NEW PROTEIN FOODS

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V

Legume Foods

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TABLE I

Most Common Legume Species

Scientific name	Common name
Acacia arabica	—
A. armata	Kangaroo–thorn
A. catechu	—
A. linifolia	Acacia
Arachis hypogaea	Peanut
Baptist tinctoria	Wild–indigo
Cajanus cajan–Ca. indicus	Pigeon pea, Congo pea, Red gram
Canavalia ensiformis	Jack beans
C. gliadiata	Sword bean
Caragana arborescens	Siberian pea–shrub
Cassia morilandica	Casia
Chamaecrista fasciculata	Partridge pea
Cicer arietinum	Garbanzo, chick-pea, Bengal gram
Coronilla vaira	Crown vetch
Crotalaria intermedia	Crotalaria
C. juncea	Sunn crotalaria
C. mucronata	Striped crotalaria
C. sagittalis	Winged crotalaria
Cyamopsis tetragonolaba	Guar
Dolichos biflorus	Horse gram
D. lablab	Dolichos bean–Field bean–Hyacinth bean
D. Uniflorus	—
Faba vulgaris	Double bean
Indigofura hirsuta	Hairy indigo
Lablab niger	—
Lathyrus adoratus	Sweet pea
L. ochrus	—
L. pusillus	—
L. latifolius	—
L. sativus	Pea
L. sylvestris	—
Lens culinaris	Lentils
L. esculenta	Lentils
Lupinus albus	White lupine
L. angustifolius	Blue lupine
L. luteus	Yellow lupine
L. *termis*	—
Phaseolus aconitifolius	Aconite bean
P. acutifolius var. latifolius	Tepary bean
P. angularis	Adsuki bean
P. aureus	Green gram, mung bean
P. calcaratus	Rice bean

TABLE I (Continued)

P. coccineus	Scarlet runner bean
P. lunatus	Lima bean
P. mungo	Mung bean, green gram
P. vulgaris	Kidney bean, navy bean Pinto or snap bean, dry bean
Pisum arvense	—
P. sativum	Garden pea, English pea Alaska pea
Psophocarpus palustris	—
P. tetragonolobus	Winged bean
Robinia pseudoacacia	Black locust
Sesbania exaltata	Hemp sesbania
Stizolobium deeringianum	Velvet bean
Strophostyles helvola	Trailing wild bean
Vicia faba	Broad bean, horse bean
V. sativa	—
Vigna catiang	Cowpea
V. sesquipedalis	Asparagus bean
V. sinensis	Makassar bean, cowpea
V. unguiculata	Catjang
Voandzeia subterranea	Bambara bean

their quality, such as storage and processing, existence of physiologically adverse factors, and culinary practice.

The soybean, *Glycine max*, is a legume but is rarely eaten as a food legume. Instead, it is processed by the oriental technologies or by treatment as an oilseed. These approaches are amply described elsewhere in this volume (see Chapters VIII and IX). But the soybean, in its composition, its nutritive value, in its reaction to heat treatment, and in its content of physiologically active substances has many similarities to the food legumes. Hence, many of the basic principles discussed here are pertinent to an understanding of the role of soybeans in human nutrition.

II. Production

No accurate statement can be made on the level of production of legume foods in the developing countries. One of the reasons for the lack of accurate figures is that in such countries most of the legume foods are grown in small land patches around the homestead to supply the needs of the family. Only that part of the produce calculated as surplus is sold in the market. Or even some of the family supply is sold when the need for money arises.

TABLE II

TOTAL WORLD ACREAGE AND PRODUCTION OF THE MAJOR FOOD LEGUME CROPS AND WHEAT, RICE, AND CORN[a]

Products	Area (1000 hectares)	Production (1000 metric tons)
Legume foods	63,089	39,614
Soybeans	33,672	40,764
Peanuts	18,496	17,398
Total legume grains	115,257	97,776
Wheat	221,900	298,000
Rice	128,800	275,900
Corn	103,392	240,252

[a] From *FAO Production Yearbook* (1969).

Data published by FAO (1969), as shown in Table II, illustrate that of the total acreage planted in legume grains, which includes legume foods, soybean, and peanuts, close to 55% of it is in legume foods (pulses). The corresponding production of pulses is approximately 40% of the total legume grains produced, only slightly less than the world soybean production. The FAO statistics demonstrate, furthermore, that the acreage for cultivation of pulses is about half of that allotted to rice and almost one-fourth of wheat and corn acreage in areas where these cereals predominate. Moreover, production records show areas where the ratio of production of cereal grains to pulses is as high as ninefold.

Most workers agree (Bressani *et al.* 1962; Bressani and Valiente, 1962; King, 1964) that on diets where cereals and legumes are the main protein sources, the best protein intake ratio is obtained when 60–70% by weight of the total intake is derived from cereals and 30–40% from legume foods. These figures suggest, therefore, that the 1966 world bean production figures could well be increased about threefold. Based on data from nutrition surveys carried out in Central America (Flores, 1961; Flores *et al.*, 1966) it has been calculated that the consumption ratio between corn and beans is around 7 : 1 for adults, and about 12 : 1 for children. These ratios could well be a reflection of the actual production of the two types of crops in these areas of the world (FAO, 1966). The FAO production figures (1969) for pulses and single cereal grains also show a 7 : 1 ratio. All of the preceding information suggests that a good case could be made for the need for an increased production of legume foods, particularly in those countries where such foods are a basic part of the habitual diets and where they could make a more significant contribution to nutrition.

REGIONS AND KINDS

Legume foods are grown in every continent of the world, with acreage varying among them for specific species and between species (Table III). With the exception of the Near East, dry beans are more commonly grown in all of them, the Far East region and Latin America leading. However, chick-peas are not as popular in the latter as in the Far East, and cowpeas appear to be more important in Africa than in other regions.

Table III also shows that yield per hectare is quite variable not only for the same species between regions but also between species in the same region, a finding suggestive that some species are better adapted to environmental conditions than others.

Increased production could, therefore, be achieved by cultivating the species which are best adapted to the environmental conditions prevailing in the region. The variability on production and yield suggests also that, without doubt, there is a definite potential in the developing countries for a substantial increase in legume food production. The data in the same table indicate further that not all species are cultivated in every continent or region, and that production is highest in the Far East, followed by Latin America, Africa, the Near East, Europe and the North American region. The figures on yield—which vary with the type of pulse and region, and which are lower for Latin America, Africa, and the Far East—could well be a reflection of a slow development of improved varieties, poor agricultural practices, and adverse effect of the environment. In this last respect, it is of interest to note that, in comparison to most other regions, the Near East shows, for example, good yields for dry beans. This could be due to better environmental conditions for this crop, since it is to be expected that agricultural practices are about at the same level in the Near East as in Latin America or in the Far East.

Variations in yield are found quite often between regions within a country. For instance Brazil is the largest producer in Latin America, with a production of around 2,420,000 tons in 1968 (Miranda Colin, 1966). Table IV shows the production of dry beans in the different regions of that country for the period 1964–1968. There is a tendency for increased production in the entire country during that period. The largest crops are obtained in the South and Northeast and the smallest in the Northern part of Brazil. Also of interest is the fact that this highest production is found in the more-developed areas, whereas the lowest corresponds to the less-developed part of the country. These differences are probably due not only to the improved agronomic practices in the South,

TABLE III

PRODUCTION OF DRIED PULSES, BY CONTINENT, IN 1966[a]

Continent	Dry beans	Dry peas	Dry broad bean	Chick-peas	Lentils	Pigeon peas	Cow-peas	Vetch	Lupines	Other pulses
Europe										
Area	4009	484	715	391	109	—	13	314	225	357
Production	863	722	841	162	67	—	12	250	257	204
Yield	2.2	14.9	11.8	4.1	6.1	—	9.2	8.0	11.4	5.7
North America										
Area	645	112	—	—	—	—	41	—	—	—
Production	805	219	—	—	—	—	24	—	—	—
Yield	12.5	19.6	—	—	—	—	5.9	—	—	—
Latin America										
Area	6293	151	297	132	64	23	—	—	4	31
Production	3776	120	188	120	40	15	—	—	6	25
Yield	6.0	7.9	6.3	9.1	6.3	6.5	—	—	15.0	8.1
Near East										
Area	190	13	248	247	307	—	13	325	7	209
Production	207	12	432	209	281	—	13	298	12	227
Yield	10.9	9.2	17.4	8.5	9.2	—	10.0	9.2	17.1	10.4
Far East										
Area	7560	1146	16	10256	973	2584	47	—	—	4199
Production	2315	946	17	6546	473	1915	27	—	—	1995
Yield	3.1	8.3	10.6	6.4	4.9	7.4	5.7	—	—	4.8
Africa										
Area	1233	463	333	400	207	127	2504	21	226	1654
Production	607	345	295	240	122	49	1083	11	56	822
Yield	4.9	7.5	8.9	6.0	5.9	3.9	4.3	5.2	2.5	5.0

[a] Data from *FAO Production Yearbook* (1969). Explanation of data: area in 1000 hectares, production in 1000 metric tons, and yield in 100 kg/hectare.

TABLE IV

PRODUCTION OF DRY BEANS IN THE DIFFERENT REGIONS OF BRAZIL, 1964–1968[a]

	Yield (tons)				
Region	1964	1965	1966	1967	1968
North	12,010	12,300	9,415	10,077	12,868
Northeast	558,083	645,538	647,226	951,389	888,428
Southeast	434,825	514,303	450,386	492,779	468,295
South	808,680	927,029	862,701	912,023	867,981
Middle east	137,085	190,626	178,872	181,309	182,104
	1,950,683	2,289,796	2,148,600	2,547;577	2,419,676

[a] From Balanço Alimentar do Brasil (1969).

but also to the better environmental conditions prevailing therein, and to the higher population density which obviously demands a higher production.

III. Consumption

A. Consumption Related to Area

Table III indicates that about 10 types of legume foods are the most commonly grown even though Aykroyd and Doughty (1964) listed 18 of them, including *Arachis hypogaea* (peanuts) and *Glycine max* (soybean).

In South America, with the exception of Uruguay and Argentina, as well as in Central America and Mexico, the bean most commonly consumed is *Phaseolus vulgaris* in all its variety of forms and colors. In lesser amounts other legume foods such as *Vicia faba* (horse bean), *Phaseolus lunatus* (lima bean), *Lens esculenta* (lentils), and *Cicer arietinum* (chick-peas), are also eaten in lesser amounts. In the United States, particularly in the Southwest, people consume the same types of legume foods as in Latin America, with preference for lima beans. In the Caribbean Islands, consumption of common *Phaseolus vulgaris* is quite high; however, preferences vary within the Islands. In Haiti, for instance, cowpeas *(Vigna catiang)* are consumed in great quantities, while in Jamaica, gandul *(Cajanus indicus)*, either green or dried, seems to be favored. In Puerto Rico, *Phaseolus vulgaris* and *Phaseolus lunatus* are highly consumed as well as *Cicer arietinum*.

In the northern countries of Africa, consumption of the various species of legume foods varies somewhat. It seems that *Vicia faba* is eaten in various forms in the largest amounts, although lentils and chick-peas are also consumed regularly.

Legume food consumption in Europe appears to be concentrated principally in the Mediterranean countries. Although not necessarily in order of importance, their consumption includes *Cicer arietinum, Phaseolus lunatus, Lens esculenta*, and *Vigna unguiculata*.

In the Near and Far East, the most favored legume foods are *Cicer arietinum, Phaseolus aureus, Phaseolus mungo, Cajanus cajan, Pisum sativum, Lens esculenta*, and *L. sativus*.

Preference for one type of bean over the other is probably related to the availability of legume foods in the area; in turn, their availability is determined by environmental conditions which favor higher yields of one over the other legume foods. The amount consumed also depends on other factors. For example, in some areas red beans, rather than white or black, are preferred, although both of the latter varieties are used together with the red. When soup is to be made, white beans are preferred over other types.

B. Amounts Consumed

Information on the amount of legume foods consumed is tabulated in Table V for all countries listed in the 1960–1962 Food Balance Sheets (FAO, 1966). As shown, 63 countries have been grouped according to the intake of all legume foods per person, per day. The same table shows the daily per capita intake of all meat products. The conclusions drawn from this table are similar to those already presented by various authors (Aykroyd and Doughty, 1964; Abbott, 1969; Altschul, 1967; Patwardhan, 1962; Jaffé, 1971; Parpia and Subramanian, 1966). In 34 countries, intake of beans reaches up to 13 g, while in 25 countries it rises to 35 g, and in 4 countries the daily ingestion reaches a value as high as 57 g, per person. Furthermore, there is an inverse relationship between the legume food intake and the amount of meat consumed. However, such consumption is the average for the entire country, a fact which tends to obscure the meaning of the figures somewhat.

It is of interest to indicate that, in general, it is difficult to find bean consumption levels for adults much above 70 g, per person, per day, independent of country, type of legume, or its availability. This ceiling is far lower than that for cereals or meat.

For reasons which have not been elucidated as yet, there is a kind of physiological limitation to the amount of legume foods that are consumed by humans. This limitation could be because legume foods cause gastrointestinal disorders, because of their bulk and low digestibility, on account of allergic reactions, or to other causes which must be explained if an increased utilization of legume foods is to be achieved.

C. Age in Relation to the Fraction Consumed

Although there are few studies on how beans are consumed in early life, Jelliffe (1955) found that in the developing countries legume foods are utilized only in small amounts for child feeding, or none at all. Furthermore, the same author indicates that in some countries beans are first fed to children at the end of their second year of life. Similar findings have been reported from Ghana (Food and Nutrition Board, Ghana, 1961) where it was found that only 2% of all the children 6–7 months old received beans in their regular diet. These findings are similar for other regions (Flores and Reh, 1955; Flores *et al.*, 1957, 1966).

TABLE V

BEAN AND MEAT INTAKE IN 63 COUNTRIES OF THE WORLD[a]

Bean intake (g/capita/day)	Number of countries according to meat intake (g/capita/day)					Total
	4–68	69–131	132–194	195–256	257–319	
2–13	9	8	8	3	5	33
14–24	7	3	0	0	0	10
25–35	10	5	0	0	0	15
36–46	0	1	0	0	0	1
47–57	4	0	0	0	0	4
Total countries	30	17	8	3	5	63

[a] From *FAO Food Balance Sheets* (1969).

It is of interest, however, to examine the results of a study by Flores *et al.* (1966) on the food intake of Guatemalan Indian children 1–5 years old, living in three rural towns, all of whom were included in a dietary survey. As the data in Table VI reveal, in all three towns bean broth intake decreased with age while that of cooked beans increased as the child became older. Flores *et al.* (1966, 1970) indicate that the same tendency was observed for meat broth and solid cooked meat products.

These findings acquire even more interest when the chemical composition of bean broth is compared to that of cow's milk or human milk (Table VII). The concentration of protein, for instance, appears to be similar in bean broth and human milk, although in regard to other nutrients, bean broth is poorer. Nevertheless, it should be kept in mind that since bean broth is not consumed alone, it is probable that other foods might supply other nutrients, particularly calories, thus improving the nutritive value of the overall intake.

TABLE VI

CONSUMPTION OF BEAN BROTH AND COOKED BEANS BY GUATEMALAN CHILDREN[a]

Children's age (years)	Consumption (g/day per child)					
	Broth			Beans		
	A	B	C	A	B	C
1 to < 2	17	38	29	5	3	2
2 to < 3	11	10	9	10	19	9
3 to < 4	7	1	4	17	25	11
4 to < 5	—	—	—	14	26	14

[a] Data from Flores *et al.* (1966), and represents three towns (A, B, and C).

TABLE VII

Chemical Composition of Bean Broth and Human and Cow's Milk

	Composition per 100 g		
Component	Bean broth	Human milk	Cow's milk
Water (g)	92.5	87.5	87.0
Calories	22	67	67
Protein (g)	1.9	1.4	3.3
Fat (g)	0.1	3.8	3.6
Carbohydrate (g)	3.5	6.8	5.4
Ash (g)	2.0	0.2	0.7
Calcium (mg)	12	32	178
Phosphorus (mg)	15	15	80
Iron (mg)	0.1	0.1	0.5

In order to characterize better the nutritive quality of bean broth, it would be of interest to analyze it in terms of the amino acid composition and biological value of its protein. If results are encouraging, it would be advisable to recommend the consumption of legume foods, which, when cooked, would yield higher amounts of solids in the broth.

The amount of legume foods consumed appears to be constant during the year and for the same age or family unit. Representative results by Flores (1961; unpublished data), Flores and Reh (1955) and Flores *et al.* (1957, 1964, 1966) for rural Guatemala are shown in Table VIII. In a 12-year period, intake per family varied between 48 and 54 g/day per person, while the daily intake for the children of these same families varied from 10 to 14 g/person in 6 years. Bean production during this same period of time remained constant in Guatemala, varying from about 42 $\times 10^6$ kg to approximately 52 $\times 10^6$ kg (Guatemala en Cifras, 1957). On the other hand, bean prices increased from $0.07 to $0.10/lb, in about the same period of time (Dirección General de Estadística de Guatemala, 1970). These last two facts could explain, therefore, the constant intake found by Flores and associates in the surveys conducted since 1953 up to the present time.

D. Consumption Related to Income and Social Status

In many reports and reviews dealing with legume foods, these have been called "the meat of the poor," suggesting greater consumption among the lower socioeconomic groups within a country. Even in many areas of Latin America, people often say, "we are going home to have our portion of beans," implying, perhaps, that beans are consumed for

TABLE VIII

BEAN CONSUMPTION IN RURAL GUATEMALA

Year	Consumption (g/day per person)		Reference
	Family	Child	
1953	54	—	Flores and Reh (1955)
1956	54	—	Flores *et al.* (1957)
1959	51	10	Flores *et al.* (1964)
1960	52	14	Flores *et al.* (1964)
1961	48	10	Flores *et al.* (1964)
1962	53	11	Flores *et al.* (1964)
1965	50	13	Flores *et al.* (1966)

lack of other foods. This is obviously a gross oversimplification and fails to recognize the positive cultural affinity for legume foods that persists in many cultures even with rising income.

Aykroyd and Doughty (1964) showed a definite decrease in bean consumption in the United States as income increased. These same authors cite studies from Maharashtra (India) in 1958–1959 which indicate that consumption of legume foods increased as income increased, both for the urban as well as rural populations. Similar results are reported for Colombia (Molta, 1969). In Guatemala, higher socioeconomic status was reflected in higher meat consumption but bean consumption remained constant, as shown by Flores (unpublished) in Table IX.

TABLE IX

MEAT AND BEAN CONSUMPTION IN GUATEMALAN FAMILIES ACCORDING TO SOCIOECONOMIC INDEX [a]

Socioeconomic index	No. of families	Consumption (g/day per person)	
		Meat	Beans
1.50	31	13	58
1.62	11	22	44
1.75	25	29	51
1.87	26	39	43
2.00	26	61	56
2.12	25	41	44
2.25	15	54	48
2.37	17	51	42
2.50	8	66	39
2.62 and more	10	40	56

[a] Flores (unpublished data).

The families surveyed were classified into various groups, according to socioeconomic indices. This index was calculated on the basis of house, furnishings, home utensils, income, ownership of land, and other characteristics of an improved economic situation. While it was evident that meat consumption increased parallel to the socioeconomic index, it was also evident that bean consumption remained essentially constant. Because of the higher intake of meat, total protein intake increased.

Intake of legume foods of urban and rural populations varies within countries. Information on legume food intake derived from nutritional surveys carried out in Central America (Evaluación Nutricional de la Población de Centro América y Panama: Guatemala; El Salvador; Honduras; Nicaragua; Costa Rica, and Panama, 1969) is tabulated in Table X. The percentage contribution of calories and of protein from cereal grains and legume foods to the total intake for Central America is shown in Table XI. In almost every country, rural populations consume greater amounts of legume foods than the urban groups.

Some of the inconsistencies in trend of consumption with increasing income can be reconciled by examining the coefficients of income elasticity of demand for legume foods as compared to other foods, as shown in Table XII. When starting at a low level of income, an increase in income is reflected in an increase in demand for legume foods and a proportionate increase in their contribution to the diet. At higher levels of income the demand tapers off, the amount consumed is stabilized, and further increases in food consumption are reflected in more products containing animal protein. Hence, although consumption is constant, the relative contribution of the legume foods is less. The trend is not uniform from

TABLE X

CONSUMPTION OF LEGUME FOODS IN URBAN AND RURAL AREAS OF THE CENTRAL AMERICAN COUNTRIES[a]

	Consumption (g/day per person)	
Country	Urban	Rural
Guatemala	45	50
El Salvador	52	59
Honduras	47	41
Nicaragua	50	72
Costa Rica	48	57
Panama	19	20

[a] Data from "Evaluación Nutricional de la Población de Centro América y Panamá" (six volumes) (1969).

TABLE XI

CONTRIBUTION OF CALORIES AND PROTEIN FROM CEREAL GRAINS AND LEGUMINOUS FOODS TO THE TOTAL INTAKE IN CENTRAL AMERICAN COUNTRIES

Country	Food	Percent of total intake			
		Rural		Urban	
		Calorie	Protein	Calorie	Protein
Guatemala	Cereal	65.0	52.6	50.5	38.3
	Legume	8.5	18.7	7.0	15.1
El Salvador	Cereal	61.8	50.1	44.1	35.2
	Legume	9.7	20.5	8.4	12.8
Honduras	Cereal	49.5	39.2	44.2	35.4
	Legume	10.7	22.8	8.1	15.8
Nicaragua	Cereal	41.5	30.9	38.5	25.5
	Legume	13.0	26.8	8.7	16.7
Costa Rica	Cereal	39.3	32.7	36.7	27.1
	Legume	10.7	25.2	7.6	17.4
Panama	Cereal	47.4	37.8	41.3	30.4
	Legume	3.9	8.8	3.7	7.4

country to country and is affected by the appreciation of legume foods in any specific culture.

Legume foods have their own aesthetic appeal. Those groups for whom such foods were mainstays of the diet will not give them up even when they can afford other foods. The following statement, quoted from "The Collector's Cook Book" (Woman's Day, 1970) indicates the aesthetics of legumes in the American context. "Legumes. If anything can get Jack and the giant together it's a steaming hot bowl of beans. Leg-

TABLE XII

RANGE OF COEFFICIENTS OF INCOME ELASTICITY OF DEMAND FOR SELECTED FOOD GROUPS IN COUNTRIES, GROUPED BY INCOME[a]

GNP per capita (U.S. $)	Food group				
	Starchy roots	Cereals	Calories	Pulses	Animal protein
> 1500	—	—	0	—	< 0.3
1000–1500	—	< 0	0–0.2	0–0.15	0.3–0.5
400–1000	< 0	0–0.2	0.2–0.4	0.3–0.15	0.5–1
125–400	0–0.15	0.2–0.5	0.4–0.6	> 0.3	1–1.5
< 125	> 0.15	> 0.5	> 0.6	—	> 1.5

[a] Prepared by A. M. Altschul from Agricultural Commodities—Projections for 1970, Special Supplement, FAO Commodity Review, p. A 14, FAO, Rome, 1962.

umes are stick-to-the-rib foods and come in fascinating array: chick-peas, split peas, and black-eyed peas, black beans, pinto beans, red and white kidney beans, lima beans, marrow, navy pea and great Northern beans, and of course, lentils. Use them in dips, soups, entrées and salads, and in economical dishes that will stock your freezer for a future busy day."

Aside from aesthetic considerations, which are difficult to analyze or explain, consumption may be influenced by specific factors, such as availability in the marketplace, convenience of preparation, length of cooking time, availability as a convenience food, freedom from adverse physiological effects, and improved nutritional quality. These observations indicate, therefore, that for populations where beans are part of the culture, they will remain as such. In this case beans could make a better nutritional contribution by improving the limiting factors that hamper their consumption, whether of an agricultural or of a nutritional nature.

IV. Variations in Composition

A. Chemical Composition

One of the major problems in evaluating data on composition is that in most cases bean samples have been identified only by the common or popular name by which they are known in a given region and, save for a few cases, not by their scientific name. The bean grain is made of three main anatomic structures: the seed coat, the cotyledons and the embryonic axis. According to Powrie *et al.* (1960), for the navy bean—the common *Phaseolus vulgaris*—these three fractions represent 7.7, 90.5, and 1.8% of the dry matter of the bean, respectively. Therefore, most of the chemical components are found in the cotyledons as also indicated by Singh *et al.* (1968).

1. *Carbohydrate*

Edible legume seeds contain from 3.0 to 8.0% crude fiber, and from 57.0 to 65.0% total soluble carbohydrate. The starch content of the mature navy bean seed has been reported to be 35.2% by Eichelberger (1922) and Peterson and Churchill (1921). The starch is located in the cotyledons of the bean seeds, and Powrie *et al.* (1960) found that this anatomic fraction of the bean contained 39.3% of starch which is present as granules embedded in a dense proteinaceous matrix. According to Veiss and Powrie (1959–1960) the average size of the native bean starch granules in suspension ranges from 25 to 28 μm; their size apparently depends on the variety of bean.

The content of starch in some legume seeds is high enough that its separation from other components is carried out industrially. For example, in Thailand, the mung bean which is processed for starch leaves a residue rich in protein (Bhumiratana and Nondasuta, 1969).

Nigam and Giri (1961) indicate that resting legume seeds have at least four nonreducing oligosaccharides, three of which were identified as raffinose, stachyose, and verbascose. Other sugars have also been identified (Williams and Bevenue, 1958). The carbohydrate fraction in other legume seeds, particularly in the nonedible ones, are galacto mannans. Important commercial sources of gums are the seeds of guar and of the carab or locust tree (Whistler, 1959).

2. *Protein* (See also Section VIII)

The crude protein content of edible legume seeds varies from 18 to 32%. Wild inedible legume seeds contain from 18 to 47% crude protein (Pant and Bishnoi, 1967; Pant and Kapur, 1963; Pant *et al.*, 1968). The protein is located in the cotyledons and embryonic axis of the beans, with only small amounts present in the seed coat (Singh *et al.*, 1968). The seed coat of the navy bean seed contains 4.8% crude protein, while the cotyledons and the embryonic axis have 27.5 and 47.6%, respectively. Because of their greater weight, cotyledons contribute the major amount of protein to the whole seeds (Singh *et al.*, 1968; Varner and Schidlowsky, 1963).

Zimmerman *et al.* (1967) studied the concentration gradient for protein, lysine, methionine, and antitryptic activity in the cotyledons of two representative varieties of oil-containing and grain-legume foods. Antitryptic activity did not invariably follow the protein distribution pattern. In all varieties analyzed, the outer cotyledon layer, representing approximately 60% by weight, was found to be richer in protein by approximately 14% in peanuts to more than 30% in chick-peas, expressed as percent difference with the inner layer. The difference in concentration of the two essential amino acids, more or less follows the same pattern.

3. *Fat*

The lipid content of legume foods constitutes a relatively small percentage of the overall composition, varying from 1–6% depending on the species. Korytnyk and Metzler (1963) determined the fatty acid composition of the glyceride fractions of lima beans and of immature lima beans, black-eye, pinto, kidney, and white beans. The glyceride fractions were shown to consist mainly of palmitic, linoleic, and linolenic acids, together with smaller amounts of stearic and oleic acids. In most cases the proportion of unsaponifiable matter was high. For lima beans, it was found to consist mainly of stigmasterol and β-sitosterol. Lee and Mattick (1961) studied the triglyceride and phosphatide content of five varieties or types of dry beans *(Phaseolus)*, and one of each of *Vicia, Vigna,* and *Pisum.* The triglyceride content ranged from 0.89% in *Pisum* to 1.54% in one of the *Phaseolus* cultivars. The fatty acids were of the kind and in the concentration as those previously reported by other workers (Wagenknecht, 1963; Baker *et al.*, 1961; Zarkadas *et al.*, 1965). The phosphatide content ranged from 0.88 to 1% with component fatty acids similar to the triglyceride fractions. However, the *Phaseolus* samples did not contain linoleic acid in the phosphatide fraction.

4. *Minerals*

The ash content of legume foods ranges from 2.5 to 4.2%. Phosphorus is found in the largest amounts, averaging around 300 mg/100 g of beans. The calcium content is quite variable, with about 100 mg/100 g of beans, indicating that legume foods are a comparatively poor source of this nutrient. The concentration of iron varies from 5 to 12 mg/100 g, which classifies legume foods as fair sources of this nutrient. Nevertheless, very little is known about the availability of these nutrients to the animal organism. According to Crean and Haisman (1964), in some legume foods, peas for instance, calcium content is associated mainly with the proteinaceous constituents of the cells. Verma *et al.* (1964) and Singh *et al.*, (1968) reported more calcium and less phosphorus concentration in the seed coat than in the cotyledons, iron content being only slightly higher in the seed coat. Because of the size of the cotyledons in relation to the size of the whole seeds, these nutrients are present in greater amounts in this anatomic fraction. Germination changes the availability of the minerals. Belavady and Banerjee (1953), for example, noticed a decrease in phytin phosphorus, while Singh and Banerjee (1955) observed an increased availability of iron after germination.

5. *Vitamins*

There is quite a large number of publications dealing with the concentration of vitamins in legume foods, as well as with the changes that take place before maturation of the seed and during germination. The interest in the latter arises because many of these legume foods are to a certain extent consumed before ripening or after some germination has been allowed. Legume foods are fairly good sources of thiamine, riboflavin, and niacin (Arroyave *et al.*, 1955; Stanberg and Lehrer, 1947; Cowan and Sabry, 1966; Daniel and Norris, 1945; Cravioto *et al.*, 1945; Willimott, 1949); and various other reports (Bressani *et al.*, 1954; Powrie *et al.*, 1960; Singh, *et al.*, 1968). Chikubu *et al.*, 1956 indicate that these vitamins are found in the germ in higher concentrations than in cotyledons.

Bhagvat and Rao (1942a) report the presence of ascorbic acid in dry seeds of *Cicer arietinum.* Soaking of dry legumes in water to stimulate germination causes an increase in the ascorbic acid content as well as in other vitamins (Bhagvat and Rao, 1942b; Murray, 1948). Chattopadhyay and Banerjee (1952) found that legume foods were good sources of choline and that the content of both choline and tocopherols increased with the process of germination. Similar studies on pyridoxine, inositol, vitamin K, pantothenic acid, folic acid, biotin, and niacin have been published by Banerjee *et al.* (1954, 1955). According to their findings, all vitamins increased during germination, with the exception of folic acid. The behavior of pantothenic acid varied depending on the species of legume foods tested. Similar results have been reported by other authors (Verma *et al.*, 1964; Nazir and Magar, 1963; Chattopadhyay and Banerjee, 1951; De and Borai, 1949; De and Datta, 1951). This information indicates that the process of germination benefits the nutritive value of legume foods.

B. Species Variations

It has been stated that there are 13,000 legume food species. Thus, it would be a difficult task to list an average composition that would hold for all of them. Their large number suggests a wide variable gross chemical composition; however, figures for the most common legume foods indicate a rather similar concentration of the major components. Table XIII summarizes the results published by a number of workers. The variation in most of the components listed is not so striking except for total protein content, which ranges from around 21 to 38%. The characteristic feature of the legume foods is, therefore, their relatively high protein content, which is intermediate between that of cereal grains and fat-free oilseed meals.

A number for total protein is not enough to characterize the value of a food in nutritional terms; it is necessary to look into the essential amino acid content. Table XIV shows the essential amino acid content of some of the legume foods listed in Table XIII (Belton and Hoover, 1948; Busson *et al.*, 1959; Danielson and Lis, 1952; Jaffé, 1949; Mahon and Common, 1950; Baptist, 1954; Jelliffe *et al.*, 1959; Khan and Baker, 1957; Vangala and Menden, 1969; Venkat Rao *et al.*, 1964; King, 1964). With a few exceptions the variability in specific amino acids between species is not large. Of those showing more variation, lysine and

TABLE XIII

Composition of Legume Foods[a]

Legume food	Protein	Ether extract	Crude fiber	Ash	Carbohydrate	Reference
Vigna sinensis	27.5	2.1	7.0	4.9	58.5	Elías *et al.* (1964)
Cajanus indicus	21.8	1.7	8.7	3.8	64.0	Braham *et al.* (1965b)
Phaseolus vulgaris	26.1	1.8	6.6	4.1	61.4	Bressani *et al.* (1954)
P. calcaratus	23.9	0.8	8.3	4.4	62.6	Bressani *et al.* (1961a)
P. lunatus	26.4	2.7	6.7	3.7	60.5	Sirinit *et al.* (1965)
P. lunatus	23.5	1.4	5.6	4.2	65.3	Flores *et al.* (1960)
P. aureus	25.6	3.0	3.5	3.0	64.9	Singh *et al.* (1968)
Psophocarpus sp.	37.6	22.5	13.8	4.4	21.7	UNICEF (unpublished data)
Pisum sativum	28.8	1.6	6.7	2.9	60.0	Zarkadas and Baker (1965)
Cicer arietinum	20.6	7.0	3.8	3.4	65.2	Flores *et al.* (1960)
Lens esculenta	29.6	3.1	3.2	2.4	61.7	Singh *et al.* (1968)
Cajanus cajan	22.9	3.8	5.0	4.1	64.1	Singh *et al.* (1968)
Cyamopsis tetragonoloba, L.	34.4	3.9	5.2	3.6	59.9	Singh *et al.* (1968)

[a] Moisture-free basis. Data given in percent by weight.

phenylalanine are probably the most important. When their values are compared to those of the FAO reference protein it becomes apparent that legume food proteins are low in sulfur-containing amino acids, and in various species, also in tryptophan. In most of the legume foods lysine is present in amounts which approach and sometimes surpass the level established for the reference protein. In an evaluation study of plant seeds —which included 379 species—as protein sources for food, based on amino acid composition, Van Etten *et al.* (1967) found that 70 species of Leguminosae had a mean lysine content above the mean for all species; this finding again indicates that legume seed proteins are good sources of this essential amino acid. Also of interest is the fact that some Leguminosae contain nonprotein amino acids, one of which is canavanine. In the study carried out by Van Etten *et al.* (1967), 23 of 70 Leguminosae species contained from 0.7 to 12.9 g of canavanine per 100 g of protein. Other authors have also reported similar values (Evans and Bandemer, 1967; Bell and Tirimanna, 1965; Bell, 1958, 1960; Vangala and Menden, 1969; Birdsong *et al.*, 1960). This is of importance since canavanine is an antimetabolite for arginine and could very well interfere with the utilization of the protein by the animal organism.

As Table XIII reveals, ether extractables show about the greatest variation in gross composition. Baker *et al.* (1961) studied the fatty acid composition of the crude fat from five legume food species. They found that the oil of the pulses differed markedly in fatty acid composition. Similar results were also obtained by Takayama *et al.* (1965), Ott and Ball (1944), Labarre and Pfeffer (1946), Gambhir and Dott (1950). It would appear, therefore, that although there are differences in the gross chemical composition between species of legume foods, the similarities among them are probably more striking. In any case, careful and extensive studies dealing with variations found and their nutritional significance have not been carried out to a significant degree.

C. Varieties

Elías *et al.* (1964) found only a small variation in the gross chemical composition and amino acid content of eight varieties of cowpeas. More variation was found in the contents of thiamine, riboflavin, and niacin. On the other hand, Kakade and Evans (1965–1966) found some navy bean varieties to be higher in protein than others, and differences were also found in their methionine content. Bressani (1970) found nitrogen content to vary from 2.69 to 4.52% in 268 varieties of *Phaseolus vulgaris* from Central America. In 129 selections, methionine content fluctuated between 0.80 and 0.356%, cystine from 0.075 to 0.21%, and lysine

TABLE XIV

ESSENTIAL AMINO ACID CONTENT OF VARIOUS LEGUME GRAIN SPECIES

Legume food species	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Cystine	Phenylalanine	Threonine	Tyrosine[a]	Tryptophan	Valine
Vigna sinensis	0.500	0.213	0.318	0.484	0.486	0.079	0.032	0.263	0.251	0.124	0.068	0.314
Cajanus indicus	—	—	0.389	0.542	0.546	0.111	—	0.258	0.221	0.125	0.026	0.282
Phaseolus vulgaris	0.412	0.173	0.319	0.205	0.500	0.067	0.015	0.323	0.309	0.062	0.068	0.360
P. calcaratus	0.470	0.215	0.339	0.260	0.545	0.077	0.017	0.365	0.287	0.052	0.052	0.371
P. radiatus	0.394	0.169	0.394	0.481	0.437	0.062	0.038	0.369	0.219	0.241	0.025	0.400
P. mungo	0.356	0.169	0.344	0.450	0.375	0.069	0.044	0.338	0.269	0.167	0.031	0.400
Cicer arietinum	0.531	0.116	0.624	0.530	0.489	0.077	—	0.491	0.224	—	0.025	0.241
Lens esculenta	4.467	0.076	0.529	0.441	0.515	0.046	—	0.146	0.193	0.154	0.010	0.306
Dolichos lablab	0.575	0.175	0.375	0.556	0.506	0.044	0.062	0.331	0.206	—	0.031	0.350
Vicia faba	0.406	0.181	0.344	0.475	0.344	0.031	0.069	0.213	0.163	—	0.056	0.319
Pisum sativum	1.107	0.169	0.525	0.682	0.713	0.081	0.075	0.362	0.306	—	0.044	0.487

[a] Data given in grams per g N.

from 0.80 to 2.39%. In this study a significant correlation (r = 0.254) was obtained between nitrogen and lysine content for 108 samples; however, there was no significant correlation between nitrogen and total sulfur-containing amino acids. Porter and Pradilla (1970) observed a negative relationship between percent protein and milligrams of sulfur per gram of protein in a very large number of *Phaseolus vulgaris* cultivars from Colombia.

Tandon *et al.* (1957) also reported highly significant varietal differences in the contents of nitrogen, lysine, tryptophan, niacin, and thiamine. That genetic differences are of major importance in determining nutrient content was also concluded by Gough and Lantz (1950) and by Dhingra and Das (1959).

Jacob (1967) stated that the four most common varieties of beans consumed in Chile contained from 47.0 to 86.1 mg of hydrogen cyanide per kilogram at a 12% moisture level, while Hamad and Powers (1965) indicated that the pectic content of dry lima bean varieties varied from 0.74 to 1.95%. In contrast, other studies have shown similarity in composition between varieties. For example, Zarkadas *et al.* (1965) working with two varieties of peas *(Pisum sativum)* determined that the fatty acid composition of the light petroleum extracts of the two pea samples, and the amino acid composition of the defatted meals, were in most instances closely similar. The two varieties were also alike in that their protein fractions showed similar electrophoretic components.

As with studies on differences between species, the research carried out on the evaluation of differences among varieties has also been limited, and no real attempt has been made to relate these differences to nutritional quality, although their significance to processing has been studied to some extent.

D. Environment, Fertilizers, and Cultural Practices

Differences in chemical composition may be attributed to the effects of soil, climate, strain of seed, and fertilizer treatment (Esh *et al.*, 1959). Large differences in thiamine and riboflavin content of beans cultivated at different locations have been reported by Eheart and associates (1946). Guyer *et al.* (1950) observed that as harvest time was delayed the yield increased but the content of ascorbic acid decreased. Tandon *et al.* (1957) found that soil significantly altered both the yield and the riboflavin content of the kidney bean *(Phaseolus vulgaris)*. However, the content of nitrogen, methionine, lysine, tryptophan, niacin, and thiamine was not affected to a detectable degree by soil fertility differences. These results are in agreement with earlier data published by Scharrer and Schreiber (1943) who indicated that different fertilizer levels increased the overall yield and the total amount of protein in beans without materially influencing the relative percentages of crude protein, true protein, and digestible crude protein.

Gough and Lantz (1950) in their work with 8 bean varieties grown at three locations in New Mexico, in three different years, observed significant differences in thiamine and niacin content due to varieties, localities, and the particular year that the plants were grown, and in riboflavin due to varieties and localities only. Tandon *et al.* (1957) further indicate that for nitrogen, methionine, tryptophan, niacin, and thiamine content in beans, the cultivar differences, which are basically genetic, are more important than the result of the interaction between cultivars and locality. Therefore, the most effective way to increase the amounts of these nutrients in beans is by selection of cultivars which are richer in these nutrients. The same authors conclude that the interaction between cultivars and localities is an important source of variation of the lysine content of beans. Consequently, in order to increase the lysine content of bean protein, selected cultivars should be grown in regions where their genetic makeup has the best chance of providing maximum nutrient value as well as yield.

While working with black beans, Tandon *et al.* (1957), as well as Greenwood (1933) with pinto beans, reached the conclusion that a negative correlation exists between yield and the percentage of protein and of other nutrients such as thiamine, niacin, and methionine.

Lantz *et al.* (1958) reported on the content of protein and nine amino acids of dried beans grown for 3 consecutive years in one location, and for 1 year in three locations. For protein content, differences were significant between some varieties, and highly significant among all locations. Differences in amino acid concentration among varieties were significant for all amino acids when such concentration was expressed as milligrams per gram of nitrogen. Location affected amino acid content more than did variety, particular year or time of planting.

Variations in nitrogen and methionine, tryptophan, thiamine, riboflavin, and niacin content between localities have also been noticed by Bressani *et al.* (1960) for the common black, red, and white bean cultivars consumed in Central America.

Some workers have attempted to study the effect of the application of different fertilizers and seeding rate on chemical composition. However, in lentils, carbohydrate, crude protein, and ash content showed no significant responses to seeding rate and fertilizer level according to Bajwa and Nassib (1965). On the other hand, Wagner (1969) reported pea beans to have a variable protein score according to P, Zn, and Fe content of the soil where they were grown. When the Zn uptake of the plant increased, a rise in methionine concentration was observed, but such effect was not evident when the soils were rich in both P and Fe. In this report it was found that the year was also a factor influencing markedly the total nitrogen content. The effects of fertilizer application, mainly minor elements, have been tested to learn whether they could change chemical composition and nutritive value of legume foods. Murray *et al.* (1952) reported that for Alaska peas *(Pisum sativum)* minor element treatment did not change protein content, which varied from 23.0 to 24.4% among treatments. Methionine content was more variable, with values as low as 1.29 and as high as 2.18 g/100 g of protein. Obviously, these findings are of great nutritional significance and studies should be repeated to confirm the results obtained.

V. Variation in Nutritive Value

A. Species Variations

It is well-known that most legume foods, if not all, contain antinutritional factors in varying concentrations which must be eliminated before they are consumed or before evaluating their nutritive quality in experimental animals. Because of differences in physical characteristics such as size, thickness of the seed coat, stage of maturity, concentration of antinutritional factors, and possibly other conditions, the degree and extent of processing before consumption varies. Obviously, this situation may influence nutritive value when comparisons are made among species.

Although not related to species differences, Murray *et al.* (1952) report that field peas grown under various fertilizer applications had variable protein efficiency ratio (PER) values; the higher figures were in peas grown with fertilizers containing only sulfur. On the other hand, Bressani (1967) found that various fertilizer applications, including the use of nitrogen-fixing bacteria and minor elements, induced no differences in the protein quality of *Phaseolus vulgaris* among the different treatments.

The biological value, digestibility, and PER of 15 species of legume foods were summarized by Kuppuswamy *et al.*, 1958. These results show the coefficient of digestibility to vary from 51 to 93%. There is no specific relationship between the species and the digestibility, since almost the same variability is observed for the same legume. These variations could be attributed to differences in the methodology employed in the assay. However, it is very possible that such differences are real and that, in any case, they should be understood in order to devise means for better utilization of the protein in the legume food. Obviously, there is little advantage in having legume foods with around 20% total protein and with a digestibility of 50%. This should place them in the same order of magnitude with respect to protein as cereal grains, which, in general, have a protein digestibility easily above 75%.

The biological value—probably the best measure of protein quality—represents the amount of protein absorbed that is retained by the animal organism. The variation among legume species ranges from 32 to 78%, which is quite large. Even within one species the variability is significantly large, either because of the condition of the protein at the moment of its assay, or on account of the methodology followed for the biological trial. In studies with rats, the same variability is reported for PER except that in this case negative values are given, which indicate poor utilization of the protein by the animals for purposes of growth. The highest value reported was 1.9 which is equivalent to about 70% of the PER value of casein.

Phansalkar (1961) also carried out studies to determine the coefficient of digestibility, biological value, and growth efficiency ratio of nine legume foods commonly consumed in India. The variability ranged from 70 to 90% in digestibility, from 45 to 74% in biological value, and from 0.5 to 1.1 in growth efficiency ratio. These figures were compared to those obtained for various cereal grains, and it was concluded that the biological value of legume proteins is lower than that of cereal grains with similar digestibility coefficients.

Banarjee (1961), on the other hand, compared five legume foods from India to casein. The PER values were higher than in most other studies of this nature, ranging from 1.16 to 1.87, with a casein value of 1.95. Similar results have been reported from India by various other workers (Chitre and Vallury, 1956a,b; Venkat Rao *et al.*, 1964).

Bressani *et al.* (1961a) evaluated three species of legume foods, *Phaseolus vulgaris, Phaseolus calcaratus,* and *Vigna sinensis,* and found that, of these, *Vigna sinensis* was of superior nutritive quality. Elias *et al.* (1964) reported marked differences in protein value among eight varieties of *Vigna sinensis* (cowpea), even though their essential amino acid composition indicated only small differences between them. In this study the PER values ranged from 1.42 to 2.30, while soybean flour fed at equal levels of intake gave a value of 3.55.

When comparing the PER values of *Vigna sinensis* to that of *Phaseolus vulgaris,* it was found that certain varieties of *Vigna sinensis* were superior in protein quality to the *Phaseolus vulgaris* sample. The differences in protein quality were attributed to variations in the physiological availability of the essential amino acids. However, since *Vigna sinensis* is more easily cooked and has lower levels of antinutritional factors than *Phaseolus vulgaris,* it is possible that the answer to the difference in protein quality is to be found in these factors rather than in their essential amino acid content. In this respect, the work on digestibility of carbohydrates in pulses carried out in India by Srinivasa Rao (1969) is of particular interest. His results showed that there are differences in the digestibility of the carbohydrates of various pulses. These findings confirm the belief that some pulses are relatively less easy to digest. Furthermore, these differences may be responsible for variations in protein digestibility and, thus, in protein quality.

Goyco and Asenjo (1965) evaluated in rats eight kinds of legume foods of popular use in Puerto Rico by a method which they called "The lactation value of proteins." As reference proteins, Goyco and Asenjo used whole egg protein and casein. Of the eight legume foods tested, only chick-peas *(Cicer arietinum),* pigeon peas *(Cajanus cajan),* and great Northern beans *(Phaseolus vulgaris)* gave a positive lactation value, equivalent to the algebraic addition of the body weight changes of mother and litter expressed as per gram of protein consumed. The five other bean samples—one of *Phaseolus lunatus* and four of *Phaseolus vulgaris* —gave negative lactation values. The chick-pea value fell in between those of whole egg and casein, suggesting as have other results (Axtmayer, 1946), that chick-pea protein is about the best among legume foods. Testing of each of the other species indicated that their protein was not of the quality needed for the very important functions of milk production and mother–litter maintenance, nor for .the development of the animal during the preweaning period. However, although with certain variants, all legume foods proved to have better growth-promoting values. In this respect Elias *et al.* (1964) found that the value of *Vigna sinensis* for purposes of body protein repletion was closer to that of soybean protein than when measured in terms of growth promotion. This finding suggests that the essential amino acid pattern of legume foods is more suitable for some physiological states than to others.

Richardson (1948) also found differences in nutritive value among various cowpea *(Vigna sinensis)* samples, while Chaves *et al.* (1952) reported a relative growth and PER value of approximately 83% of the nutritive value of casein. Nitsan (1971) found that *Vicia faba* had a lower protein quality than soybeans, probably due to the lower nitrogen utilization of the *Vicia.*

Reports from other investigators (Koj, 1966; De Groot and Slump, 1963; Kakade and Evans, 1965–66; Evans and Bandemer, 1967; De

Souza and Pechnik, 1949), using different approaches for the protein evaluation of legume foods, also found differences between species as well as between varieties or cultivars of the same species which have not been properly explained. It would seem, therefore, that legume foods could be of greater value in nutrition if the reasons for their variations in digestibility, biological value, or any other measure of protein quality could be ascertained.

B. Methods of Preparation

Legume foods are prepared for consumption at the home following a variety of procedures involving heat in the presence or absence of water, the purpose of which is to render the food nontoxic, to eliminate the seed coat, and to soften the cotyledons. There are various popular ways to accomplish this. One procedure is simply to cook the seed in water for long periods of time until soft. The time required to achieve softness of the seed has been an indication of its culinary quality and popularity. A second method is to soak the seed for a short period of time which facilitates the removal of the seed coat. The latter is removed either by scrubbing the wet seed or by letting it dry, after which mechanical dehulling is applied. Once dehulled, the cotyledons are cooked and consumed. Descriptions of these home procedures have been published (Venkat Rao *et al.*, 1964; Aykroyd and Doughty, 1964; Patwardhan, 1962), although little information is to be found on the changes that take place in the nutritive value of the protein.

Dako (1966) discussed the nutritive value of African legume foods in relation to the pretreatment to which they are subjected in that area of the world. This author found that cooking of pigeon peas *(Cajanus cajan)* improved their nutritional value but that supplementary soaking or germination did not further improve protein quality. Elias *et al.* (in preparation) studied the changes in protein quality that accompany the various procedures used in Central America for cooking the beans. In this region as well as in others of Latin America, beans are consumed after cooking either whole, strained, or fried. Cooking improves protein quality, as is the case for almost all legume foods. In this respect, strained beans were found to be slightly superior to cooked whole beans, a finding that the authors explain on the basis of a lower level of hulls, as these are almost totally removed with the straining process. On the other hand, fried beans had a definitely lower protein value, even though the calorie content was higher due to the addition of oil or animal fat during frying. The available lysine value in fried beans was found to be lower than in the other preparations.

Bressani *et al.* (1963) found that home cooking for 4 hours gave protein quality values equal to those obtained by pressure cooking for 20 min. This last procedure is becoming more popular when the necessary kitchen equipment is available and fuel supply is cheap, particularly in urban areas of various countries where beans form a well-accepted part of the diet. In the rural areas, however, cooking is still with firewood, a process that demands longer periods of time before the cotyledons are sufficiently soft.

In India, seed coat–free legume foods are called "dhal." Although no specific information was found in the literature on whether or not the nutritive value of legume foods changes with the cooking of dhal, observations of other cooking procedures suggest that some improvement in nutritive quality may occur as the result of removal of the seed coat.

A common method of consuming beans, especially in the developed countries, is as canned beans. Powrie and Lamberts (1964) in their studies with rats found that increasing temperature of canning decreased protein digestibility as well as weight gain of the rats, PER, and biological value. The decreases were smaller for beans processed with sucrose–glucose solutions than when processed with glucose alone.

Toasting was reported by Acharya *et al.* (1942) to cause a slight improvement in the biological value of the protein of various legume foods. However, the value of toasted *Vicia faba* is not as high as when it is water-cooked (Borchers and Ackerson, 1950, Nitsan, 1971).

Chattopadhyay and Banerjee (1951, 1952, 1953) found that germination brought about an improvement in the biological value of three out of five legumes to the extent of 10–20%. However, they did not detect changes in the amount of trypsin inhibitors in any of the five samples studied.

C. Effects of Heat

The majority of foodstuffs are subjected to heat treatment of varying degrees before they are consumed. The conditions and extent of the heating procedures may affect foods adversely or beneficially with respect to their physical and organoleptic characteristics, as well as in regard to the utilization of the nutrients they contain. The nature and the extent of these changes depend mainly on the temperature and heating time, exposure, and moisture content. No attempts will be made to describe in detail such effects, since there are excellent reviews on this subject (De Souza and Pechnik, 1949; Liener, 1958, National Academy of Sciences —National Research Council, 1950; Patwardhan, 1962).

1. *Beneficial Effects*

It is well known that appropriate exposure of foodstuffs to heat treatments is advantageous to attain some desirable effects on its chemical, physical, organoleptic, and nutritive properties. Blanching for enzymatic inactivations permits a uniform quality of vegetable foods and prolongs the shelf-life of many foodstuffs.

The heat treatment applied to legume foods does improve their texture and palatability, and also helps to destroy or inactivate some heat-labile toxic compounds such as the trypsin inhibitors, hemagglutinins, and probably other enzyme inhibitors, as has been shown by several investigators (Chaves *et al.*, 1952; Koj, 1966; De Groot and Slump, 1963; Kakade and Evans, 1965–66; Evans and Bandemer, 1967).

2. *Detrimental Effects*

These are mainly related to excessive time of cooking and to moisture content of the cooked beans. Bressani *et al.* (1963), reported that cooking black beans for 10–30 min at 121°C improved their protein utilization as compared to raw beans. Longer cooking, however, caused a drop in the nutritive value of the beans as judged by the amount of available lysine in the samples studied, the weight gain of the rats, and the PER values obtained.

Other investigators have also indicated that excessive heat treatment causes a reduction in the nutritive value of legume seeds (Patwardhan, 1962; Borchers and Ackerson, 1950; Hayward *et al.*, 1936; Weitfall and Hauge, 1948; Baldwin and Movitt, 1942). The detrimental effects of heat on cereal foods have been reported by several investigators. Murlin *et al.* (1938) indicated that whole oat grain had a higher nutritive value than when processed. They reported similar results for wheat samples heated with sugar (sucrose and maltose) or subjected to puffing, a process used in the preparation of breakfast cereals. In this respect, Sure (1951) also indicated that only 4 out of 15 breakfast cereals tested had an acceptable nutritive value. These heating effects have been attributed to a destruction or inactivation of some essential amino acids, lysine being the most affected (Stewart *et al.*, 1943; Block *et al.*, 1946).

a. *Direct action of heat on protein quality.* Heat processing can affect adversely the protein quality of food-stuffs through chemical reactions which lead to the destruction or inactivation of some amino acids. These chemical reactions are classified into at least three types:

1. The reaction between certain amino acids and other protein constituents. In this case, the amino acids are not destroyed, since the enzyme-resistant bonds can be broken by acid hydrolysis, but not by the

normal process of digestion. Destruction of amino acids does not occur because they are completely recovered after acid hydrolysis.

2. Reducing sugars react with amino acids that possess reactive nitrogen groups, giving rise to the well-known Maillard reaction. In this case, the complex formed is not attacked by digestive enzymes, although the sugar amino acid complex can be released by acid hydrolysis.

3. The destruction of certain amino acids can occur in some reactions between proteins and carbohydrates. Lysine, methionine, arginine, and tryptophan have been reported to be involved in these types of interactions (Liener, 1958; National Academy of Sciences—National Research Council, 1950; Rice and Jack, 1953).

A reduction in the nutritive value of processed milk due to losses in lysine has been reported by Mauron (1961) and by Mauron *et al.* (1955). Carpenter (1960) also observed a decrease in the protein quality of fish flour prepared under conditions of high temperature treatment. The changes in soybeans and cottonseed processed for oil extraction illustrate very well the effect of excessive heat on amino acid availability and protein quality. Overheating of soybeans has been shown to reduce its protein quality through either decreasing the availability of cystine and methionine, or by rendering the meal more resistant to proteolytic enzymes (Smith, 1962; Hayward *et al.*, 1936, 1937; Fritz *et al.*, 1947; Kunitz, 1945; Riensen *et al.*, 1947; Melnik *et al.*, 1946).

During cottonseed processing, gossypol—the yellow toxic pigment present in cottonseed—reacts with the free lysine amino group, lowering the biological availability of this amino acid. Due to the fact that lysine is the first limiting amino acid in native cottonseed protein, the gossypol–lysine reaction reduces further the nutritive value of cottonseed protein (Bressani and Elías, 1968b; Martínez *et al.*, 1961; Elías *et al.*, 1969b; Braham *et al.*, 1965a).

The nutritive value of foodstuffs rich in carbohydrates may be reduced upon heat treatment, and the value restored by the addition of lysine—if this is the amino acid that was inactivated. There is also a decrease in available lysine when protein concentrates containing little or no carbohydrate are subjected to severe heat. Severe heat treatment of protein concentrates has also been shown to reduce the availability of the sulfur-containing amino acids. Very little information concerning the availability of amino acids other than lysine and methionine exists, but the observations that isoleucine, an amino acid with an unreactive hydrocarbon side chain, is unavailable in certain purified proteins, suggest that other amino acids may also be present in an unavailable form.

b. *Specific studies on beans.* Adachi *et al.* (1958) indicated that the *in* *vitro* digestibility of lima and navy beans was not affected by the dehydration and cooking process reported in their study. González del Cueto and associates (1960) reported that the lysine content of chick-pea *(Cicer arietinum)* decreased when this legume seed was heated in the autoclave at 121°C for 30 and 60 min. Studies carried out by Powers *et al.* (1961) on the processing conditions for canning dry lima or pinto beans, indicated that temperatures from 230° to 270°F did not affect the amount of starch or pectin fraction leached from legumes. De Groot (1963) found that the digestibility of red beans and the biological value of lima beans and green beans, decreased after dehydration in hot air.

The bitter taste of peas *(Pisum sativum)* can be eliminated by autoclaving for a short time at pressures ranging from 8–10 lb/in^2. According to the authors (Austin and Austin, 1963), the cooked legumes can be ground without drying, giving a high-protein flour.

Kakade and Evans (1965) state that the *in vitro* digestibility of navy beans *(Phaseolus vulgaris)* is improved by a mild heat treatment. However, excessive cooking (4 hours) result in lowering of digestibility. They suggest that the detrimental effects may be due to the reaction of the free amino groups with carbohydrates. Further studies on this problem were carried out by these same authors (Kakade and Evans, 1963–1964) using *in vivo* tests. They reported that rats fed raw navy beans lost weight and died, probably because of the presence of a toxic factor, or factors, and to a deficiency of sulfur-containing amino acids. Cooking the beans in the autoclave for 5 min destroyed the trypsin inhibitor and hemagglutinin, since rats fed the autoclaved beans gained weight. Once again, they pointed out that excessive heating reduced the nutritive value of the beans due to the destruction or inactivation of certain essential amino acids.

Interesting results on the effect of length of heat processing and the addition of sugars in the input liquid of canned navy beans were reported by Powrie and Lamberts (1964). Cooking of canned beans in water at 121°C from 20 to 70 min causes a lowering in the apparent digestibility of the proteins. Likewise, reductions in the weight gain of rats, the PER, and the biological value were observed. The addition of sucrose alone in the input liquid of the canned beans caused a slight reduction in the nutritive value of the proteins, while the presence of glucose in the canned product impaired significantly the digestibility and biological value of the protein. The simultaneous addition of glucose and sucrose in the bathing solution did not affect the protein quality as much as glucose alone.

The amount of "available" lysine has been a measure of the effect of heat processing on the nutritive value of proteins. Kakade and Evans

(1966) determined the amount of available lysine in raw and heated navy beans. Their results revealed a significant correlation between the chemical method and the enzymatic method for this determination. Although the chemical method does not detect the presence of trypsin inhibitors in raw bean samples, they nevertheless suggest this analytic procedure as a simple, rapid, and inexpensive method to study the effect of heat processing on the nutritive value of processed vegetable proteins.

La Belle *et al.* (1969) investigated the effect of processing conditions for the preparation of precooked dehydrated beans on the quality and the nutritional value of the final product. Their results showed again that the PER was reduced by prolonging cooking. However, the nutritive value was not affected by the levels of sugar coating (sucrose and dextrose) used in the process to avoid "butterflying."

D. Improvement in Nutritive Value: Amino Acid Deficiency

Controlled heating improves the nutritive quality of legume foods, an effect due to the destruction of antinutritional factors (Borchers and Ackerson, 1950; Klose *et al.*, 1949; Jaffé, 1950; Liener, 1962; Johns and Finks, 1920; Hirwe and Magar, 1953). The quality of the protein, however, is not sufficiently high to meet the needs of experimental animals under various physiological conditions.

In previous sections we pointed out that, in general, the essential amino-acid pattern of legume protein is exceptionally good when compared to reference patterns or to animal protein sources, except that legume protein is deficient in sulfur-containing amino acids with a secondary deficiency in tryptophan. Obviously, addition of these limiting factors to legume proteins will result in a significant improvement in the quality of the protein.

Knowledge of the sulfur amino acid deficiency in beans is quite old, dating as far back as 1920, when various investigators (Johns and Finks, 1920, 1921; Finks and Johns, 1921; Sure, 1922) demonstrated that cooked, but not raw, legume foods induced normal growth in rats when the protein was supplemented with cystine. These results were not understood completely at the time until Rose (1938) showed that cystine stimulates growth when methionine is present in suboptimal quantities, but not when it is entirely absent from the diet. Woods *et al.* (1943) as well as Lehrer and associates (1947) in a study on the nutritive value of Alaska field beans, reported that the daily gain was tripled and the protein efficiency doubled when either the cooked or raw peas were supplemented with 0.3% of methionine. Russell *et al.* (1946) published the results of their studies on varieties of lima beans and snap beans *(Phaseolus vulgaris)* as well as peas. Growth from feeding the legumes, even when cooked, was poor unless they were supplemented with 0.1% methionine.

Richardson (1948) added 0.2% methionine as a supplement to heated lima and pinto beans, and reported an improvement in protein quality. He also found that the protein quality of Southern peas could be improved to the level of egg albumin when supplemented with methionine, tryptophan, and lysine. In tests with Southern peas and pinto beans, 0.2% methionine was required to support maximum growth rate. Jaffé (1949) also found that of 12 legume foods studied, all responded to methionine supplementation; however, pigeon peas *(Cajanus indicus)* required the addition of both methionine and tryptophan to improve protein quality. Similar results on *Cajanus indicus* were obtained by Braham *et al.* (1965b). These authors found this legume to be nontoxic when fed raw; autoclaving for 20 min at 16 lb pressure improved its quality significantly. Maximum improvement in protein quality was observed when the cooked flour of *Cajanus indicus* was supplemented with 0.1% tryptophan and 0.3% methionine.

In most of these studies, however, the effect of methionine was to improve the pattern of the essential amino acids, but no effect on protein digestibility has been reported or obtained (Bressani *et al.*, 1963). In one study, Purdom and Brown (1967) found that tryptophan addition to *Phaseolus vulgaris* diets decreased fecal nitrogen, evidence of improved digestibility; however, methionine had no such effect.

All of these studies indicate, without any doubt, that methionine is the main limiting amino acid in legume food protein, and that its addition improves its quality significantly. Nevertheless, for practical purposes, fortification with methionine will be difficult since legume seeds are commonly eaten after processing at home.

Based on the above statements, it is not yet certain if bean protein quality should be improved by methionine addition or if it would be better to increase the digestibility of the protein or the total protein content of the legume foods. It should be kept in mind that beans are consumed together with cereal grains which provide enough methionine to balance the essential amino acid pattern of the mixture (Bressani and Elías, 1968a). (This will be discussed in more detail in another section.) On the other hand, if beans are consumed along with foods of low protein content, such as cassava flour, it would seem better to improve the total quantity of protein, as well as its methionine content. (This will also be discussed in a following section.)

Both methionine and total protein content can be increased by supplementation with small amounts of proteins rich in this amino acid and in protein. This approach can only be practical when legume foods are processed at the industrial level, either as dry-cooked flours or as purees.

Very little has been done in this respect, probably because, as indicated earlier, beans and legume foods, in general, are cooked at home for direct consumption.

E. Physiological Effects

Legume foods are known to contain certain toxic substances classified as: *(a)* trypsin inhibitors; *(b)* hemagglutinins; *(c)* goitrogenic factors; *(d)* cyanogenetic glucosides; *(e)* lathyric factors, and *(f)* compounds which cause favism. There are excellent reviews on these subjects (Liener, 1962, 1964; Jaffé, 1968; Nagarajan, 1969; Pusztai, 1967); therefore, these will not be discussed in the present chapter. Attention will be given to other less-known effects of legume foods which could affect their utilization as protein sources for young and adult humans.

1. *Flatulence*

One of the best known problems that results from the consumption of legume foods is increased flatulence production in the individual. In this respect, Steggerda (1962, 1965, 1968), working with human subjects, indicated that when beans are consumed, the normal physiology of the gastrointestinal tract is altered so that flatulence production is markedly stimulated. He observed that with a pork-bean diet, fed to human subjects, flatus production increased from 16 cm^3/hr on a normal diet to an average volume of 190 cm^3/hr. Along with the volume increase, it was observed that CO_2 content rose from a normal level of 10–12% to above 50%. It was suggested that the CO_2 normally produced in the gastrointestinal tract was not being effectively absorbed either because of the presence of some inhibiting agent or due to an increased motility of the intestine. Nielsen (1962), on the other hand found that bean feeding did not appear to change intestinal motility, as measured by ingestion of carmine dye together with the meal. However, he did find elevation in breath hydrogen from near zero to 20–50 ppm. Murphy (1956) observed increases in rectal gas, from 10- to 20-fold, with a higher concentration of CO_2 and hydrogen gas. According to Murphy (1956) and Steggerda (1962), the increased carbon dioxide concentration may be the result of various mechanisms acting alone or in combination. The above authors proposed the following mechanisms: decreased activity of the carbonic anhydrase enzyme; gut wall irritation; foam formation; and vascular contraction or an increase in intestinal motility. These same authors believe that legume foods contain a carbonic anhydrase inhibitor that is present in smaller or greater concentrations in different samples of beans.

Sánchez *et al.* (1967) indicate that with some cultivars of lima beans flatulence stimulation activity does not appear until about 1 week before the beans are at the green mature state, and continues to increase to a maximum when the dry beans are ready for harvest.

Rockland (1969) obtained evidence suggestive that the primary cause of flatulence may be the production of gas by gram-positive, anaerobic bacteria present in the gastrointestinal tract after stimulation by unknown factors in dry beans. Furthermore, he suggests that *Clostridium perfringens,* the main intestinal anaerobe, is probably the primary source of flatus gases. The hypothesis could be correct in view of the findings by Kakade and Borchers (1967) that gas-producing efficiency of rats fed heated navy beans was significantly reduced when antibiotics were also fed. The effects of various antibiotics was also described by Rockland (1969) and Rockland *et al.* (1969) using *C perfringens* as the gas-forming bacteria. Bornside and Cohn (1965) also observed that the class of bacteria most responsible for the reaction was the gram-positive anaerobic spore-forming clostridia type which normally inhabits the intestinal tract of animals and humans.

Steggerda *et al.* (1966) showed that the gas-producing factor is to be found in the low molecular weight carbohydrate fraction which includes sucrose, stachyose, and raffinose. Rackis *et al.* (1970) concluded that these three oligosaccharides are connected with the gas-producing factor when incubated with anaerobes. Furthermore, they indicated that soybeans contain phenolic compounds, syringic and ferulic acids, which are inhibitors of gas production.

The specific factor or factors in beans responsible for flatulence have not been established as yet, even though Murphy (1967, 1969) found that the flatulence factor in beans can be extracted from cooked beans with 60% ethyl alcohol. He emphasizes that the factor is low in molecular weight, perhaps even below 10,000. He also reports that the protein, starch polysaccharides, and lipids of beans, are not responsible for gas production.

2. *Heat-sensitive Inhibitors*

Not all legume foods are improved by autoclaving, and, if the effect of heating is to destroy trypsin inhibitors, it can be concluded that not all legume foods contain them or that, if present, the concentration or activity is variable among species and even cultivars. Borchers and Ackerson (1950), for example, determined that of 17 species of legume seeds investigated, eight were improved nutritionally by autoclaving, while nine were not. No correlation was observed between the effect of autoclaving on nutritive value and the presence or absence of the trypsin inhibitor in the raw legume seed. Jaffé (1949, 1950) reported on the digestibility of eight kinds of legume foods fed raw and autoclaved as well as on the trypsin inhibitor activity. Autoclaving caused a greater increase in the digestibility of the legume foods with higher initial trypsin inhibitor activity, which varied from 178 $\times$ 10^{-4} units/g in lentils *(Lens esculenta)* to 4.38 in *Dolichos lablab*. Soybeans and kidney beans also had high trypsin inhibitor activity values, above 4 $\times$ 10^{-4} units/g.

Studies at INCAP on *Phaseolus vulgaris* revealed that inhibitors are present very early in the formation of the seed. Zimmerman *et al.* (1967) reported more activity in the outer layers of the seed than in the inner layers.

The function of these inhibitors in the bean apparently has not been studied; their significance to the plant should receive attention, so that if findings prove that they are not useful to the plant, they may be genetically eliminated. On the other hand, since they are high in cystine content, their presence might be useful from the nutritional point of view, since sulfur-containing amino acids are, as already indicated, limiting in legume protein. Kakade *et al.* (1969), however, found, in chick studies, that the cystine of the navy bean trypsin inhibitor is not released by digestive enzymes.

3. *Hypocholesterolemic Property*

Another characteristic resulting from the consumption of legume foods which has merited some attention is their hypocholesterolemic property. Grande *et al.* (1965) compared the effects on serum cholesterol of ingesting the carbohydrate of bread and potatoes with those of the carbohydrate of legume foods, when they were isocalorically substituted for sucrose. The diet containing leguminous seeds induced a serum cholesterol level lower by 9% than that of sucrose diet. Other reports have confirmed the hypocholesterolemic effects of diets containing a high proportion of leguminous seeds. Mathur *et al.* (1961, 1965), for example, noted that people of low socioeconomic status in Agra, India, whose staple diet was chick-peas *(Cicer arietinum)*, had much lower serum cholesterol levels than those who did not consume that diet. In the Netherlands, Groen *et al.* (1961) observed that Trappist monks had lower serum cholesterol levels than Benedictines, and noted that legume foods were an important part of the diet of the former. In studies with 20 volunteers, Luyken and associates (1962) showed that introduction of 100 g of legume foods, mainly brown beans, resulted in a mean serum cholesterol decrease of 12 mg/100 ml.

The cholesterol-depressing effect caused by the bean diets could obviously be due to the presence of some unknown substances in the beans that have a hypocholesterolemic effect. In this respect, Mathur and co-workers (1963, 1964) have reported that the cholesterol-depressing action of *Cicer arietinum* in rats fed a diet containing cholesterol and cholic acid, is also produced by the fat-free seed and by its lipid extract. It should be indicated that bean lipids contain relatively high levels of unsaturated fatty acids. Grande *et al.* (1965) postulated that the decrease in serum cholesterol concentration was caused by the carbohydrate fraction of the leguminous foods.

4. *Muscular Dystrophy*

A further effect from consumption of legume foods, particularly raw, has been the production in the animal of muscular dystrophy. Hogue *et al.* (1962) report that a ration containing raw kidney beans, when fed to ewes, was effective in the production of nutritional muscular dystrophy (NMD) in the lambs. Autoclaving the beans decreased the incidence of NMD; it is suggested that kidney beans contain a heat-labile vitamin E antagonist. They also indicate that autoclaved beans exhibited negative vitamin E activity in the prevention of exudative diathesis in the chick. Other legume foods have been reported to have antivitamin E activity. Sanyal (1953) reported that *Pisum sativum* contained a factor which decreased the effectiveness of vitamin E in the prevention of fetal resorption in the rat.

Hintz and Hogue (1964) reported that the addition of 50–75% raw kidney beans and vitamin E to 1-day-old chick diets, increased the incidence of nutritional muscular dystrophy to 45–100%, indicating that beans contain an antivitamin E factor, since the vitamin E–deficient diet produced NMD at the rate of 95–100%, while 20–25 IU of vitamin E per kilogram decreased the incidence to 5–6%. Extracting and autoclaving the beans indicated two antagonists to vitamin E, one alcohol-soluble and heat-stable and the second not alcohol-soluble and heat-labile.

5. *Discussion*

Toxicity and other factors in legume foods are of practical importance in nutrition as well as of academic interest, since understanding their physiological action could lead to an increased utilization of this group of foods.

VI. Food Mixtures

A. Protein Concentrate: Legume Food Mixtures

The supplementary effect of animal protein to legume proteins was studied by De Groot and Van Stratum (1963) who postulated that a true supplementation was obtained only with a combination of beans and eggs, and explained their results on the basis of the common methionine deficiency in the beans and in the other animal proteins.

The supplementary effect of pea protein to partially replace egg protein was also studied by Esselbaugh *et al.* (1952) in human subjects. By using the nitrogen balance technique at a low level of protein intake, they found that the egg replacement value was 95.1% for pea protein alone and 100% for methionine-supplemented pea protein.

The nitrogen retention of corn was significantly improved when it was supplemented with pea flour, or with pea flour plus fish flour, or pea flour with milk (Hansen *et al.*, 1960; Brock, 1961). These authors also concluded that nitrogen retentions were comparable to the values obtained with the milk diets when the corn–pea mixtures were supplemented with 12% milk or with 10% fish flour. Ganapati and associates (1961) also reported favorable results from feeding a *Cicer arietinum*–milk diet to children 6 months to 5 years of age, indicating that, in general, pulse protein was well tolerated by the children. A mixed diet of three cereals (rice, finger millet, and wheat flour) and four legumes (lentil, green gram, black gram, and pigeon pea) supplemented with skim milk was fed to children 1–6 years of age, with satisfactory results, according to the data reported by Baptist and De Mel (1955).

A vegetable protein mixture containing 37.8% of protein based on 47% autoclaved chick-pea *(Cicer arietinum)*, 35% defatted sesame flour, and 18% heat-processed, low-fat soybean flour, was developed by Guggenheim and Szmelcman (1965). Biological trials carried out with such mixture indicated a relatively high nutritive value, with a PER of 2.90 and a biological value of 74. The most limiting amino acids in this formula were methionine and tryptophan. Metabolic studies carried out by Matoth *et al.* (1968) in infants showed that these vegetable protein mixtures compared favorably with cow's milk diets as judged from nitrogen retention and weight gain.

Nirmala *et al.* (1968) demonstrated that the relative nutritive index of a combination of horse gram *(Dolichos lablab)* and sesame seeds was 53.6 against 100 for skim milk. Chick-pea has also been included in a supplement mixture developed by Tasker and co-workers (1961); the combination consists of 50 parts of a low-fat peanut meal, 25 parts of a low-fat coconut meal, and 25 parts of a chick-pea flour. This protein mixture was used to supplement a maize–tapioca diet with encouraging results, as compared to diets prepared with skim milk powder. Tasker *et al.* (1962) have also demonstrated that a mixture of chick-pea flour, peanut flour, and skim milk improves the nutritive quality of a maize–tapioca diet.

Recently, Elías *et al.* (1969a) reported on complementation between cottonseed protein and each one of the following leguminous seeds: cowpea *(Vigna sinensis)*, pigeon pea *(Cajanus cajan)*, and black beans *(Phaseolus vulgaris)*. The highest protein quality in the combination of cottonseed and cowpea was obtained when the first provided 60% of the protein of the diet and the second 40%. The same optimum proportion was found for the mixture of cottonseed and black beans, although the mixture had a lower nutritive value. In the case of pigeon pea and cottonseed protein, the best combination occurred when the first contributed 30% and the second 70%. Based on these results, they formulated INCAP Vegetable Mixture 17, with the following composition: cottonseed flour, 27%; legume seed flour, 45%; corn flour, 25%; and 3% of torula yeast. The protein quality of this mixture was similar to the other formulas developed by INCAP (Bressani *et al.*, 1961b, 1966, 1967). The authors also indicate that the mixture can be prepared from the raw ground beans, since cooking before consumption destroys the antinutritional factors in the legume foods.

Since sesame *(Sesamum indicum)* and sunflower, like cottonseed, are deficient in lysine, De Groot and Van Stratum (1963) demonstrated that a beneficial supplementary effect between these oilseeds and legume protein is obtained, therefore, permitting the formulation of protein-rich foods based on these components. Since the oilseed flours, particularly sesame, are relatively good sources of methionine, mixtures of these with beans should be of high protein quality. In this respect, Elías *et al.* (in preparation) found that 12% sesame flour improved the protein quality of instant black bean powder, as tested in rats.

Chaves *et al.* (1962) showed that the combination of cowpea *(Vigna sinensis)* and cashew nut flour *(Anacardium occidentale)* has a relatively high nutritive value; this mixture contained 75% of its total protein derived from cowpea flour and 25% from cashew nut flour. The authors indicate that this mixture would be useful in combating protein malnutrition in the northeast part of Brazil.

Vegetable protein mixtures containing a blend of chick-pea, cottonseed, or peanut flour, and cereals such as ragi *(Eleucine caracana)* or Kaffir (*Sorghum vulgare*), or wheat, have been reported by Daniel *et al.* (1970) to have a nutritive value similar to INCAPARINA, a vegetable protein mixture developed by INCAP (Bressani *et al.*, 1961b). The proportions of these components in the mixture were: 65% cereal; 25% cottonseed or peanut protein concentrate; and 10% of the chick-pea flour.

Low-cost balanced foods for feeding weaned infants based on corn or ragi, oilseed meals, Bengal gram *(Cicer arietinum)*, and skim milk powder, have also been reported by Daniel *et al.* (1967). The PER of the food based on 70 : 20 : 10 blend of maize, groundnut (*Arachis hypogea*) and Bengal gram, was 2.10, as compared to 3.50 for milk. Fortification with lysine and methionine increased the PER to 2.48.

Daniel *et al.* (1968) also studied the supplementation effect of Bengal gram, red gram, and soya bean as compared with skim milk powder to the Indian diets usually based on cereals, such as ragi Kaffir corn (*Sorghum vulgare*) and Pearl millet (*Pennisetum typhodeum*). Their report indicates that the incorporation of 15% of Bengal gram or red gram, which provides 2.5% of extra protein to the normal diet, increased significantly its nutritive value.

Desai and co-workers (1968) studied the supplementary value of a protein food based on ground-nut flour (2 parts), fish flour (1 part), and Bengal gram flour (1 part), fortified with vitamins and minerals to low-protein diets. They concluded that the addition of 2.5–5.0% of extra protein from this supplement brought about a highly significant improvement to the poor Indian diets based on rice or Kaffir corn, or maize and tapioca flours, as judged by the weight gain of rats fed these experimental diets.

A blend (40 : 40 : 20) of ground nut flour, Bengal gram, and sesame flours named Protein Food I, and a blend (40 : 30 : 30) of groundnut, soybean, and sesame flours, named Protein Food II, were evaluated in depleted albino rats, by Panemangalore *et al.* (1967). These authors found a PER of 2.81 and 2.98 for the protein mixtures I and II, respectively, which with the addition of lysine and methionine increased to PER values of 3.11 and 3.24.

Pilot-plant studies aimed at preparation of weaning foods based on ground nut flour, Bengal gram flour, green gram flour, and cornstarch, have been reported by Chandrasekhara *et al.* (1968). They compared roller-drying and a macaroni process; the roller-drying process gave a more acceptable product. Nutritive evaluation indicates a PER of 2.3 which was increased to 2.5 and 2.7 by supplementation with methionine and milk solids, respectively.

Recently, other protein foods containing chick-pea, sesame, and groundnut were developed by Hanafy *et al.* (1970a, b, c) in Egypt. A blend ratio of 3 : 2 : 1 (groundnut, chick-pea, and sesame), was found to be readily acceptable by both children and adults. Biological evaluation of the protein mixture, which included growth and nitrogen retention in young rats and synthesis of their serum protein and hemoglobin, indicated that this food is an adequate source of protein. Other parameters measured, such as maturation, reproduction, lactation, and breeding, also corroborated their previous results. Amino acid supplementation of this mixture indicated that methionine was the first limiting amino acid.

A procedure for the preparation of textured mung protein has been reported by Bhumiratana and Nondasuta (1969). The extracted protein is mixed with various ingredients according to the formulas that they developed; wheat flour and sesame for the "Kaset cookies"; wheat flour for the "Kaset biscuits"; and wheat flour and soybean residue for the "Kaset noodle." In all cases, the nutritive value is enhanced by the addition of the limiting amino acids (lysine, methionine, and threonine); the mixture is completed with seasoning ingredients.

An attempt to supplement whole wheat flour with a legume called guar dhal was reported by Kawatra *et al.* (1970). Guar dhal is obtained from guar *(Cyamopsis tetragonoloba)* in the process of extraction of the gum from this seed and contains about 54% of crude protein. According to the authors, the addition of 10% of guar dhal to whole wheat flour resulted in maximum growth, increased the nitrogen content and decreased the lipid content of the liver as compared to whole wheat flour fed without supplementation.

The development of six different protein mixtures containing cowpea has been reported by Salzano Lago *et al.* (1970). The percent of protein provided by the different ingredients in the six formulas described was as follows: mixture 1 (FMA): cowpea, 32%; corn flour, 8%; and cottonseed, 60%; mixture 2 (FMC): cowpea, 65%; corn flour, 5%; and cashew nut flour, 30%; mixture 3 (FC): cowpea, 69%; and cashew nut flour, 31%; mixture 4 (FMAL): cowpea flour, 20%; corn flour, 5%; cottonseed flour, 55%; and whole milk powder, 20%; mixture 5 (FAL): cowpea flour, 29%; cottonseed flour, 52%; and whole milk powder, 19%; mixture 6 (FML): cowpea flour, 44%; corn flour, 9%; and whole milk powder, 47%. Total protein in the mixtures varied from 16 to 25 g%, with an acceptable PER which was highest in the protein mixture containing whole milk powder. The authors recommend the addition of animal protein sources in order to increase the nutritive value of protein mixtures based on vegetable sources.

B. Cereal and Legume Food Mixtures

From previous discussions in this chapter it is evident that the protein of leguminous seeds is considered to be a rich source of lysine and that its major deficiency lies in the sulfur-containing amino acids. Furthermore, pulses and beans contain relatively high amounts of protein as compared to other common foodstuffs. On the other hand, cereals have a low protein content, are in general lysine-deficient, but have adequate amounts of the sulfur-containing amino acids. These chemical and nutritive characteristics of legume foods place them as natural complements to cereal-based diets.

It is logical to conclude that bean protein should complement the protein in cereal grains. In fact, studies carried out by several investigators have indicated that the protein value of a mixture of bean and cereal grain is superior to that of each of these components fed individually (De Groot and Van Stratum, 1963; Adolph *et al.*, 1955; Phansalkar, *et al.*, 1957). These authors emphasize that there is a point in the combination where an optimum supplementary effect is observed: in general, this maximum effect occurs when about 50% of the legume protein is replaced by cereal protein.

Bressani *et al.* (1962) reported that the best combination of cooked black beans and lime-treated corn was one where each component contributed 50% of the total protein of the diet. In terms of weight, this would be 72% of corn and 28% beans.

Attempts to treat protein-malnourished children with corn–bean diets consisting of about 87% corn and 13% beans, have been reported by Gómez *et al.* (1957), Scrimshaw *et al.* (1961), and Hansen (1961). Recovery is slow because the bulk of the corn–bean diet in the above proportion does not permit an appropriate food intake to supply enough of the protein required for such purposes. Similar results were reported by Brock *et al.* (1955) who investigated combinations of cowpea *(Vigna sinensis)* with cereals.

Bressani and Elias (1969) reported on the protein value of various combinations of cooked black beans and opaque-2 corn. Their results showed that the highest protein quality was obtained when 50% of the protein of the diet was derived from each one of the components, thus corroborating previous studies by Bressani *et al.* (1962) with common corn and black beans. It is of interest to point out that in both studies, that is, using common corn and beans, and opaque-2 corn and beans, the combination that gave the highest nutritive quality was the same when each component provided the same amount of protein. The difference, however, was in the numerical value of protein quality, which was higher for the opaque-2 corn–bean mixture. The reason probably is that the common corn–bean diet was limiting in lysine.

The beneficial effects of the mutual protein-supplementation between polished rice and cooked black beans has been described by Bressani and Scrimshaw (1961) and Bressani and Valiente (1962). In both studies, the results revealed that good combinations between the two foods were in the range of 50–80% of rice protein, and 50–20% for black beans. They recommend a "rice–black bean" mixture, with a 65–35% protein distribution in order to improve not only protein quality, but also to increase to some extent the protein content of the mixture. Baptist (1956) showed that the growth rate of rats fed a vegetable diet composed of

19–20% rice, 80% legumes, and 1% green vegetables, compared well to that of rats receiving the stock colony diet which consisted of one of the vegetable rations supplemented with milk and meat.

Calloway *et al.* (1965) reported on the improved protein quality of a mixture of wheat and peas as comparable to egg protein. The nitrogen contributed by ingredients in the different protein mixtures studied was distributed as follows: wheat : pea : ragi, 50 : 35 : 15; wheat : pea : corn gluten, 50 : 30 : 20; wheat : pea : Brazil nut, 60 : 25 : 15; wheat : pea : egg, 50 : 30 : 20; wheat : pea, 60 : 40. The authors indicate that when appropriate levels of both essential amino acids and protein are provided, the nutritive value of the vegetable protein mixtures is equal to that of egg protein.

Sirinit *et al.* (1965) reported that optimum nutritional performance was attained when beans constituted 20–30% by weight of mixtures with corn, sorghum, or rice. At a 30% level of beans in the mixture, sorghum showed the best responses. These results have served as the basis for the development of a protein-rich food known as K-1000 which is being fed in mothercraft centers in Haiti (King *et al.*, 1966a,b; 1968; Bunce *et al.*, 1970).

VII. Storage Effects

The problem of storage of dry beans seems to be relatively simple; as a matter of fact, beans can be considered as one of the more stable foods. However, when dry beans are stored for long periods, some technical precautions are required to avoid any detrimental effects on their nutritive value, on their quality for processing, and on their organoleptic and culinary characteristics. The reports by Burr *et al.* (1968) and Muneta (1964) indicate that moisture content, temperature, and storage time, are the three most important variables to be controlled in order to maintain bean quality, and these are interrelated.

A. Quality for Processing

Adequate storage conditions are of paramount importance to maintain dry bean quality for processing. By quality we mean minimum cooking time, uniformity in color and size of the seeds, absence of fissures, and normal sanitary conditions. For example, Dawson *et al.* (1952) found that when pea beans were stored for 1 year at about 24°C, they required longer cooking time than those stored at 4°C.

Weston and Morris (1953) reported that there were no significant varietal differences in equilibrium moisture values for different varieties of dry beans stored at 25°C in relative humidities ranging from 11 to 75%. It was not possible to obtain equilibrium moisture values for higher relative humidity (80–98%) due to the development of mold growth.

Morris and Wood (1956) showed that dry beans stored for 6 months at 25°C with a moisture content higher than 13% deteriorate significantly in flavor and texture. In 12 months the lipid acid value increased significantly with close correlation to the losses in quality. On the other hand, the samples with less than 10% moisture, stored at 25°C for 2 years, maintained their quality and compared favorably with the control samples stored at −23.3°C.

Burr *et al.* (1968) also concluded that high temperature, high moisture content, and long storage time were the most important factors which increased the cooking requirements of several varieties of dry beans. They found that a moisture content of 10% or less in beans did not impair significantly their cooking quality, regardless of the storage temperature and time. However, at moisture contents higher than 10%, the cooking quality of beans deteriorated, the extent depending on storage temperature and time. Muneta (1964) reported differences in the cooking time of seven varieties of dry beans and of the Alaska pea, after 18 months of storage. This author also found a high correlation between moisture content of beans in storage and cooking time.

Mattson (1946) suggested that the difference in cooking quality among varieties of dry peas was related to their contents of phytic acid and calcium. According to this author, it is possible that when the phytic acid content is low, the pectin in the middle lamella forms insoluble calcium and magnesium pectates which contribute to the poor cooking quality. Smithies (1960) reported a good correlation between cooking quality and the amount of phytic acid in dry peas at low average phytic acid content. Based on these studies, Kon (1968) investigated the possibility that the deterioration in the cooking rate of dry beans stored at high temperatures and high moisture was correlated with changes in the pectic substances present in beans. He found no significant differences in either the amount of total pectic substances or the pectic material fractions extracted from the low and high moisture beans.

Muller (1967) suggested that the softening of peas during cooking occurs through a reaction between Na/K phytate in the cotyledons and the insoluble Ca/Mg pectate in the cell walls, especially those of the seed coats. He analyzed these components in the several samples and indicated that other factors such as the thickness of the seed coat palisade layer and the contents of lignin and α-cellulose in the seed coats were also involved. Crean and Haisman (1963) indicated further that the phytic acid in dry peas is totally water-soluble, and that it is probably stored in peas as the potassium hydrogen salt. They concluded that the effect of phytic ions on texture is small.

Probably the most important drawback in the utilization of dry beans, apart from their relatively high cost, is the long time required by them to soften during cooking. If this is important for the food processor, the problem is more crucial for home economy since cooking of beans requires a considerable amount of fuel and time to reach the optimum cooked condition. Studies carried out by Bressani *et al.* (1963) have shown that to cook dry beans at atmospheric pressure, a minimum of 2 hours is necessary.

B. Organoleptic and Culinary Quality

From studies quoted previously, it is clear that moisture content during storage is one of the most important factors that also affects the culinary properties of dry beans. Morris and Wood (1956) demonstrated that dry beans with a moisture content above 13%, stored at 25°C for 6 months, deteriorated in flavor and texture. They also indicated that in long periods of storage of up to 12 months beans became unpalatable in flavor and texture. However, beans stored at 25°C with a moisture content below 10% kept their quality for 2 years.

Buggs *et al.* (1964) reported on the stability of cooked legume powders, air-packed and stored for various periods at 32°C, as compared to a control that was nitrogen-packed and stored at 34°C. The sensory evaluation by duo-trio tests indicated that flavor changes occurred in the air-packed bean samples. Further studies on this aspect, carried out by Burr *et al.* (1969), revealed that moisture content during storage of the cooked lima bean powder was an important factor in determining flavor deterioration of the product. Their studies showed that cooked lima bean powder stored with a moisture content of 4 and 5% was more stable than the powder with 10% moisture.

Nitrogen packing increased significantly the shelf-life of the product. The addition of 3 ppm of butylated hydroxytoluene was also effective in both air and nitrogen packs. Flavor changes in the nitrogen-packed or antioxidant-treated powder with 4% moisture were detected after 11 months of storage at 22°C or after 7½ months at 38°C.

C. Nutritive Value

There is no specific information on the effect of storage conditions on the nutritive value of dry beans. However, from results of studies carried out for other purposes (Bressani *et al.*, 1963) it is logical to conclude that deterioration of the physical, chemical, and organoleptic properties of dry leguminous seeds will probably affect their nutritional quality, since dry beans stored for long periods of time require excessive cooking or heat processing (Morris and Wood, 1956). Such deterioration can affect the protein quality of beans through a decrease in the amino acid availability, as has been shown for other foods (Liener, 1958; Bressani and Elías, 1968a, b; Altschul *et al.*, 1958; Martínez *et al.*, 1961; National Academy of Sciences—National Research Council, 1950).

VIII. Protein Extraction and Concentration

A. General

Among the first recorded studies on the extraction-fractionation of the proteins from leguminous seeds are those of Ritthausen (1883) and Osborne (1894, 1910). These authors pointed out that salt-soluble globulins are the predominant class of proteins in seeds of *Phaseolus vulgaris*. Since then, this observation has been ratified by various investigators, using 1–3% solutions and extracting over 70% of the nitrogen (Jones *et al.*, 1922a, b; Johns and Finks, 1918; Johns and Waterman, 1920a, b; Jones and Johns, 1916–17; Jones *et al.*, 1937–38; Smith *et al.*, 1959; Powrie, 1961; see also Bondi, 1958; Altschul *et al.*, 1966).

Sodium hydroxide solutions are excellent solvents for the nitrogenous constituents of the legume seeds. Smith *et al.* (1959) reported that 96.4% of the total nitrogen of the kidney bean meals was extracted with 0.01 *N* sodium hydroxide solution. Powrie (1961) was able to extract about 91% of the protein from *Phaseolus vulgaris* using three successive extractions with 0.02 *N* NaOH solution. Differences in the amount of nitrogen extracted may be due to concentrations of sodium hydroxide in the extracting solution, ratio of meal to solvent, presence of other salts such as NaCl, and to species of legume foods (Smith *et al.*, 1959; Powrie, 1961; Haug *et al.*, 1970a; Evans and Kerr, 1963; Pant and Tulsiani, 1969; Zarkadas and Baker, 1965; Zarkadas *et al.*, 1965; Adriaanse and Roberts, 1970). The sodium hydroxide extract may contain up to 10% protein on a dry weight basis but precipitation of the extracted protein at the isoelectric point increases nitrogen content to 15–16%, representing purer fractions.

Haug *et al.* (1970b, c) were able to increase the extractability of nitrogen compounds from pea beans and red kidney beans by treatment with cellulases. Pant and Tulsiani (1969) reported that proteins of considerable purity from *Phaseolus* seeds are best extracted with sodium chloride solution (5% weight/volume) with subsequent dialysis of the extract.

Bell and Young (1970) prepared a pea *(Pisum sativum)* protein concentrate containing 60% protein, by stirring pulverized peas in dilute aqueous calcium oxide solution at pH of 9.3, at room temperature, for 15 min. The protein-rich fraction was obtained from the supernatant by drum-drying. The pea protein concentrate, tested in mice, had low digestibility and biological values in comparison to egg or fish protein concentrate.

The methods for extracting and fractionating the various proteins from legume seeds have also been useful in preparing proteins which are either responsible for toxic effects or else inhibit the action of certain enzymes. Jaffé and Hanning (1965) and Seidl *et al.* (1969) isolated a globulin fraction from black bean *(Phaseolus vulgaris)* which was resistant to hydrolysis by pepsin, trypsin, chymotrypsin, papain, ficin, hurain, and subtilisin. Denaturation of the globulin by heat or urea, only slightly improved hydrolysis by the cited enzymes.

The presence of such proteins in legume foods may offer an explanation for the low digestibility usually reported for this group of foods (Seidl *et al.*, 1969). Even after proper heating, the apparent protein digestibility of black beans is rather low and may be related to the low digestibility of the bean globulin described by these investigators.

B. Protein Concentration

While extraction and fractionation of legume seed proteins is of sufficient interest as a means of learning more about the various factors that influence the nutritive quality of these foods, as well as to characterize the differences which may exist between them, it is doubtful that these procedures may be used directly in food preparations. In this regard, Altschul (1967) indicates that unless other products are obtained from legume seeds, these will not compete with oilseed proteins as components of protein-rich foods.

There are at least two instances where legume seeds are now processed for starch: such is the case of *P. mungo* (Bhumiratana and Nondasuta, 1969) and of guar, used for the preparation of gum (Kawatra *et al.*, 1970). In Thailand, *P. mungo* is processed for the preparation of starch, leaving behind a protein-rich product which is already included in special food preparations (Bhumiratana and Nondasuta, 1969). The process involves grinding and soaking of mung beans to a fine paste, followed by addition of water and separation of the fibrous residue and starch. The protein in solution is coagulated at a temperature of 80°C and at a pH of

4–5, and is then dried or used directly. This product contains 43% protein.

In the case of guar, the meal has been processed further by washing with acid or water, a process which provides a nontoxic product of improved quality (Kawatra *et al.*, 1970). By this process, protein is concentrated from about 46% in the meal to fractions containing up to 49%. However, the concentration of crude fiber is around 11.5%, which, if eliminated, could be reflected in an even higher protein concentration.

Tookey *et al.* (1963) described a dry milling process for the separation of polysaccharides from leguminous seeds, including *Crotalaria intermedia.* The process involves impact grinding, air classification, and screening to separate coarse endosperm particles. The next steps consist of flaking and grinding of the endosperm flour. According to the authors, the yields obtained were over 20% of the original seed weight. Of special interest was the finding that various fractions contained up to 59% protein, in comparison with 30% protein content in the ground seed. Similar results were obtained from the seeds of *C. intermedia, Cyamopsis tetragonoloba* (guar), and *Cassia morilandica.* Although none of the three seeds are consumed by humans, the process is of sufficient interest to be considered for edible legume seeds.

Deschamps (1958) described a procedure for obtaining chick-pea protein. Also of possible practical interest are the findings of Zimmerman *et al.* (1967) who reported that the outer part of the cotyledons of chickpeas and kidney beans, as well as peanuts and soybean, contained more protein, lysine, and methionine than the inner cotyledons' mass. Therefore, by selective grinding or fractionatión, it might be possible to provide protein-rich materials of potentially higher nutritional value.

IX. Prospects

A. Technical

1. *Increased Production*

Pinchinat (1965) stated that the problems related to an increased production of legume foods in Central America could be traced to one or more of the following factors: *(a)* ecological conditions; *(b)* incidence of disease and insects; *(c)* quality of the seed; *(d)* cultural practices and handling of the crop, and *(e)* poor relation between demand and production. Agricultural practices are completely improper because most legumes are grown on small plots that interfere with the adoption of improved techniques which obviously need large investments. For example, in Guatemala 73% of the bean production in 1950 was on farms varying in size between 1 and 32 hectares.

Some efforts are under way in various areas of the world to increase legume production. These include increased acreage in areas best suited for bean production, development of better varieties, increased agricultural credit, agricultural extension, and improved marketing. The results of these efforts definitely show that by means of new agricultural technologies and interest, it is possible to substantially increase yields. For example, Miranda Colin (1966) reported that production in 1952 in Mexico amounted to approximately 235,000, increasing to about 680,000 tons in 1962 by implementing better agricultural practices.

Similar increases have been reported from Brazil as shown by regions in Table IV (Comissão Nacional de Alimentação, 1969), Colombia (Camacho *et al.*, 1968), and from Central America (Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos Alimenticios, 1969).

The exponential projection of bean production in the different regions of Brazil, from 1970 to 1980, is shown in Table XV. The average rate of the annual increment in the national bean production is in the order of 5.3%; the average rate of annual increment for the different geographical regions ranges from 1.6 to 8.1%.

If technological advances in plant breeding and seed selection combined with improved agricultural practices have in many countries served to provide substantial increases in the cereal grain and oilseed yield per acre, consistent and organized research efforts should give similar results with the grain legumes; some evidence in this regard has already been published (Miranda Colin, 1966; Miranda, 1969; Inter-American Institute of Agricultural Sciences of the OAS, 1971; Camacho M., 1968). Much more research in agricultural aspects and food science and technology is required on legumes to increase yield. Cultivars with better yields than the current varieties must be found or developed to have better soil nutrient utilization, resistance to disease and to insect attack, and better interaction with the nitrogen-fixing bacteria. Agricultural research should also determine the best crop management practices in terms of soil preparation, moisture and nutrient needs, as well as insect and weed control. There is no question but that the primary influence affecting the relative role of legumes, particularly in underdeveloped countries, is the ability to increase yield, and this is the first priority.

2. *Changes in Composition*

Since cereal grains supply most of the caloric intake and significant amounts of protein, research on legume foods should concentrate on making them more efficient protein complements to cereal proteins. However, there are areas of the world where cereal grains do not supply the needed calories. In such places starchy roots replace cereal grains; it is

TABLE XV

EXPONENTIAL PROJECTION AND AVERAGE RATE OF ANNUAL INCREMENT IN BEAN PRODUCTION BY GEOGRAPHICAL REGIONS IN BRAZIL

Region	Exponential adjustment (tons)			Average rate of annual increment (%)
	1970	1975	1980	
North	13,104	16,059	19,681	4.1
Northeast	1,009,888	1,492,096	2,204,550	8.1
Southeast	436,890	401,675	369,298	1.6
South	1,156,920	1,682,711	2,447,461	7.8
Middle east	218,253	294,464	397,286	6.2
Brazil	2,771,083	3,589,336	4,644,025	5.3

precisely in those areas where legume foods should provide, almost in a mandatory way, not only more protein but also higher amounts of the limiting nutrients in legume foods, that is, the sulfur-containing amino acids.

As stated in an earlier section, numerous unrelated results suggest that there is sufficient variability to select the better-quality legume foods not only in respect to a better balanced nutrient content, but also in regard to lower levels of physiologically adverse substances.

3. *Improved Nutrition*

In other sections of this chapter, various approaches are presented that suggest possible available ways to nutritionally improve legume foods. This improvement in their nutritional quality would then have a definite impact in improving the overall quality of the diets, of which they are an important constituent.

Aside from the antinutritional factors present in legume foods, their main limitation, insofar as protein quality is concerned, lies in the sulfur-containing amino acids. Therefore, their addition to the legumes in varying amounts, up to 0.3%, has caused significant improvements in the protein quality of legume proteins.

For practical applications, however, it is essential to consider various aspects of the diet, of which beans form part, before concluding that the addition of methionine to legume foods—which improves their quality—will also improve the quality of the diet. These aspects are: *(a)* the level of beans in the diet to ascertain how much protein it contributes to the total protein content; *(b)* to determine whether the other components of the diet are cereal grains, and *(c)* if they are starchy foods, such as cassava flour.

The mutual supplementation of each other's amino acid deficiencies in mixtures of legumes and cereals has already been discussed in Section VI. We discuss here the question of adding a third component to the mixture, one or more amino acids. This point is well illustrated by Fig. 1. There is a point of maximum complementation between corn and bean protein that takes place in diets where 50% of the protein is equally derived from corn and beans. If the protein contribution of corn to the diet exceeded 50%, lysine became the most limiting amino acid. On the other hand, if more than 50% of the protein of the diet was derived from beans, methionine became the limiting amino acid. From these findings it is obvious that if the other component of the diet is a low-protein-containing starch food, beans provide practically all the dietary protein; thus, the diet is limiting in the sulfur-containing amino acids.

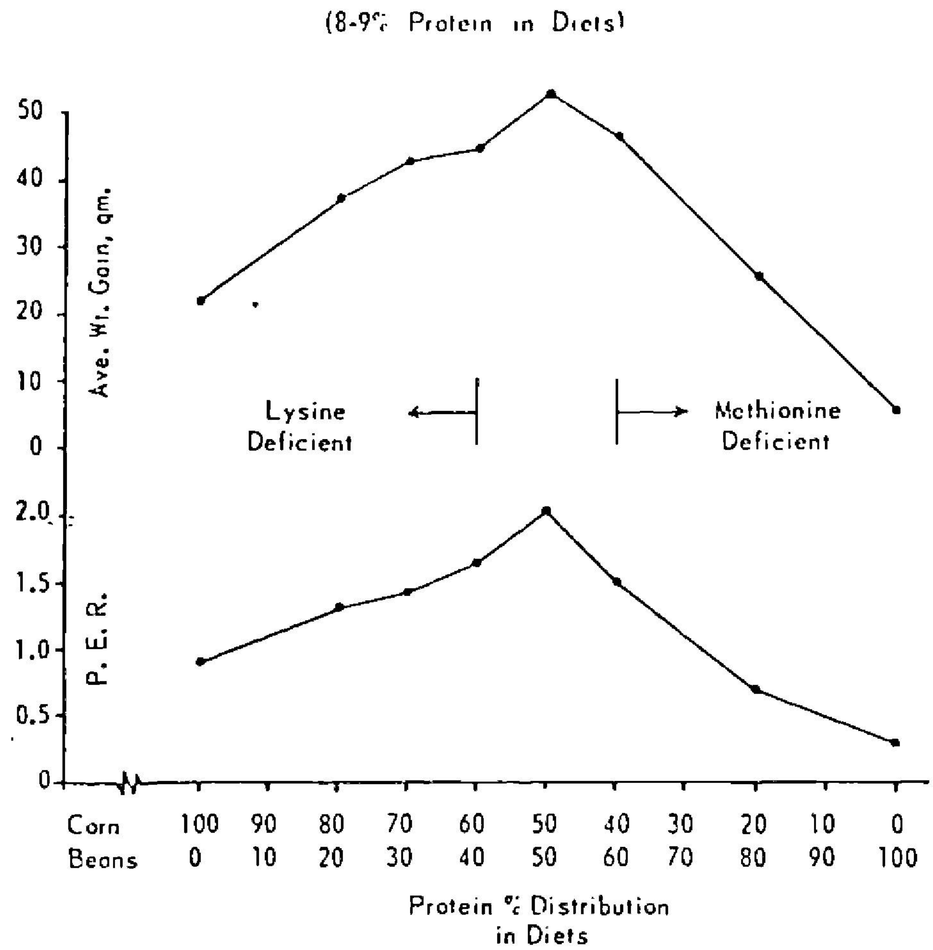

Fig. 1. The complementation of the amino acids of corn and beans. Rats were fed diets containing 8–9% protein in which corn protein was replaced isoproteically by *Phaseolus vulgaris* (Bressani *et al.*, 1962).

TABLE XVI

EFFECT OF LYSINE, TRYPTOPHAN, AND METHIONINE ON THE PROTEIN QUALITY OF A CORN–BEAN DIET[a]

Diet[b]	Average weight gain (g/28 days)[c]	PER
Corn with no lysine or tryptophan + beans with no methionine	69	2.11
Corn with lysine and tryptophan + beans with no methionine	103	2.64
Corn with no lysine or tryptophan + beans with methionine[d]	66	1.93
Corn with lysine and tryptophan[e] + beans with methionine	108	2.69

[a] Data from Bressani (1972a).
[b] 72.4% corn + 8.10% beans (Bressani, 1972a).
[c] Average initial weight: 44 g.
[d] 0.30% DL-Methionine.
[e] 0.30% L-Lysine HCl; 0.10% DL-tryptophan.

In the case of some Latin American diets, corn supplies more than 50% of the dietary protein, as compared to beans; therefore, the diet is deficient in lysine and tryptophan, which are the limiting amino acids of corn proteins. This is illustrated in Table XVI where a 72% corn–8% bean diet was supplemented with lysine, tryptophan, and methionine (Bressani, 1972a).

The results show that a response was obtained by the addition of lysine and tryptophan, but not of methionine, whether added alone or in the presence of the other two amino acids. This indicates that corn has sufficient sulfur-containing amino acids to meet these deficiencies in beans. The other two, lysine and tryptophan, are deficient because corn protein is limiting in these amino acids, and tryptophan is also low in legume foods. Similar results have been obtained in the case of other legume–cereal mixtures such as rice and beans (Bressani and Valiente, 1962), and wheat and beans (Carpenter, 1970). (See Section VI, B, this chapter).

As indicated previously, bean-starch food diets would be of higher quality if the bean proteins were supplemented with methionine. Still, the total protein intake would not probably be sufficient. A possibility, explored at the laboratory level, is to increase the methionine as well as the protein levels in beans, through the addition of 8% soybean protein to cooked beans. Results for corn–bean diets, as illustrated in Table XVII, show that a highly significant response was obtained in the weight gain of rats fed the diets containing either increased levels of beans or 8% of the high-protein beans. Similar results have been achieved by the addition of sesame flour to cooked beans (Elías *et al.*, in preparation).

Supplements such as those described herein could possibly be added to industrially prepared bean powders or as simulated bean kernels (Bressani, 1972b).

TABLE XVII

EFFECT OF BEAN PROTEIN QUANTITY AND QUALITY ON THE NUTRITIVE VALUE OF CORN–BEAN DIETS AS CONSUMED IN GUATEMALA

Treatment to basal diet[a]	Average weight gain (g/day)	Average food intake (g/day)
8% Cooked beans	2.26	14.9
8% Cooked beans + DL-methionine	2.31	13.7
18% Cooked beans	4.74	16.2
8% Cooked beans + 8% soy protein	7.23	20.2

[a] 72.4% Lime-treated corn + 8.1% black cooked beans (Bressani, 1970).

4. *Preprocessed and Convenience Foods*

It is believed that one of the most practical ways to find a privileged place for a new food in the market is to make it more convenient for the housewife. If this statement applies to other foods, there is no doubt that it would also apply successfully to dry beans. Advances in food technology have permitted the development of different methods for the preparation of attractive dry-bean products. The majority of the research work in this area has been focused on reducing cooking time and in maintaining a good and acceptable physical appearance of the final product.

Esselen and Davis (1942) prepared dehydrated baked beans which could be reconstituted by rehydration with cold water; after heating for 90 min the product was ready to eat. Feldberg *et al.* (1956) developed a process for "quick" cooking pea beans which consists in soaking them for a period of 8 hours, followed by cooking for 20 min at 250°F. To avoid "butterflying" or fissures of cooked beans during drying, the authors also investigated freezing and dipping them in a sugar solution. The final product was ready for consumption after rehydration and a cooking time of 5–10 min. A blanching step before soaking was recommended by Dorsey *et al.* (1961) in order to destroy lipoxidase activity and also to accomplish complete hydration.

Steinkraus *et al.* (1964) pointed out that these methods imply certain disadvantages both in terms of cost and of the product's quality. These investigators developed a process for the production of precooked dehydrated beans which involves hydrating the dry beans by soaking in water, precooking in steam, coating, and dehydrating. The processed beans are ready for consumption after covering them with hot water followed by boiling for 30 min. The main features of this process are: *(1)* the loss of bean structure that normally occurs during cooking and drying is economically controlled; *(2)* the characteristics of baked-bean flours as well as their flavor are obtained without any baking step; *(3)* by varying the concentration of dextrose on the coating mixture, the brown color produced can be controlled; and *(4)* dry beans stored under adverse conditions and requiring increased cooking rates can also be utilized to produce a final product of good quality when rehydrated.

Subba Rao *et al.* (1964) reported that pressure cooking is more effective in increasing the cooking quality of pulses than the method of soaking them in a solution of inorganic salts such as sodium bicarbonate, trisodium phosphate, and ammonium carbonate.

Rockland and Metzler (1967) developed a process for preparing quick-cooking lima and other dry beans which consists of: *(1)* intermittent vacuum treatment, named hydravac process, for 30–60 min, in a solution of inorganic salts, *(2)* soaking for 6 hours in the same salt solution; *(3)* rinsing; and *(4)* drying. The solution of inorganic salts utilized was composed of sodium chloride, sodium tripolyphosphate, sodium bicarbonate, and sodium carbonate. Cooking time of the dry-processed beans varies between 25 and 35 min depending upon variety, previous history, and processing conditions. These investigators point out that the process minimizes the number of split "fishmouth" and "butterflying" beans which occur in the drying step, and that the nutritional value of the protein in the processed material is not altered. Further studies by Rockland and Gardiner (1969) report modifications of the quick-cooking dry-bean process, to prepare frozen, hydrated common beans. According to this procedure, the cooking time of the final product varies from 10 to 20 min depending on the bean variety and processing conditions. They also studied the effect of the individual components of the inorganic salt solution in order to reduce chemical costs.

The use of papain in the preparation of quick-cooking beans has been reported by Bathia *et al.* (1967) who found that treatment of cooked beans with papain results in a product which, in a short time, reconstitutes to a smooth slurry. They also state that the use of sodium chloride has some disadvantage on the stability of the product because it results in rancidity.

Brown and Carlson (1969) studied the effect of several drying conditions and their effects on the appearance of quick-cooking dry beans. They concluded that appearance of the quick-cooking bean samples was only slightly affected by the drying procedures and that the bean quality seems to be more important in product quality, with special reference to lima beans.

Since cooking quality is one of the most important aspects taken into consideration by the food processor, Bourne (1967) devised a method to separate hard-shell beans from normal beans. The procedure is based on the fact that the size distribution of a given lot of dry beans follows a normal distribution pattern, but the hard-shell beans are concentrated in the smaller sizes. Rejection of the smallest 20% of the unsoaked beans removed 70% or more of the hard-shelled. On the other hand, during soaking, normal beans imbibe water and swell while hard-shell beans do not swell and are further concentrated into smaller sizes. By size-grading again after soaking, hard-shell beans can be practically eliminated from normal beans, resulting in better quality products.

B. Role

1. *Relation to Animal Products*

The role of legume foods in relation to animal products may be discussed from various points of view. The analysis is different when the role is analyzed within dietary habits and culinary practices as carried out in developing countries in contrast to developed areas. In the latter, it would appear that legume grains will never constitute important food items as nutrition sources, while in the former, legume foods already play a considerable role. In the less-developed countries, legume foods provide a substantial part of the protein intake and, because of this, significant efforts are being made in many areas to solve the production problems that have limited their availability.

Dry legume foods contain 25% or more of protein per unit of weight, and the cost of 1 kg of bean protein generally is one-tenth of that of beef protein. This could be the reason why, even in more-developed countries, soybean protein is being utilized to produce simulated animal protein foods that range from milklike beverages, to chicken, meat, and fish. From the nutrition standpoint as well as from the use made of them at the dining table they already have taken the place of animal products, particularly in those regions where the latter are costly. Therefore, their use may well increase further if the limiting factors are corrected, particularly those concerned with production, with the undesirable physiological effects they cause, and with digestibility.

When viewed from the chemical composition angle, including their amino acid content, legume foods contain as much protein or more than beef, as well as more calories, although fat calories are lower in legume foods than in beef. Both protein sources do not differ much in their essential amino acid content, particularly in regard to lysine, and, although beef protein has a higher sulfur-amino acid content, both protein sources are limiting in this amino acid. Since legume foods are usually consumed together with cereal grains, these in most cases are able to supply enough sulfur-containing amino acids to partially meet this deficiency in legume foods. Therefore, from this point of view, it appears that the diet based on legume foods consumed by people is not significantly poorer than the one containing beef. The similarity, however, is applicable only to beef protein and not to other animal protein sources.

Finally, legume foods could be highly valuable as constituents of supplements of animal feeds, either in the form of grains or pastures (Reem, 1967).

Some legume foods, for example field peas *(Pisum sativum),* have been fed quite extensively to swine and poultry in various areas of the world to replace soybean protein (Bell and Young, 1970; Bell and Wilson, 1970; Moran, Jr. *et al.*, 1968). Levels as high as 30% of the diet have been recommended with acceptable results. Although this recommendation obviously does not apply to those areas of the world where legume foods are important protein sources for human consumption, particularly in the case of legume foods of popular use, there are other legume foods which could also be utilized for such a purpose.

2. *Relation to Modern Oilseed Products*

Legume foods may play various important roles in relation to oilseed products. One possibility is to extend the availability of oilseed proteins in the form of protein-rich foods, as shown in a previous section of this chapter. Because oilseed proteins are by-products of the vegetable oil industry, the cost of legume food protein is probably higher than that from oilseeds. However, legume foods have the advantage of being recognized as human foods, while oilseed proteins, as such, are not. This situation carries both advantages and disadvantages for the oilseeds. Because they are an industrial crop they can be transformed into animal food analogs, as mentioned earlier, and this could be an advantage as the demand for such foods grows. But this requires all the accessories of an industrial food operation, not easily achieved in many less-developed countries. In such areas legume foods have the advantage over oilseeds.

C. Conclusion

Food scientists, with the help of plant geneticists, should find cultivars with a higher nutrient content, with lower levels of physiologically adverse substances—either trypsin inhibitors, hemagglutinins, or flatulence factors—with higher digestibility, and with more desirable culinary characteristics. Food scientists should also study the physical and functional properties of legumes to favor preparation of food products of a pleasing flavor, odor, and appearance so as to make them highly acceptable by the consumer.

We believe that if the previously mentioned technological aspects are taken into account, in those regions of the world where beans constitute an essential part of the dietary habits, their future offers great hopes. In other areas, better technology will permit legume foods to compete more successfully against the sophistication of other foods.

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