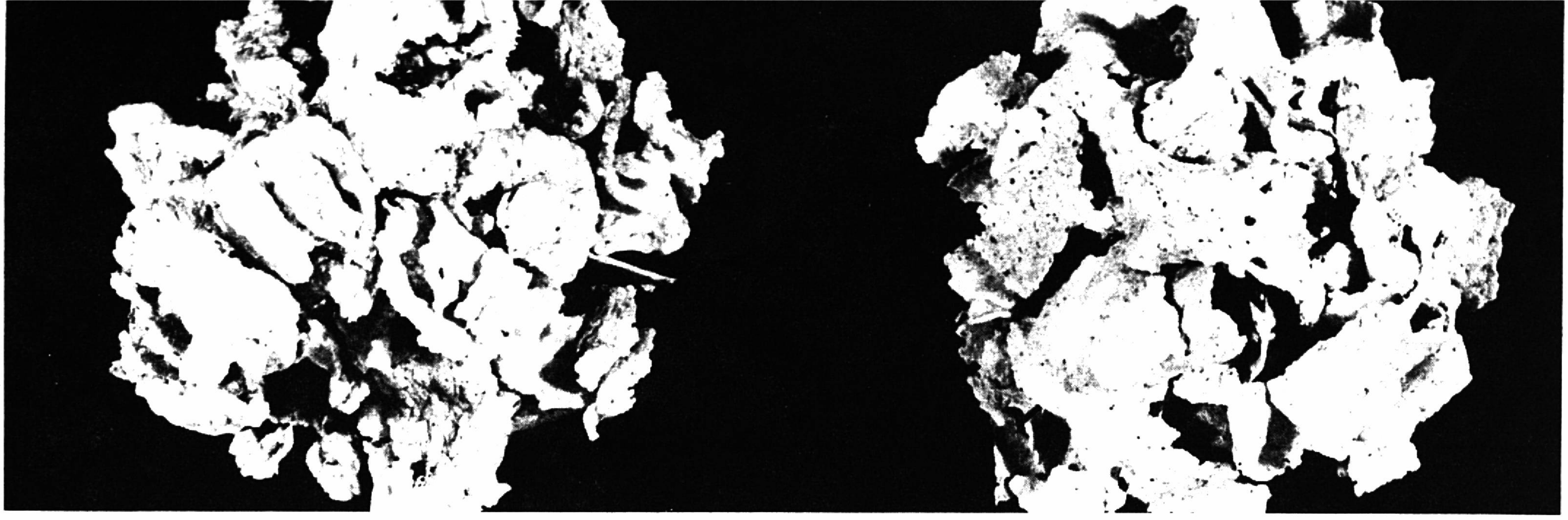

Fig. 1—**EXTRUDED SNACK PRODUCT** *made from mixtures containing Black-eyed pea. Left: 81% Black-eyed pea and 19% cassava flour. Right: 72% Black-eyed pea and 28% corn flour*

Black-eyed pea, a protein extraction efficiency of 87% could be attained through a one-stage extraction system of 1 hr, using a solvent:meal ratio of 100:4, 25°C, and pH 9.0 as extracting conditions; or through a two-stage extraction system of 1 hr each, using a solvent:meal ratio of 100:12, 25°C, and the pH of the aqueous suspension (6.8) as extracting conditions. The starch recuperation was 84 and 76% for the one- and two-stage extraction systems, respectively. It is of interest to note that the protein concentrates recovered by isoelectric-point precipitation (pH 4.0) and dried at 60°C after extractions at pH 6.8 and pH 9.0 had a higher essential amino acid content, a higher protein score, and a higher nutritive value than the original meal. Furthermore, the protein concentrate obtained through the one-stage extraction system at a pH of 9.0 proved to have a significantly ($P < 0.05$) higher nutritive value than the original Black-eyed pea meal.

ECONOMICS & USE OF CONCENTRATES

An economic analysis of the protein-starch extraction processes cited above for the Jack bean (Molina and Bressani, 1975) and the Black-eyed pea (Molina et al., 1976a) showed that in the first case, the most economically feasible was the two-stage extraction process at the pH of the aqueous suspension (6.6) and 25°C, with an extraction efficiency of 84%; while in the second case, the one-stage extraction process at a pH of 9.0 and 25°C proved to be the most economically feasible. In both instances, the protein concentrates obtained through isoelectric-point precipitation and subsequent centrifugation were considered for drying in a tray or tunnel dryer in order to offer a simply drying technology for its application in developing countries. In applying these drying methods, it was found that using an inlet air temperature of 60°C was the minimum necessary for the whole process to be economically sound, with a minimum production rate of 340 lb of dry protein concentrate per day.

Some functional properties and the cost calculated for the protein concentrates prepared from Jack bean and Black-eyed pea under the above-cited conditions appear in Table 1. Costs were calculated for the production of the cited products in Guatemala, where the local current price for a pound of soy flour (with high nitrogen solubility index) varies between $0.25 and $0.30 (equivalent to $0.50-$0.60/lb of soy protein as soy flour), which makes the calculated costs for the protein concentrates economically attractive. Concerning the functional properties studied, there is little doubt as to the possible practical applications of the products, especially in food systems demanding a high emulsifying capacity. The ability to form a gel using a 10% suspension of the material was negative, even when using the material prior to drying—a finding indicating that such proteins as extracted and recovered were unable to form a gel—and drying temperature had no effect on this property. All the functional properties evaluated, with the exception of the gelation ability, were significantly ($P < 0.05$) affected by the drying temperature, being in general improved as the drying temperature was lowered (Molina et al., unpublished data). The calculated costs for starch ($0.20/lb) are also considered competitive with the prevailing local Guatemalan prices of corn starch ($0.30/lb). However, more studies are needed in order to define the quality of the starch obtained from the legume seeds studied.

These economic studies calculated for the production of the aforementioned protein concentrates in Guatemala are, in our opinion, quite promising and representative of the production costs under similar operating conditions in other Latin American countries. We believe that the cost of the raw materials (Black-eyed pea and Jack bean) considered for the cost estimations cited here were relatively high ($0.09/lb); however, this value also represents in part the potential of these nonconventional legume seeds as crops for tropical humid soils inadequate for other products (Rachie, 1973).

Among the general protein-starch extraction schemes, the possibility exists that instead of drying, the protein concentrate obtained by isoelectric-point precipitation and centrifugation may be resuspended at a pH of 7.0-7.5, and that this suspension may be used as either a beverage or a milk extender. Preliminary results obtained in our laboratories indicate that for this purpose, the protein concentrate from the Jack bean offers better possibilities than that from the Black-eyed pea because the former has a better milky flavor.

It should be mentioned that the protein concentrates obtained from the Jack bean and Black-eyed pea were found to have an insignificant concentration of trypsin inhibitors and hemagglutinins (0 TUI/mg and 1, and 3.4 TUI/mg and 0, respectively).

It is encouraging that preliminary results indicate that similar processes as those cited above can be applied to other nonconventional legume grains such as velvet bean, pigeon pea, and the like, with similar promising results.

Concerning possible uses, Molina et al. (1976a) and Molina and Bressani (1975) have indicated the possible inclusion of the protein concentrates in the formulation of pasta products and their use as meat extenders in the production of "tacos" or similar products containing ground meat. The possible use of bean *(P. vulgaris)* protein isolates in bread-making has already been reported (Satterlee et al., 1975). Preliminary results in our laboratories indicate that this can be another probable use for the protein concentrates from the Black-eyed pea or Jack bean.

USE OF BEANS AND FLOUR

The protein complementation effect obtained between cereals and legume proteins has already been mentioned (Bressani et al., 1962; Bressani and Elías, 1974). Since this complementary effect is translated into a significant ($P < 0.05$) improvement of the protein quality of the 50:50 (protein-wise) cereal:legume seed mixture (Bressani and Elías, 1974), technological efforts have been carried out to develop conventional processed food products applying such a principle and, at the same time, opening other possibilities for the utilization of nonconventional legume grains as protein sources.

—Continued on next page

• **Pasta.** Working with a semolina:corn:soy flour system, Molina et al. (1975) reported the beneficial effect of a heat treatment of the corn flour for its use as partial substitute for semolina in pasta production. Later, Molina et al. (1976b) reported that the beneficial effect observed was mainly due to a partial gelatinization of the cornstarch by the heat treatments evaluated. Considering that one of the major components of the legume seeds in general is starch, a process was developed for pasta production using a 25:45:30 semolina:corn:peeled legume seed flour mixture in which the starch of the mixture was gelatinized through a drum dryer. The pasta products thus obtained proved to have a quality and an organoleptic acceptance equal to those of products prepared from 100% semolina, with a significantly ($P < 0.05$) improved protein quality (Molina, 1974; Molina et al., 1974b). These findings clearly indicate the possibility of using nonconventional legume grains as improvers of protein quantity and quality for pasta products, with concommitant economic benefits for non-wheat-producing countries. At present, other methods to effect the starch gelatinization in these mixtures intended for pasta production (i.e., extrusion cooking) are being evaluated; these improvements would probably also make the whole process more economical and/or technically appealing.

• **Bread.** In recent years, technological developments have allowed the production of protein-fortified bread. Most of the technology has been developed for the use of soy flour in bread-making. In general, when considering composite flours for this purpose, the main problems encountered have been the volume and texture of the final product. Thus, several additives have been studied and recommended to alleviate these limitations. Among the most important additives recently recommended for a wheat and soy flour system or similar systems intended for bread-making, we can cite stearoyl 2-sodium lactylate (Marnett et al., 1973; Tsen and Hoover, 1973) and xanthan gum (Christianson et al., 1974).

In our laboratories, highly-acceptable breads have been obtained using a 70:10:20 wheat:corn:Black-eyed pea flour mixture, and either stearoyl 2-sodium lactylate as a chemical additive or a laminated wheat dough as a mechanical (or physical) alternative to obviate the volume and texture limitations (de la Fuente et al., 1975).

• **Baked Goods.** In the case of cookies or similar bakery products from soft wheat flour, very acceptable products have been obtained with a 40:30:30 wheat:corn:Black-eyed pea flour mixture without any need for chemical additives or mechanical alternatives (de la Fuente et al., 1975). The Black-eyed pea flour can be substituted by pigeon pea, velvet bean, or Jack bean meals without any detrimental effect. Again, these findings clearly show another alternative for the use of nonconventional legume grains as protein sources in products, where by complementation with the cereal (wheat) proteins they can enhance the protein quality of the final product. We believe that these findings are also of special interest for the non-wheat-producing countries.

• **Latin American Dishes.** The possibility of using nonconventional legume grains such as the Black-eyed pea, pigeon pea, or Jack bean as "diluters" of the common bean *(P. vulgaris)* in the preparation of several typical Latin American dishes has been found attractive from several points of view. Agronomically, these nonconventional legume seeds can be grown in tropical humid lowlands inadequate for the growth of the common bean and most of the other crops common in the Latin American region (Rachie, 1973). Nutritionally, nonconventional legume grains contain significantly lower amounts of trypsin inhibitors and hemagglutinins (Bressani and Elías, 1974). Therefore, technology has been developed for the preparation of highly-acceptable dehydrated bean soups or bean purées from a mixture of 50:50 nonconventional legume grains and common beans (Elías, 1973). Mention should be made that since the Black-eyed pea can be obtained in cream, red, or black varieties, this legume grain looks most appropriate for the above-mentioned purpose, since it obviates the color dilution in the case of products using mixtures with black or red common beans. The development of canned products from these mixtures is presently underway.

• **Extruded Products.** Another approach has been the development of extruded products containing nonconventional legume seeds as a protein source. Nutritional data for some of the mixtures extruded through a simple extruder-cooker, such as the Brady Crop Cooker (Brady, Div. of Koehring Co., Des Moines, Iowa), are presented in Table 2. As the data reveal, the operation allows for the fortification of the mixtures (18% protein) with DL-methionine, with subsequent enhancement in protein quality. The general appearance of some of the products prepared is presented in Figure 1. As may be observed, the products obtained were partially expanded. Their organoleptic evaluation showed that they were highly acceptable as a high-protein snack. At present, an economic analysis of the whole process is being conducted to define the feasibility of this possible utilization of nonconventional legume grains in food systems.

• **Substitutes.** Preliminary evaluation indicates that Black-eyed pea in its immature stage can also be used either fresh or in processed products as a substitute for string beans in the formulation of different food products. This possibility is also being examined by our group as a probable working alternative for the utilization of the Black-eyed pea or other nonconventional legume grains in formulating conventional food products.

MORE RESEARCH URGED

There seems to be little doubt that the use of nonconventional legume grains can constitute another protein source in food systems. It is our belief that more research should be encouraged in this field, in order to study the basic characteristics of the thousands of nonconventional legume grain species available and to define their possible use as a protein source in food systems. Such research wherever possible should be made in collaboration with agronomic institutions, to take into account the agronomic potential of the different species, particularly in those tropical humid soils which are inadequate for other crops. This research would be of great value to aid in solving the world protein shortage problem, which becomes more acute in the developing countries.

REFERENCES

Altschul, A.M. 1966. Legumes and a hungry world. In "Report of the 8th Annual Conference on Dry Bean Research," p. 3. USDA, Agric. Res. Serv., Albany, Calif.

Bhumiratana, A. and Nondasuta, A. 1971. Report on protein food development project, 2nd report. Inst. of Food Res. and Prod. Dev., Kasetsart Univ., Bangkok, Thailand.

Bressani, R. and Elías, L.G. 1974. Legume foods. In "New Protein Foods," Vol. 1A, Technology, ed. A.M. Altschul, p. 230. Academic Press, Inc., New York.

Bressani, R., Valiente, A.T., and Tejada, C.E. 1962. All-vegetable protein mixtures for human feeding. VI. The value of combinations of lime-treated corn and cooked black beans. J. Food Sci. 27: 394.

Christianson, D.D., Gardner, H.W., Warner, K., Boundy, B.K., and Inglett, G.E. 1974. Xanthan gum in protein-fortified starch bread. Food Technol. 28 (6): 23.

De la Fuente, G., Molina, M.R., and Bressani, R. 1975. Factibilidad de sustitución de harinas de panificación por harina de maíz y fortificación con harina de frijol de costa *(Vigna sinensis)*. Presented at XXI Meeting of Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Salvador, El Salvador, April 7-11.

Elías, L.G. 1973. Problems and potentials in storage and processing of food legumes in Latin America. In "Potentials of Field Beans and Other Food Legumes in Latin America," ed., D. Wall, p. 52. CIAT Series Seminars No. 2E, Centro Internacional de Agricultura Tropical, Cali, Colombia.

Evans, R.J. and Kerr, M.H. 1963. Extraction and precipitation of nitrogenous constituents of dry navy beans *(Phaseolus vulgaris)*. J. Agr. Food Chem. 11: 26.

Hang, Y.D., Wilkens, W.F., Hill, A.S., Steinkraus, K.H., and Hackler, L.R. 1970. Studies on the extraction of proteins from red kidney beans. I. Improvement in filterability of aqueous bean extract. Cereal Chem. 47: 259.

—Continued on page 179

Marnett, L.F., Tenney, R.J., and Barry, V.D. 1973. Methods of producing soy-fortified breads. Cereal Sci. Today 18(2): 38.

Molina, M.R. 1974. El papel de la tecnología de alimentos en la utilización de leguminosas de grano. Presented at XX Meeting of Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios (PCCMCA), San Pedro Sula, Honduras, Feb. 11-15.

Molina, M.R. and Bressani, R. 1975. Protein-starch extraction and nutritive value of the jack bean and jack bean protein isolate. In "Nutritional Aspects of Common Beans and Other Legume Seeds as Animal and Human Foods," ed., W.G. Jaffé, p. 153. Arch. Latinoamer. Nutr., Caracas, Venezuela.

Molina, M.R., Argueta, C.E., and Bressani, R. 1974a. Extraction of nitrogenous constituents from the jack bean *(Canavalia ensiformis)*. J. Agr. Food Chem. 22: 309.

Molina, M.R., Gudiel, H., de la Fuente, G., and Bressani, R. 1974b. Use of *Phaseolus vulgaris* in high protein quality pasta products. Presented at IV Intl. Cong. of Food Science and Technology, Madrid, Spain, Sept. 23-27.

Molina, M.R., Mayorga, I., Lachance, P.A., and Bressani, R. 1975. Production of high-protein quality pasta products using a semolina-corn-soy flour mixture. I. Influence of thermal processing of corn flour on pasta quality. Cereal Chem. 52: 240.

Molina, M.R., Argueta, C.E., and Bressani, R. 1976a. Protein-starch extraction and nutritive value of the black-eyed pea *(Vigna sinensis)* and its protein concentrates. J. Food Sci. 41: 928.

Molina, M.R., Mayorga, I., and Bressani, R. 1976b. Production of high-protein quality pasta products using a semolina-corn-soy-flour mixture. II. Some physico-chemical properties of the untreated and heat-treated corn flour and of the mixtures studied. Cereal Chem. 53: 134.

Pant, R. and Tulsiani, D.R.P. 1969. Solubility, amino acid composition, and biological evaluation of proteins isolated from leguminous seeds. J. Agr. Food Chem. 17: 361.

Powrie, W.D. 1961. Extraction of nitrogenous constituents from the navy bean seed, *Phaseolus vulgaris*. J. Agr. Food Chem. 9: 67.

Rachie, K.O. 1973. Relative agronomic merits of various food legumes for the lowland tropics. In "Potentials of Field Beans and Other Food Legumes in Latin America," ed., D. Wall, p. 123. CIAT Series Seminars No. 2E. Centro Internacional de Agricultura Tropical, Cali, Colombia.

Satterlee, L.D., Bembers, M., and Kendrick, J.G. 1975. Functional properties of the Great Northern bean *(Phaseolus vulgaris)* protein isolates. J. Food Sci. 40: 81.

Smith, C.R., Jr., Earle, F.R., Wolf, I.A., and Jones, Q. 1959. Comparison of solubility characteristics of selected seed proteins. J. Agr. Food Chem. 7: 133.

Tsen, C.C. and Hoover, W.J. 1973. High-protein bread from wheat flour fortified with full-fat soy flour. Cereal Chem. 50: 7.

Based on a paper presented during the symposium, "Non-Conventional Protein Resources," at the 36th Annual Meeting of the Institute of Food Technologists, Anaheim, Calif., June 6-9, 1976.