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GRAIN QUALITY OF COMMON BEANS

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INTRODUCTION

Food grain legumes represent the main supplementary protein source in the starchy food-based diets consumed by large sectors of the population living in developing countries. Their nutritional value is, therefore, of the greatest importance, particularly since their intake is less than desirable for those population groups who require better protein quality in their diets. Since the topic to be reviewed is quite broad, it is necessary to focus on one food grain legume, assuming that the research on common beans, *Phaseolus vulgaris*, is in general applicable to other food grain legumes and vice versa.

A number of reviews have been published on various aspects of food grain legumes such as chemical composition and nutritional value (1–4) and their chemistry and technology (5). More specific topics such as grain legume carbohydrates (6), the nutritional implications of tannins (7), the influence of storage and processing on textural defects (8), enzyme inhibitors (9, 10), flatulence factors (11), and the physiological effects of legumes in the human diet (12) have also been reviewed.

This paper discusses the importance of arriving at grain quality characteristics in food grain legumes, an activity which requires the participation of breeders, agronomists, food scientists and nutritionists.

THE GRAIN QUALITY CONCEPT

Until very recently, bean breeders paid little attention to bean grain quality, a concept which reflects the needs and expectations of producers, processors, consumers, and nutritionists. The concept was introduced in breeding programs for cereal grains, mainly wheat, in response to the demands of the processing sector, who needed not only high grain yields but quality for milling, product manufacture, and consumer acceptability. Today this concept is being developed for many other food crops, including cereal grains, root crops, food grain legumes, fruits, and vegetables (13–17).

Grain quality characteristics include a number of desirable attributes related to production and postharvest technology, as well as to the physical, chemical, technological, and nutritional properties of the grain, which are not necessarily related to each other, nor to yield. In many cases, these grain quality characteristics are not well defined and are difficult to measure. Therefore, the first step is to identify the desirable grain quality characteristics, and to define them in physical, chemical, technological, and nutritional terms. Only then can appropriate methodologies be developed to quantify them. The problem presents many obstacles for most food grains, and significantly more so for food grain legumes, due to the complexity of their chemical make up (1–7), their behavior during storage (8) and processing, and to the varied preferences of consumers (17–20).

GRAIN QUALITY OF BEANS

Information on some grain quality characteristics for common beans, from production through consumption, is given in Table 1. In production, the farmer expects high and stable yields of beans which he can market at an attractive price. These attributes are obtained through breeding for disease resistance and pest control, and through the development and application of acceptable agricultural practices. The farmer wishes to have, at harvest time, pods which reach their physiologically mature state at the same time, varieties that have a short growing period, with seeds easily separated from pods of uniform size and color. Upon storage, the farmer wishes to have beans that are resistant to insect attacks, retain their color, and perhaps most important, have a slow development of the undesirable hard-to-cook condition. The user, whether a housewife or the food industry, wishes to process a bean that is rapidly hydrated, has a short cooking

Table 1. Identity of Some Grain Quality Characteristics for Common Beans (*Phaseolus vulgaris*)

Area	Attribute
Production	High and stable yields Homogeneous pod dry-down
Harvest	Good separation and recovery of grain from pod Uniform seed size and color
Storage	Resistant to insects and to development of hard-to-cook conditions Color stability of seed
Processing (home and industrial)	Rapid hydration Short cooking times Thick cooking liquor Color stability Low seed coat content
Biological utilization	Good acceptability (site specific) Free from antinutritional factors High digestibility and protein quality

time, and produces a thick cooking liquor with good flavor and texture. The bean should also have moderately split grains, with thin seed coats and good color stability. Finally, to help in providing nutrients to the individual, the beans must have good acceptability, a very difficult characteristic to identify, since it depends on the cultural background of the consumer.

Processing should effectively eliminate antinutritional factors without affecting bioavailability of other nutrients. Common beans should also have a high nutrient availability, particularly protein, and be effective supplements to other staple foods, particularly cereal grains. The task is to attain these and other attributes through their identification and definition, and through the development of appropriate methodologies for evaluation. This requires a multi- and interdisciplinary approach, involving agricultural scientists and scientists working in food science and technology, as well as in nutrition.

COMPONENTS OF GRAIN QUALITY OF COMMON BEANS

As with most grains, bean grain quality in terms of utilization falls into three large areas, as shown in Table 2. These are: yield (which is not a subject of this review), consumer acceptability, and nutritional value. The latter two characteristics are very difficult to define and controversial to measure since they depend to a large extent on culture, life-style, and the food consumption patterns of different populations. In any case, the consumer's likes and dislikes are basic in determining the acceptability characteristics of the raw grain and its processed

Table 2. Components of Acceptability and of Nutritional Quality of Common Beans

Acceptability components
- Appearance, color, flavor, size (society specific)
- Cooking time (hard-to-cook)
- Texture
- Food-derived products
  - -Cooking liquor
  - -Fried beans
  - -Color
- Integrity of bean after cooking

Nutritional components

Positive
1. Nutrition-related
   - Adequate protein content
   - High lysine content
   - Excellent supplementary protein to cereal grains
2. Health-related
   - Good source of dietary fiber

Negative
1. Antinutritional factors
   - Enzyme inhibitors
   - Hemagglutinins
   - Flatulence factors
   - Tannins
   - Phytic acid, saponins
2. Nutrition-related
   - Protein digestibility
   - Sulfur amino acid deficiency
   - Dietary fiber
   - Carbohydrate bioavailability

products. Of all acceptability characteristics, cooking time is, without doubt, the most important. Additional acceptability attributes include the color and thickness of the cooking liquor, the cohesiveness of fried beans, and the particle size and color of the products. The integrity of the bean after cooking is of importance in industrial applications, and possibly at the household level.

The nutritional components of acceptability, some of them not recognized by the consumer, have been classified into positive and negative factors (Table 2). The *positive factors* are nutrition-related and include an adequately high protein concentration level containing high amounts of lysine, so that it becomes an excellent protein supplement to cereal grains. Methionine content should also be higher since it is the limiting amino acid in legumes. The health-related positive attributes include the hypocholesterolemic and hypoglycemic effects that bean consumption has, possibly because of beans' high dietary fiber content.

The *negative factors* have been classified into two groups: (*a*) the antinutritional factors, which include the enzyme inhibitors, hemagglutinins, flatulence factors, tannins, saponins, and phytic acid; (*b*) the negative nutrition-related factors, including low protein and carbohydrate digestibility, sulfur amino acid deficiency, and probably dietary fiber. Although dietary fiber is today a subject of much interest for populations in the developed world, its significance for populations in developing countries must be studied and considered in greater detail since the diets consumed in developing countries are made up to a very large extent of vegetable foods providing sufficient fiber. Furthermore, consideration must be given to the implications of dietary fiber in reducing bioavailability of nutrients in diets which very often are of poor nutritional quality.

EFFECTS OF PROCESSING

The nutritional quality of food grain legumes has been the concern of many food and nutrition scientists, because the nutritional quality of grain legumes cannot be predicted from their chemical composition. The main reason is that food grain legumes contain relatively large amounts of enzyme inhibitors and other antiphysiological substances, which interfere with the biological utilization of the nutrients, beginning at the gastrointestinal level (21–32).

Thermal processing destroys the antiphysiological substances and is, therefore, mandatory for the evaluation of the nutritional quality of beans. However, processing, and particularly thermal processing, may also damage the nutritional quality of food grain legumes if conditions are not well defined and controlled. Therefore, the evaluation of the nutritive value of food grain legumes must consider their chemical composition as well as the conditions used for processing.

Once having determined the processing conditions for optimizing nutritional quality of grain legumes, this knowledge can be transferred to the homemaker and to food processors as well as to the plant breeder interested in developing varieties with appropriate acceptability and nutritional quality. Although the main reason for processing is to render the grain soft for consumption, the effects must go beyond changes in physical structure and texture and include inactivation of toxic factors, without decreasing nutritive value.

At least six methods are used for processing food grain legumes. The most common is cooking in water, using whole or dehulled grain. This is conducted at atmospheric pressure or under pressure, with or without previously soaking the grain. Cooking can also be conducted under dry conditions at high temperature for a short time by extrusion cooking or solid-to-solid heating. Other methods include germination and fermentation, dehulling and milling, and more recently, irradiation.

Moist Cooking

The most common method of preparing common beans for consumption, as well as many other food legumes, is by cooking in excess water to allow for hydration of the beans. Table 3 describes the various home cooking practices. These simple steps may be conducted at atmospheric pressure or by the use of a pressure cooker (18, 20). The cooking may be done on whole dry beans, whole soaked beans, or dehulled beans. However, studies conducted in Guatemala show that only from 7% to 17% of the households surveyed used a soaking treatment (18).

In some specific situations, salts are added. Thus, a mixture of sodium carbonate and bicarbonate (1:1) is used in processing cowpeas (33). These salts plus citric acid (34) are used in preparing horse gram (*Dolichos*). Salts have also been used for the preparation of quick-cooking beans by soaking the grains in salt solutions (35, 36). The objective of the process is to make beans soft for consumption, and the objective of variations in cooking procedures is to reduce as much as possible the time needed for achieving softness. Dehulled beans cook faster than whole beans (37). Likewise, beans which have been soaked with or without salt prior to thermal treatment cook faster (33–38). These salts probably facilitate uniform penetration of water into the center of the grain legume and into the cell structure. However, there may be changes in color and flavor that render beans totally or partially unacceptable. Pressure cooking is obviously a faster cooking process than cooking at atmospheric pressure.

The products of the moist-cooking process include the cooked beans and the cooking liquor (39). The cooking liquor may be separated from the cooked beans and used to feed young children (18), or if left with the cooked grain, it is consumed as such or further processed. In rural areas of the Central American countries, a 3-day supply of beans is prepared in one batch. The beans which remain with the cooking broth after the first day's consumption are reheated as many times as required, until the original batch has been consumed; this home cooking method requires less energy as compared to cooking beans every day (40).

Table 3. Moist Cooking of Beans: Process and Variables

Process	Variables		
1. Raw beans	Whole or dehulled		
2. Water addition	Dry or soaked		
3. Additives	None or salts		
4. Cooking	Atmospheric pressure	or	under pressure
5. Product: cooked beans + cooking liquor	Mashed		Sieved
	[+ Fat and heat; fried beans]		

Some societies further process the cooked beans into different products such as strained beans (with large amounts of the seed coat removed), which have a thick consistency (39). Further cooking with oil yields fried beans, which have a paste consistency (39). Fried beans are also prepared from ground cooked beans, from cooked bean powder, or from quick-cooking beans (41).

The other much used moist process, particularly in developed countries, is canning (42). In general, dry beans are hydrated to a 50% level by soaking for 10–18 h. This is followed by sorting, canning in 2% hot brine solution, exhausting in a vapor tunnel, and thermally processing in a retort, at 15 lb/in.^{2} for about 20 min (121°C). Bean type and processing variables influence quality attributes and nutritional value (43–45).

Mechanism of Cooking

Due to the relatively long period of cooking required to make beans tender and acceptable for consumption, it is necessary to understand the physical and chemical events taking place during cooking. Hydration of beans, whether for home or industrial cooking or for canning, is an important and basic property for cooking. In addition to softening the seed, water participates in chemical reactions, heat transfer, and chemical transformations such as protein denaturation and starch gelatinization. Water penetration encounters at least three physical structures of the bean grain. The first is the seed coat; the second is the middle lamella, which keeps individual cells together; and the third, the cell wall keeping the cell together. Not all varieties show similar hydration patterns. The most common exhibits a fast water uptake at the beginning of hydration and reaches a plateau at the end of hydration. Various investigators (44–51) have found different hydration times among bean varieties. Weight doubling usually takes place in about 7 h; however, some varieties require two or three times as much time (44–51). Norstrom and Sistrunk (43, 52) found that a low original moisture level in the bean resulted in higher hydration rates. However, Burr, Kon, and Morris (53) reported that high-moisture beans that had been held in storage absorbed water somewhat faster than similar beans of low moisture content.

The passage of water through the surface of the bean is limited first by the permeability of the seed coat. Bourne (54) observed that during water soaking of beans from 16 to 18 h at 21°C, hard-shell beans as well as small beans absorbed less water. Furthermore, rejection of the smallest 20% of the beans removed 75% or more of the hard shells.

The route of water penetration into the bean seed is controversial. In common beans (*P. vulgaris*) three structures have been proposed as possible sites of water penetration. These are the hilum, the microphyle, and the raphe. The entry of water into the seed structure has been reviewed by Swanson et al. (55), who observed that structural changes occurred during water imbibition. Hydration rate is increased by using hot water (44, 48, 56, 57), pressure (58), and vacuum (59) as well as additives (34–36). Table 4 shows the effect of altitude on water uptake over time for the same variety of beans. Heating increased the rate of hydration and reduced the differences due to atmospheric pressure (58).

The physical characteristics of the seed appear to be important for water absorption. Several studies (56, 60–64) reported that water absorption depends on the microstructure of the seed coat, microphyle, hilum, and protein content. However, Agbo et al. (47) found that neither protein nor starch content differences could explain the variable water uptake among cultivars. Decortication increases water uptake (51). The seed coat thickness and the size of the hilum have the greatest effects on water absorption by the seed (62–64) during the first 12 h of soaking. Tannins have also been reported to affect water uptake in a negative way (65).

The second barrier that water encounters for cell penetration is the middle lamella, which breaks down upon cooking and is partially responsible for seed softening. Numerous other factors are also believed to influence the texture of water-soaked legumes (62–64). Some of these factors are of a physical nature and some of a biochemical nature catalyzed by heat upon cooking.

Pectins are the main chemical constituents of the intercellular middle lamella, which probably exist as an insoluble polyelectrolyte gel with cross-linking

Table 4. Percent Water Absorption of Beans at Room and Boiling-Water Temperatures at Different Altitudes

	At boiling-water temp.			At 22°C		
Minutes	2256 masl[a]	1524 masl	229 masl	2256 masl	1524 masl	229 masl
0	5.7	5.7	7.1	5.8	5.7	6.7
10	27.0	24.4	34.7	7.2	9.4	11.3
20	34.8	37.5	46.1	8.3	13.1	19.5
30	38.6	43.3	50.7	10.8	11.1	18.1
40	44.4	46.6	55.6	14.5	12.6	18.8
50	47.8	53.2	57.3	13.7	15.1	25.4
60	54.1	51.9	59.0	10.0	19.3	24.9
70	56.2	56.5	59.7	16.3	19.3	25.3
80	56.5	57.9	61.3	13.0	20.8	31.9
90	58.0	59.7	61.2	15.6	21.3	32.3
100	59.2	57.8	67.7	15.4	28.9	32.4

From R. Bressani, Ref. 58: Effect of altitude of cooking on the nutritional quality of common beans.
[a]masl: meters above sea level.

provided by divalent cations such as calcium (66). The change in the solubility of pectin substances during cooking might involve the removal of calcium ions interacting with the pectins (67, 68). Phytic acid being a chelating agent, it diffuses from the cell during cooking, and after passing the cell wall may remove divalent cations, which will result in the solubilization of the middle lamella (69–71).

Upon heating, a number of physical changes take place. Hahn et al. (72) used light and scanning electron microscopy to characterize intracellular configurational changes of starch granules during gelatinization of standard and quick-cooking lima bean cotyledons. Intracellular gelatinization of starch was initiated at about 76°C for water-soaked, and at 85°C for quick-cooking beans. Rockland and Jones (73) found changes in cell wall and cell structure of cotyledons from large lima beans. They also reported resistance of cooked bean cells to fracturing, as did Silva and Luh (74). In boiling water, starch granules, the main structural components of the cell, gelatinized within the intact cell; and increasing numbers of granules gelatinized with increasing temperatures and became more uniform in appearance. Other physical changes include losses in protein solubility and leaching of soluble constituents and electrolytes (75–79). The loss of solids, which differs among bean cultivars, starts when beans are soaked (if this is done) and increases on cooking (75, 79, 80). Minerals are also lost, particularly K and P, and Mg to a lesser extent (76, 79, 81–83). The events described probably take place almost simultaneously during cooking, or immediately after a certain degree of hydration has taken place.

Changes in Enzyme Inhibitors

Food grain legumes are known to contain relatively large amounts of various enzyme inhibitors and toxic compounds, most of which are inactivated upon processing. This topic has been reviewed recently by Van der Poel (10).

Cooking at atmospheric pressure, cooking under pressure, and canning reduce trypsin inhibitors. The disappearance is temperature and time dependent. Cooking for 90 min at atmospheric pressure reduced 100% of the trypsin inhibitor (TI) activity (84). This is important since most bean cooking is done at atmospheric pressure in developing countries. Similar results have been noticed by other workers (10, 21–25, 29, 30, 32). Pressure cooking, usually conducted at 121°C, results in different levels of inactivation of TI, depending on time of exposure. Yadav and Liener (85) found 55% inactivation within 5 min, and 100% inactivation within 30 min of pressure cooking.

The same inactivation takes place for hemagglutinin activity (10, 20, 26, 28, 86, 87). Antunes and Sgarbieri (86) found lectins to be inactivated after 15 min at atmospheric pressure, and at 7.5 min under pressure. Amylase inhibitors are also inactivated by heat processing, but they seem to be somewhat more resistant than the other antinutritional factors (25, 31, 32, 88).

Changes in Tannins

The tannin compounds in common beans are heat-stable substances which have been shown to affect the utilization of the nutrients in beans.

The tannin content of beans has been determined by a number of researchers. Ma and Bliss (89) reported that beans with a bronze testa color contained, on the average, 7.80 mg/g of catechin equivalent; beans with a black testa color, 6.65 mg/g; and white beans, 2.31 mg/g. In another set of samples, they found red beans to contain 12.56 mg/g. Similar values have been reported by others (7, 90–92). Ma and Bliss (89) found the cotyledons to have only small amounts of polyphenols. Bressani, Elias et al. (90, 93) showed seed coats of black beans to contain higher amounts of polyphenols than red seed coats, and white to contain only small amounts. Upon cooking, polyphenolic compounds undergo a redistribution, with higher amounts present in the cooking broth (90, 94) than in the cooked beans. Polyphenols in cooked as compared to raw beans, analyzed without the cooking liquor, show losses which range from 18% to 50% (90, 92, 95). Changes in polyphenol content begin to take place upon soaking and increase with cooking, more so if cooking is done under pressure (80, 90, 95). Only part of the polyphenolic compounds not recovered from the analysis of the cooked grain is present in the cooking broth (82, 83, 90, 94). Bressani and Elias suggested that the unaccounted losses could be polyphenolic compounds which bind to protein during cooking. This would also make protein unavailable to enzymatic attack (90). Absorption spectra of heated water extracts of beans show an increase in condensed tannins, which would bind protein (96). Spectrophotometric absorbance curves at 285 mm (UV) show a reduction in peak number, from 7 peaks for the untreated extract to 4 peaks for the cooked extract, with an increase in the condensed tannin peak. This would partially explain the low tannin recoveries found.

Changes in Phytic Acid

Food grain legumes contain from 0.28% to 2.0% phytate, and values for *Phaseolus vulgaris* vary from 0.74% to 2.10% (97–99). Phytic acid in the cotyledons of grain legumes represent about 98.5% of the total phytate in the seed (100). Phytate is generally considered to be fairly heat stable, and cooking in water without any previous treatment, such as soaking, does not result in substantial losses. A number of authors (101–103) found that various treatments could reduce the phytic acid content of beans; however, some degree of autolysis is necessary. This can be accomplished by the addition of phytase, germination, fermentation, and soaking. Reddy, Balakrishnan, and Salunkhe (104) found germination to reduce phytic acid, but cooking whole beans or bean cotyledons in water at a 1:4 ratio for 45 min did not show any breakdown in the phytate phosphorus. These workers found some losses of phytate at the beginning of cooking, but as cooking continued, losses decreased, as if reabsorption were taking place. Kumar et al. (105) also reported losses of phytin content during germination and no appreciable change in phytin P/total P upon cooking. Similar results were reported by Tabakhia and Luh (106), who found some reduction upon canning. Others (107–110) reported similar results in food grain legumes other than *Phaseolus vulgaris*, that is, only small, nonsignificant reductions in phytic acid upon cooking. Iyer et al. (111) found a reduction in phytate during the combined process of soaking and cooking. This has also been reported by Sathe and Salunkeh (112). These workers indicate that soaking and cooking may remove 50–80% or more of the endogenous phytate in bean seeds.

Other Changes

Although food grain legumes are better known for their protein and antiphysiological substances, including oligosaccharides or flatulence-producing sugars, they are also relatively good sources of Ca, P, Fe, and K; and of thiamine, riboflavin, and niacin. Little research, however, has been done on the retention of these minerals and vitamins during the traditional water-cooking methods utilized in the home. Variable amounts of leachates result during domestic-type cooking or other types of wet cooking. Bressani et al. (80), working with common beans, found losses of solids ranging from 8.0% to 10.3%. This loss was affected by variety, cooking time, bean size, and other factors. The solids lost contained relatively high amounts of protein and ash. Similar results have been reported for Tepary beans by Kabbara et al. (113). The leachate is rich in mineral content, particularly K (81). Rodriguez-Sosa et al. (76) found significant differences between raw and cooked beans in Ca, Mg, P, Na, Cl, and K content. Due to the conditions used for cooking, losses of vitamins also take place, and Singh (114) has reviewed such effects in chickpeas. Soaking and cooking have been shown by various workers to decrease oligosaccharide content, although not as much as germination, fermentation, and roasting (79, 111, 114, 115).

The domestic practice of soaking and cooking has also been shown to reduce the saponin content of food grain legumes. Khokhar and Chauhan (116) found lower saponin values in *Vigna acotinifolia*. Similar results were reported by Jood et al. (117) in chickpea/black gram and in black gram, as well as with the amphidiploids of black gram/mung bean by Kataria et al. (118, 119).

Effect on Protein Quality

It is difficult to establish the effect on protein quality of the traditional wet-cooking procedure used for common beans, since a number of measured effects take place simultaneously. Thus, the inactivation of the antiphysiological substances in beans and the concurrent increase in protein quality are both well documented in the literature. In this section, the effects of wet cooking on protein quality—assuming antiphysiological substances are completely inhibited—are briefly reviewed. The interpretation of the data may be confounded because cooking may be done at or below atmospheric pressure; because cooking time may vary among samples due to both genetic and storage effects; and due to the previous treatment of the sample, for example, if it is or is not soaked. Nevertheless, wet cooking, either at atmospheric pressure or under pressure, improves the protein quality of beans up to a point beyond which it decreases (120–122). In some cases, losses of lysine have been cited as responsible for the decrease in protein quality (123). These losses vary with the length and severity of heat treatment and with the type of legume. The variation with the type of legume appears to be due to the amount of reducing sugars in the legume. Others (124, 125) have reached the same conclusion.

Dry-Thermic Processing

A different approach to development of acceptable flavor and texture, to inactivation of antinutritional factors, and preservation of the nutritional value of common beans, is dry-heat cooking. Two approaches have been studied: dry roasting and extrusion cooking.

Roasting

Food legume roasting and parching or bean puffing is practiced in India and Africa (5) with various food legumes, but not much in Latin America with the common beans. The dry roasting of beans in the absence of moisture has been regarded as an inefficient means of improving the nutritive value of common beans. However, dry roasting of navy beans was shown by Carvalho, Jansen, and Harper (126) to enhance the nutritional value of the protein. In this study, beans were roasted at 190°C and 220°C for 30 and 10 sec, respectively, and the nutritive value was compared to beans cooked in the autoclave at 120°C for 8 min. The relative protein value for the 190°C- and 220°C-roasted grains were 59.9 and 59.6, and 57.2 for the autoclaved beans. Trypsin inhibitor activity, expressed as TI/mg of dry sample, was as follows: raw beans, 17.3; autoclaved beans, 2.4; 190°C-roasted beans 4.9; and 220°C-roasted beans, 3.1. These values are equivalent to 86%, 72%, and 82% inactivation, respectively. Yadav and Liener (85) reported similar results for beans dry roasted for 20–25 sec at 190–204°C using a salt bed as a medium for heat exchange. The protein quality, measured as PER, for this product was 1.92, with a protein digestibility of 69.2%. The protein quality of the sample pressure cooked for 15 min was 1.69, with a protein digestibility of 66.0. The corresponding trypsin inhibitor units and hemagglutinin units were 4.1 and 0.2 for the dry-roasted sample, and none for the 15-min-autoclaved sample. The protein digestibilities are low and no different from values reported by other authors (1, 2, 3, 5).

Yadav and Liener (85) found some residual TI in the roasted beans, but available lysine was similar to that observed from autoclaved beans. On the other hand, Murthy and Urs (127), with bengal gram, found that roasting decreased protein digestibility from 79% to 57%, puffing gave a reduction to 67%. Lysine availability also decreased. Aguilera et al. (128), using ceramic beads as the heat transfer media for dry roasting of common beans, found no changes in available lysine or degree of starch damage. Residual trypsin inhibitor activity and hemagglutinin varied from 92% to 22% and 48% to 1%, respectively. The conditions used were bead temperatures of 240–270°C and contact times of 1–2 min. The roasted product showed reduced water-soluble nitrogen and gel-forming capacity; and increased water-holding capacity and cold paste viscosities. Similar results were obtained by Loayza and Bressani (129, 130) for various food legumes. From these studies, it may be concluded that dry roasting is an acceptable process; however, it may result in products of lower protein quality and digestibility, with some residual levels of trypsin inhibitor activity and with special functional characteristics for different applications. The process influences in a positive way the removal of the hulls by air aspiration, giving products high in fiber, whereas a classification process gives products high in protein and starch (131–133).

The dry-heat treatment has been useful in the control of the development of hard-to-cook beans according to Molina et al. (134), who used steaming and retort but suggested the use of dry-heat treatments. Aguilera and Steinsapir (135) observed that tortola beans roasted with hot sand at 105°C for around 3 min hardened at a slower rate than control samples after 10 months of storage. In another study, however, Aguilera and Ballivian (136) found that roasted beans artificially adjusted to the same moisture contents as control beans became significantly harder than the controls stored at the same moisture and temperature for 9 months. Hohlberg and Aguilera (137) indicated that sand roasting is a feasible and simple method to preserve storage quality of beans. However, roasted beans will slowly harden with time (138). Roasting treatment after field drying was shown to be useful for disinfecting and reducing moisture content in the seed. Likewise, roasting at temperatures above 100°C proved to be successful in inactivating enzymes probably involved in bean quality deterioration.

Extrusion Cooking

Precooked bean flour constitutes one form in which beans are consumed. Often this is produced by pressure cooking, drying, and grinding. From the resulting flour, various foods are prepared such as soups, fried beans with the addition of fat, and other products. Extrusion cooking is a useful technique for this purpose, and various studies have been published. It has been reported (121) that beans processed using an X-25 Wenger Extruder gave a bean flour with a protein digestibility and protein quality higher than the bean flours processed by either atmospheric or pressure cooking, or by roasting. Available lysine was reduced about 12.5% by extrusion cooking, and trypsin inhibitor decreased 18.5%. Using a Brady Crop Cooker extruder, it has been reported (139) that extrusion cooking improved significantly the functional properties of soft and hard-to-cook beans. The process also inactivated trypsin inhibitor activity to values similar to those obtained by pressure cooking. Protein quality and protein digestibility were also increased by the process. The digestibility of pressure-cooked beans was 67–68% as compared to 81–82% for beans cooked by extrusion cooking.

Similar results were obtained (140) for cowpeas and common beans, alone or in 50/50 mixtures by weight. The highest protein quality was obtained by extrusion cooking as compared to cooking and drying in a drum dryer, or by pressure cooking followed by hot-air drying. Extrusion cooking is also a process appropriate for hard-to-cook beans, which require long cooking periods with a concomitant high fuel energy expenditure. Molina et al. (141) found extrusion processing to be very effective in cooking hard-to-cook beans, resulting in high protein quality as well as good functional properties. Pak and Araya (142) found extrusion cooking to give a flour of high quality, useful in the preparation of cereal blends for feeding young children. Similar results were reported by Joao, Elias, and Bressani (143) for extruded blends of cowpea and maize or cowpea and cassava. Dry instant fried bean flour with acceptable taste and nutritive value has been produced by extrusion cooking of beans with 18–22% oil added before processing (144).

The extrusion process has been shown to improve the protein quality of grain legumes, alone or in mixtures with cereal grains, for chicks (145–147) and swine (146, 147). Cabezas et al. (145), reported a high energy digestibility for extruded cowpeas. Bressani, González, and Sosa (148) found that extrusion-cooked poor-quality beans could replace, up to 18% by weight, the soybean in a poultry diet, without affecting weight gain or feed efficiency. The extrusion-cooking process not only improves the nutritive value of the grain legume, but it introduces attractive functional properties (149). Aguilera et al. (150) used air-classified high-protein fractions from common beans for extrusion-cooking studies. Products in which 10%, 20%, and 30% texturized bean high-protein fraction replaced equal quantities of texturized soy protein had similar functional properties. They concluded that air classification followed by extrusion cooking is a feasible alternative for dry processing of beans into human food products. Similar studies have been conducted by Dixon Phillips et al. (151) using cowpea flours, and by De León et al. using soft and hard-to-cook beans (139).

The air-classified bean starch fraction processed by extrusion cooking has been examined by Gujska and Khan (152) for functional characteristics. Properties such as expansion density, color, oil absorption, oil emulsification, and water absorption were different for the various grain legumes used. These characteristics were also affected by extrusion temperatures.

Most of the studies on extrusion cooking of grain legumes have shown the product to have a protein quality similar to that obtained by other cooking methods. Thus Elias, Hernández, and Bressani (139) reported a loss of around 12.1% of available lysine. Jeunink and Cheftel (153) found a 3.2% lysine loss, which would not affect protein quality. They also found a loss of 8.5% sulfur amino acids in extruded beans (153), which could decrease protein quality.

The number of studies on extrusion cooking of beans is relatively small and more data would be useful.

Germination

All food legumes are subjected to heat treatment before consumption; however, in some situations, due to poor cooking quality, they are germinated before cooking. The methods developed through the years are based on traditional home practices (154, 155). These involve an initial soaking of the whole beans for about 24 h, then spreading them on a damp cloth for around 48 h. The sprouted beans are consumed raw with salt, parched, or mixed with flavoring substances and fried or boiled. Germination is in itself a complex process and many contradictory results have been reported.

During germination there is increased enzymatic activity which induces changes in major and minor chemical components. The protein content, for example, may decrease; however, Hofsten (156) found little change in the amino acid profile, and no change in the chemical score. Nevertheless, prolonged germination does cause a significant decrease in protein quality in common beans and cowpea (157–159) even though no change in quality was reported from other studies with chickpeas (160). In all these studies, protein digestibility remained essentially the same. The decrease in protein quality is probably the result of losses during cooking of some important amino acid such as methionine, or to reactions between free sugars and the protein.

Germination induces other changes which are attractive from the nutritional quality point of view. Ascorbic acid and some of the B vitamins, including B_{12}, increase (156). No major change takes place in mineral composition although Kylen and McCready (161) and Reddy et al. (104) reported changes in the phosphorus fraction of grain legumes. Nonphytate phosphorus increases at the expense of phytic acid. So, it would appear that germination may improve the absorption of minerals. Data from several grain legumes suggest that 20–70% or more of the phytic acid is hydrolyzed during germination (104, 106). With respect to the flatus-causing sugars, some authors (162–164) report over 70% losses. However, Shurpalekar et al. (165) indicate that germination did not alter to any great extent the flatus-inducing capacity of Bengal and green gram. Noor et al. (159) and Jood et al. (117) noticed a significant reduction in the tannin content of mung beans after 4 days of germination. Satwadhar et al. (166), found a decrease in tannins after 24–48 h germination, but an increase after 48 h. Cooking decreased tannin content from 20% to 50% of original values. In other cases, tannins did not change (160). These controversial results are difficult to explain, but they could be due to differences in germination conditions. Germination seems to reduce trypsin inhibitors, which are further reduced by cooking, according to results from a number of workers on various food legumes (158, 160, 167, 168). Various workers have reported improved protein and carbohydrate digestibility upon germination and cooking (169–172).

Fermentation

Fermented foods are important diet components in many areas of the world, particularly Africa, the Near East, and Southeast Asia, but not to any great extent in Latin America. Mital and Steinkraus (173) showed that certain lactic acid bacteria are capable of utilizing the oligosaccharides in grain legumes as carbon sources. Reddy and Salunkhe (174) and Reddy et al. (175) observed that phytates decrease during lactic acid fermentation of mixtures of food grain legumes and rice. Furthermore, there is evidence that fermentation increases the level of some vitamins (176, 177). Deshpande and Damodaran (5) found that the nutritional effect varied with respect to food legume species and varieties.

Studies on *Phaseolus vulgaris* are very few. Camacho et al. (177, 178) reported the changes indicated above for lentils, chickpeas, and cowpeas; and more recently with *P. vulgaris* and lupins.

Dehulling and Milling

One of the interesting features in processing food grain legumes for consumption is that in some regions of the world, such as India and the African countries, the seed is dehulled (150, 155, 179, 180) before cooking, while in other regions, beans are consumed whole, as in Latin America (154). The dehulling process is either done directly on the dry seed, with relatively high losses; or on seed which has been moistened and dried, as is done for cowpea (181, 182), or on beans which have been cooked (183). The dehulling process, as used in India to produce dhal (5, 155, 179), has been well-described (5, 129). The dehulling of beans induces some interesting changes in various chemical and nutritional characteristics. Kon et al. (184) studied the effects of seed coat removal on cooking time of dry beans. They observed reductions of 42%, 53%, and 70% in the cooking time of dehulled, unsoaked bean varieties. This, in itself, is of interest since cooking time is a problem in bean consumption. The dehulling method may also affect textural quality, as shown for cowpeas (182, 185). The effects of dehulling on phytic acid, polyphenols, and enzyme inhibitors of *P. vulgaris* were studied by Deshpande et al. (100). Dehulling significantly increased the phytic acid content of beans (range 1.63–3.67%) from values in whole beans (range 1.16–2.93%). This increase was explained on the basis that phytic acid is present mainly in the cotyledons. The removal of the seed coat, which represents 7–10% of the dry weight, induces a concentration on a unit weight basis. The increase may also be due to better extraction efficiency for analytical purposes. Deshpande et al. (100) also found that dehulling increased trypsin, chymotrypsin, and α-amylase inhibitor activity of beans. The explanation given for this increase was similar to the one offered for phytic acid. Dehulling decreased tannin content by 68% to 95%. This was expected, since tannins are found in the hulls of beans (89). Deshapande et al. (100) also reported that dehulling improved the *in vitro* protein digestibility, probably due to the removal of dietary fiber and tannins present in the seed coat. As shown in Table 5, the dietary fiber of the seed coat of common beans is quite high (62–82%) (Bressani, Velásquez, and Acevedo [186]). Of the total dietary fiber (DF) in 8 varieties of beans, 1.7–4.2% was soluble DF and 66–73% was insoluble DF. These values increased with cooking. The effects of dehulling of common beans on the nutritive value of the cotyledons were reported by Bressani, Elias, and Braham (187). In these studies, the dehulling operation yielded 80% cotyledons, 12% hulls, 7% fines, and 1% total loss. Protein content in the hull fraction was 16.0% (dry weight beans); 23.2% for the whole bean, and 23% in the cotyledon. As shown in Table 6, protein quality and protein digestibility for both the whole bean and the co-

Table 5. Dietary Fiber in Whole Beans, the Seed Coat and the Cotyledon Before and After Cooking (%)

Dietary fiber	Whole	Cotyledons	Seed coat
		Raw Beans	
Soluble	5.8 (3.4–8.4)[a]	6.3 (3.6–8.9)	2.6 (1.7–4.2)
Insoluble	13.9 (11.6–20.0)	7.7 (5.4–8.9)	69.1 (66.5–73.0)
Total	19.4 (15.6–25.5)	14.0 (11.5–16.7)	70.7 (61.6–74.8)
		Cooked Beans	
Soluble	5.0 (4.4–6.2)	4.0 (1.9–7.8)	4.6 (1.7–6.3)
Insoluble	21.2 (19.4–25.1)	14.0 (12.4–15.3)	73.1 (68.3–76.4)
Total	26.2 (23.5–30.2)	18.1 (15.8–21.8)	77.8 (74.1–80.6)

From Ref. 186.
[a]Range.

Table 6. Effect of Dehulling on the Protein Digestibility and Protein Quality of Common Beans

	Whole bean		Dehulled bean	
Cooking time, min	PER	Prot. dig., %	PER	Prot. dig., %
10	0.91	60.8	1.60	70.8
20	0.66	61.6	1.35	73.1
30	0.51	59.9	1.45	71.6
40	0.43	60.3	1.15	73.1
50	0.46	57.7	1.20	69.7
Casein	2.60	91.2	—	—

From Ref. 187.

tyledon (dehulled bean) decreased with increased cooking time. However, at all cooking times, protein quality and digestibility were significantly higher for the cotyledons, and there was a small decrease with respect to cooking time. These increases were attributed to the removal of dietary fiber and tannins with the hulls. The effect of decortication has also been studied with other grain legumes. Dixon Phillips and Adams (188) found that the PER of cowpeas increased from 1.16 in whole cowpeas to 1.47 in dehulled cowpeas. Apparent protein digestibility increased from 73% to 78%. These results were attributed to the reaction of tannins with protein during cooking, decreasing protein quality and utilization. Hull removal appears attractive in expanding the use of common beans; however, its presence during cooking may contribute to the flavor of beans, at least in Latin America (189).

Milling and air classification of food legumes has not been studied extensively, although the possibility of obtaining high-protein and high-carbohydrate fractions, is of interest. The most extensive studies are those of Vase et al. (190) and Sosulski and Youngs (191). These workers demonstrated the possibility of producing protein concentrates from prior-milled grain legumes, particularly from peas and fava beans. The fine flour obtained was then subjected to a special air stream which concentrated the protein based on differences in size, shape, and density of the starch granule and the lighter protein-rich fractions. Sosulski et al. (192) have reported on the oligosaccharide content of 11 legumes and their air-classified protein and starch fractions. The protein fractions were 40–90% higher than the original flour in α-galactosides, especially raffinose manninotriose, stacchyose, and verbascose. The starch fractions were depleted in α-galactosides, with 1.2–2.8% of the fraction.

Irradiation

Irradiation as a process to make beans edible for consumption, in association with other processes, has not been studied extensively, even though the few reports available show it to be effective. Sreenivasan (193) and Nene et al. (194, 195) used cobalt-60 to irradiate red gram (up to 3 Mrad). They reported no change in total protein nor in the amino acid profile of the protein. Likewise, no change in TI activity was observed; however, *in vitro* enzymatic digestibility with pepsin and trypsin increased. Nene et al. (194, 195) found some small and subtle physicochemical changes in macronutrients in irradiated beans. Several low molecular weight radiolytic breakdown products of irradiated legume starch and protein have been characterized, which may affect the functionality of the irradiated legume. Of importance also was a reduction in oligosaccharide content and in cooking time (196, 197). Iyer et al. (111, 198) found a 50% reduction in cooking time in irradiated beans, confirmed by Aguilera et al. (8). This last characteristic is of particular significance, since one of the most serious problems with beans is their long cooking time, which increases upon poor storage. Aguilera et al. indicated that beans irradiated with 10, 50 and 100 krad had generally lower hardness values than the controls, but they could not demonstrate a clear relationship between irradiation dosage and texture. They suggested it was probably due to the use of low levels of irradiation dosage. Reddy et al. (199) found similar results in *Phaseolus vulgaris*, with respect to protein content and *in vitro* enzymatic digestibility. Furthermore, these workers reported that the nutritional value of all varieties of beans studied, based on chick growth, was significantly improved by gamma-irradiation. Short-term feeding studies with rats fed irradiated-bean diets did not reveal any mutagenic activity by *in vivo* or *in vitro* tests (196, 197).

ACCEPTABILITY CHARACTERISTICS

In most developing countries, improved nutrition for the majority of the population depends on increased availability and access to basic foods. In Latin America, most population groups consume diets high in cereal grains and starchy foods, such as cassava and plantain. In Guatemala, for example, maize provides 65.0% of the daily calorie intake and 53% of the daily protein intake (200). The main supplementary protein source in these diets is derived from the common bean, which provides around 19% of the daily protein intake and 8.5% of the daily energy intake (200). These figures correspond to an intake of roughly 360 g/day of maize and 50 g/day of beans. Animal protein sources, which are more expensive, provide 8.1% of the daily calorie intake and 23% of the daily protein intake (200). Complementation studies have shown that optimum protein quality of a maize and bean diet is obtained when consumed in a 7/3 weight ratio (201). This ratio can be achieved if maize intake is decreased to 287 g/day and bean intake is increased to 123 g/day (dry matter intake of 410 g from these two foods). But bean intake very seldom goes above 50 g. This could be due to low availability and high cost, or to the difficulty in consuming more beans. For children, who need better-quality protein, the situation is worse. Although a higher contribution of beans to both the daily calorie and protein intake would be highly desirable, particularly for children, it will not be achieved unless the consumer's needs and preferences, and grain nutritional quality, are taken into account in the development of new bean varieties.

There is a growing awareness that increases in food availability are achieved through genetic improvement and better agronomic practices. However, this is not enough—postharvest technologies, the market, the possibility of producing added-value products at the sites of production, and the preferences of the consumer must also be considered. For most food crops, and for beans in particular, the success of a new introduction is based on decisions made by persons with different interests which reflect the various steps in the food production chain. However, the consumer is the one who finally determines whether a bean is acceptable. Von Herpen (19) indicated that consumer acceptability of beans had to meet at least three criteria: the physical, cooking, and eating characteristics of beans; the market situation; and the household situation. The preferred characteristics in beans often reflect deep-rooted cultural traditions (202).

Physical Aspects of the Grain

Raw Grain

The main physical aspects of beans associated with consumer acceptance include color, size, shape, and brilliance of seed coat. Voysest (203) conducted a study on consumer preference for bean color in Latin America. In general, the report shows that in Mexico, medium-sized blacks, yellows, and creams are preferred; while in Central America, small red and black cultivars are consumed. In the Antillas, big red beans are eaten. The situation in South America is more complex with respect to bean color and size. Flores et al. (204), using available nutrition survey data, reported that in Central America preferences for bean color varied from country to country. Black beans were preferred in Guatemala and Costa Rica, and red-colored beans in Honduras and Nicaragua. Both black and red beans were acceptable in El Salvador. There was only a very small preference for white-colored beans. In more recent studies, Bressani et al. (18) and Diamant et al. (20) confirmed the preference for black beans in Guatemala, although smaller amounts of red are also consumed. In the United States, white-colored beans are preferred, and Wassimi et al. (205) stated that in the breeding, producing, and processing of navy beans, a higher level of seed whiteness should be encouraged. Bean size constitutes another important physical characteristic in determining consumer acceptance. Size is usually measured by weight. Small beans weigh less than 0.25 g/seed, medium sizes weigh between 0.25 and 0.40 g/seed, and large weigh over 0.40 g/seed. Bean size preference also differs markedly among countries, and even among regions within a country. For example, Von Herpen (19) found that in Medellin, Colombia, 67% of the beans consumed were large reds, and only 12% preferred medium reds. In Tegucigalpa, Honduras, 95% of the consumers preferred small reds, and in Guatemala 98% selected small blacks. Bean shape is apparently less important since bean shape is often quite similar among the various bean sizes or weights. On the other hand, the brilliance or shininess of the seed coat is a quality criteria for consumer acceptability of beans.

Studies conducted in Guatemala (18, 20) found that among 600 consumers, 34% indicated the principal characteristic of good quality of raw beans was a black grain, and 18% indicated it had to be a shiny grain. Brilliance is considered to be highly associated with freshness. According to Moh and Alan (206), the gloss of the seed coat is an agronomic characteristic that determines the market value of the grain in many parts of Latin America. The condition of the presence of gloss is called "shiny"; and its absence, "dull." The shiny factor is genetically controlled, being dominant over the dull, and is inherited as a simple Mendelian trait.

Softness of the bean grain is another quality criterion in determining consumer acceptance. This preference has been reported in many studies (17–20, 46, 207–209).

Cooked Grain

Acceptability criteria also apply to cooked beans. Bressani et al. (18) reported softness in cooking, flavor, and the color and thickness of the cooking broth to be quite important. Diamant et al. (20) indicated that good-quality cooked beans were characterized by split grains, thick cooking broth, and spreadability. Cooking performance and eating characteristics of beans are acceptability factors (19). Since acceptability is subjective, acceptability is related to ethnic preferences and to rural versus urban likes and dislikes. These in turn influence consumers' cooking methods, raw bean selection criteria, and methods of judging cooked bean quality (18, 19, 20). As a result, trying to improve beans by genetic manipulation becomes a plant breeder's most demanding challenge.

It is important that in the development of new bean varieties, researchers consider not only the agronomic qualities, but also the desirable characteristics of the raw bean and of the cooked product as perceived by consumers of different backgrounds.

Factors Related to Postharvest Biochemistry, Handling, and Storage

Acceptability criteria for beans are highly associated with the cooking time required to make beans soft for consumption. Cooking times under normal atmospheric pressure may vary from 24 to 240 min (18), with most families reporting values between 60 and 95 min. Diamant et al. (20) found cooking times to range from 102 to 290 min. For the same bean cultivar, less cooking time was required at lower altitudes than at higher altitudes, as shown in Figure 1 (58). Cooking times for a black bean variety cooked under similar conditions but at different altitudes varied from approximately 78 min at sea level to 250 min at 2256 meters above sea level. Prolonged cooking times were also reported by Shellie-Dessert and Hosfield (209) for cowpeas.

Cooking time is, therefore, an important constraint in bean consumption and preparation, not only for the time involved but because of the high fuel consumption required to cook both freshly harvested beans and, in particular, beans which have been kept under poor storage conditions (210–214).

Hard-to-Cook Beans

The hard-to-cook condition is a well-known phenomenon (210–215) and has received significant study in recent years. The hard-to-cook characteristic results in important postproduction losses (216, 217), extremely high fuel consumption (209, 211, 212, 214, 218), and beans that are unacceptable to the consumer. Furthermore, due to the prolonged cooking time, the nutritional value of the protein decreases because of methionine and lysine losses (215, 219).

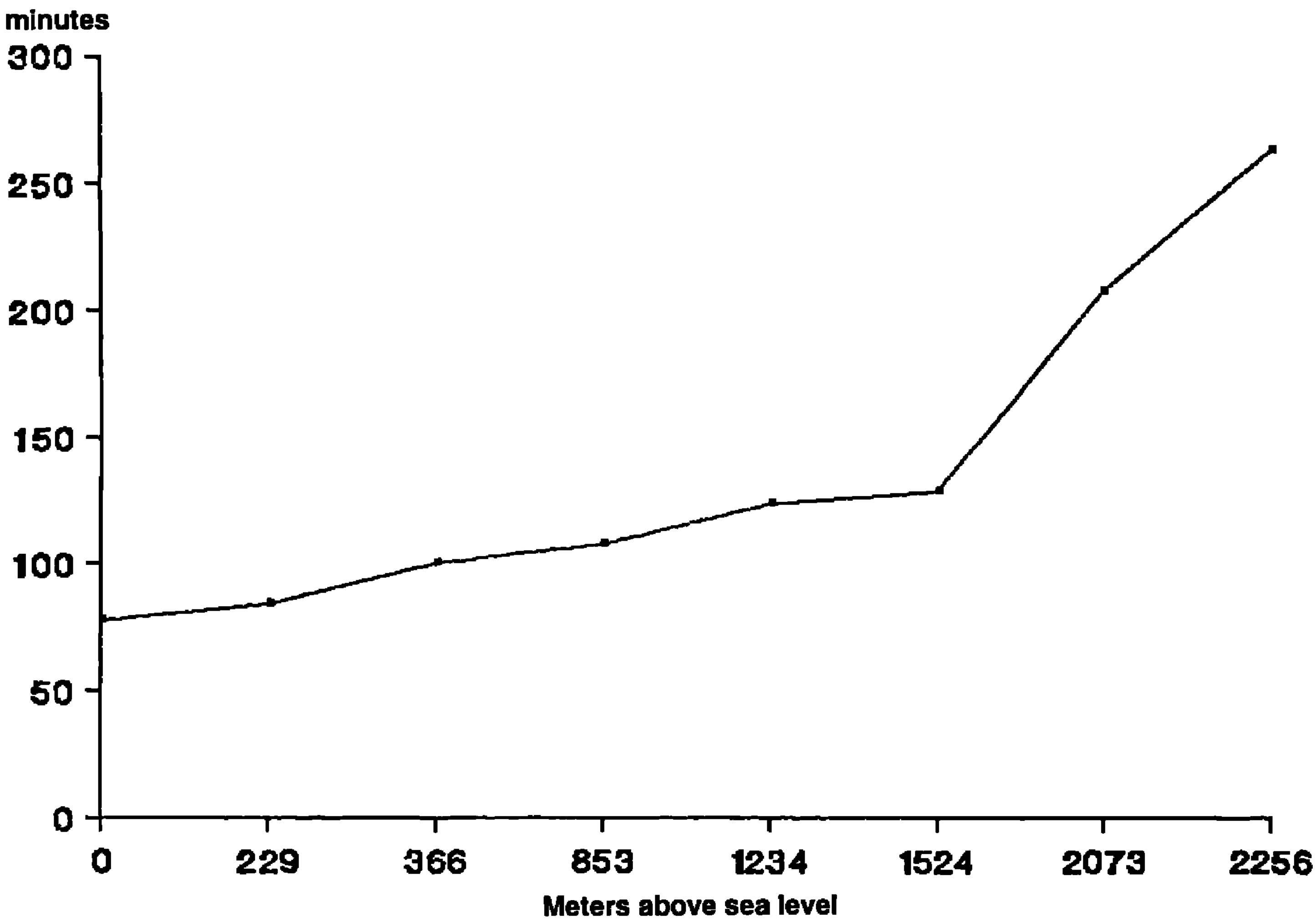

Figure 1. Effect of altitude on bean cooking time.

Hardness in *Phaseolus vulgaris* may result from different causes. Grain legumes which fail to imbibe water in a reasonable length of time, 18–20 h, are called "hard-shell legumes" (54, 220, 221). Grain legumes which are capable of absorbing water, but do not soften even when they are fully hydrated and cooked, are called "hard-to-cook" (210–214, 221, 222). Most authors studying the hard-to-cook defect indicate that the problem develops when beans are improperly stored at high relative humidity and temperatures (199, 223, 224).

The analysis and interpretation of the research results is difficult because the conditions used to develop the defect are neither well described nor standardized, and the methods used for sample preparation, cooking, and evaluation differ between researchers. Furthermore, the bean samples are not well identified with respect to genetic composition, origin, age after harvest, postharvest handling, and uniformity of grain size. This lack of standardization has been complicated by the fact that there are at least three ways to develop the hard-to-cook defect: the classical method of adjusting bean moisture, increasing storage temperature and relative humidity; the method of storing beans in plastic, cloth, or paper bags without adjusting moisture of the beans; and the most recent method, subjecting the beans to an acetate buffer at pH 4.0–4.1 (224, 225). It is probable that all methods produce the same condition, but there may be basic differences in the mechanisms leading to the hard-to-cook defect. The problem is of such great importance that it merits a comparative study among the methods used to induce cooking in hard-to-cook beans, with the proviso that methodologies be standardized.

Mechanisms

The hard-to-cook defect is characterized texturally by the restricted softening of the bean cotyledons upon cooking. This is thought to be the result of changes within the middle lamella/cell wall complex that inhibits cell separation. According to this theory, there is a failure of phytate to chelate divalent cations in the pectates of the middle lamella, rendering this structure resistant to heat softening. The phytate becomes unable to fulfill its role because it is degraded enzymatically by phytase (the enzyme phytase is probably activated by elevated storage conditions) (8, 69, 70, 79, 199, 225–227). Water penetration in the cotyledon is of great importance for separation, and it allows heat transfer, starch gelatinization, and protein denaturation to take place. In hard-to-cook beans, water does not completely penetrate the cotyledon cells due to barriers which develop during storage, barriers that are produced by both enzymatic and nonenzymatic reactions. The hard-to-cook condition may also be the result of concomitant reactions taking place along with the role of phytic acid. Muller (228) suggested that lignin within the cell walls of the cotyledons may affect the cooking quality of grain legumes. Molina et al. (134) observed that the lignified protein content of bean cotyledons increased with storage time at 25°C and 70% RH.

These authors reported a significant correlation between cooked bean texture and lignified protein content. Whitmore (229) suggested that initial lignification may involve crosslinking of the cell wall by formation of lignin/protein complexes. Fry (230) showed that the initiation of lignin deposition could be associated with pectin/phenol complexes within the middle lamella by providing sites for this oxidative process. In this respect, De Mejia (216) showed tannin content to decrease in red and black beans upon storage. Evidence for lignification was provided by Hincks and Stanley (231), who isolated cell wall material from controls and hard-to-cook beans. Transmission electron microscopy indicated that potassium permanganate-fixed material produced heavier depositions of manganese dioxide in cell corners, secondary walls, and middle lamella of hard-to-cook beans. This pattern is seen during the lignification of plant tissue. The lamellated appearance of cell wall material from hard beans suggested that this was the result of cellulose deposition, a process known to occur before lignification. Bressani et al. (232) found increases over initial values in hemicellulose and lignin content of beans which had been stored at 4°C. However, in a 90-day test, beans stored at 38°C had much higher hemicellulose and lignin content. The hard-to-cook condition of beans may be the result of more than one mechanism (67), and it is logical to assume that more than one type of tissue is involved. As already indicated, the seed coat has been shown to affect water imbibition, thus increasing cooking time. The seed coat chemical components could influence the chemical changes in the cotyledons during storage. Linares et al. (65) and De Bosque et al. (91) showed a correlation between seed coat percentage and cooking time. More recently, De León et al. (37) showed that whole beans stored for 6 months at 37°C and 90% RH had a significantly higher cooking time than similar samples stored without seed coats under the same conditions.

Storage Stability of Hard-to-Cook Beans

Various methods have been proposed to improve the storage stability of beans. These are based on processes which will inhibit enzymatic activity or on processes which will reverse the phytate-cation mechanism.

One proposed approach is the use of heat (135, 141, 233). However, if improperly carried out this does not destroy peroxidase activity, used as an index of bean processing. Irradiation has also been proposed (194, 195, 198, 199, 233). Peroxidase activity was reduced by application of 500 krad or a combination of 50 krad and roasting at 80°C for 2 min (233).

Other approaches have been proposed to solve the hard-to-cook problem. It has been noticed that not all beans harden at the same rate. This may indicate that there are genetic differences which could serve as a basis for bean selection (65, 91, 92, 235–240). If this is confirmed, it may be possible, through breeding programs, to select bean varieties with delayed hard-to-cook development.

Control of the hard-to-cook condition might be effective if more attention were given to bean growing conditions. Based on studies with three cultivars of pinto beans grown in 3 locations, Quenzer et al. (241) reported that growing site influenced cooking time more than cultivar. Similar results were published by Proctor and Watts (242), with 3 cultivars of navy beans grown in 3 different locations. Bhatty et al. (243) obtained similar results with lentils. Wassimi et al. (244) found that lentils watered with adequate levels of N, P, Ca, Mg, S, B, Cu, Fe, Mn, Mo, and Zn, and a high level of K, produced the fastest-cooking lentils. Furthermore, high levels of K and Na in the seed were associated with good cooking quality.

More recently, Parades-López et al. (225) tested the cooking time of 2 Mexican bean cultivars grown in 2 locations differing in soil Ca and Mg content. Beans from the high-Ca site had longer cooking times, which increased more rapidly after accelerated storage and in soaking tests (224). Handling of beans after harvest may also influence the hard-to-cook problem. Thus, Garcia and Bressani (245) found that extended solar drying resulted in beans with a longer cooking time.

Even though much important research has been conducted in attempting to solve this problem, it still persists. At the present time, storing beans with 12–14% moisture at low T and low RH appears to be the most efficient way of maintaining the cooking quality of beans.

NUTRITIONAL FACTORS

Positive Attributes

Nutrition-Related Positive Attributes

Bean Protein Content: Food-grain legumes, in general, and common beans, in particular, contain relatively high levels of protein. The amount of protein in grain legumes, including common beans, has been reported to vary from 17.0% to 39.4% crude protein (246). Among 87 different samples, protein content varied from 22% to 39%, with an average of 28% (247). This variability has never been explained. It is probably due to both genetic and environmental factors (248). Of the total nitrogen content, *Phaseolus vulgaris* contains from 8.3% to 14.5% nonprotein nitrogen (249–252). It is not known whether samples with a high crude protein content also contain higher NPN.

Protein fractionation using different solvents indicates that common beans contain albumins, globulins, prolamines, and glutelins (253). The most abundant proteins are the globulins, which represent, for *Phaseolus*, about 75% of the total protein. Albumins represent around 15% of the total proteins, and glutelins about 10% (253–257). Small amounts of 60% aqueous ethanol-soluble proteins have been reported, on the order of 0.65–1.20% (250). The albumins are richer in lysine than the globulins, and also in total sulfur amino acids. However, the albumin-to-globulin ratio is below 1 (253–258).

Essential Amino Acid Content: The amino acid composition of *Phaseolus vulgaris* has often been reported (252, 259–262). Bean proteins are rich sources of lysine (6.7–7.2 g/16 g N). This is one of the most important nutritional attributes of beans. Legume grain proteins are, however, deficient in the sulfur-containing amino acids methionine (1.1–1.3 g/16 g N) and cystine (1.0 g/16 g N), which determine the protein quality of grain legumes. Some authors have reported on the relationships between total protein in beans and their amino acid composition, particularly lysine and sulfur amino acids. Protein content appears to be negatively correlated with lysine content (246, 248). This indicates that as protein content increases, more globulins (*Phaseolus*) are deposited in the grain, and the albumin/globulin ratio decreases. Likewise, protein content has been negatively correlated with sulfur amino acids (246, 248). This relationship indicates that the protein quality aspect of beans cannot be corrected by increasing protein content, unless albumins increased with the increase in total protein, or with the increase in proteins rich in sulfur amino acids. These results indicate that it would be best if protein content were decreased to levels between 18% and 20%, while the present levels of sulfur amino acids and of lysine were maintained. This may result not only in better-quality protein, but in higher yields.

Protein Complementation–Bean Supplementation of Cereal Grains: The supplementary and complementary value of food grain legumes to cereal grains is well documented (263–267). Some typical response curves for common beans and maize, and for rice and sorghum are shown in Figure 2. The data show that as the protein contribution of common beans to the diet increases, there is an improvement in protein quality. For maize this is close to a 50/50 protein ratio; that is, 50% of the dietary protein is derived from beans, and 50% from maize. The 50/50 protein ratio corresponds to 30 parts beans and 70 parts maize by weight. The response with sorghum is similar, and both are slightly different from the response with rice (268, 269). The response is quite similar for other legume grain and cereal grain combinations (270). This effect has been explained on the basis of two amino acids, lysine and methionine. The increase in protein quality when bean protein is added in increasing amounts to cereal protein is due to bean lysine contribution to the mixture. When the peak response is obtained, methionine becomes limiting. This limitation increases as more bean protein is added in the mixture. The 50/50 protein ratio is equivalent to 30 parts bean and 70 parts maize or cereal by weight. This means that beans are excellent supplements to cereal grains. Higher protein quality results when the complementary study is done with dehulled beans and maize, for example. The point of maximum response does not change, although the protein quality is higher (187, 269).

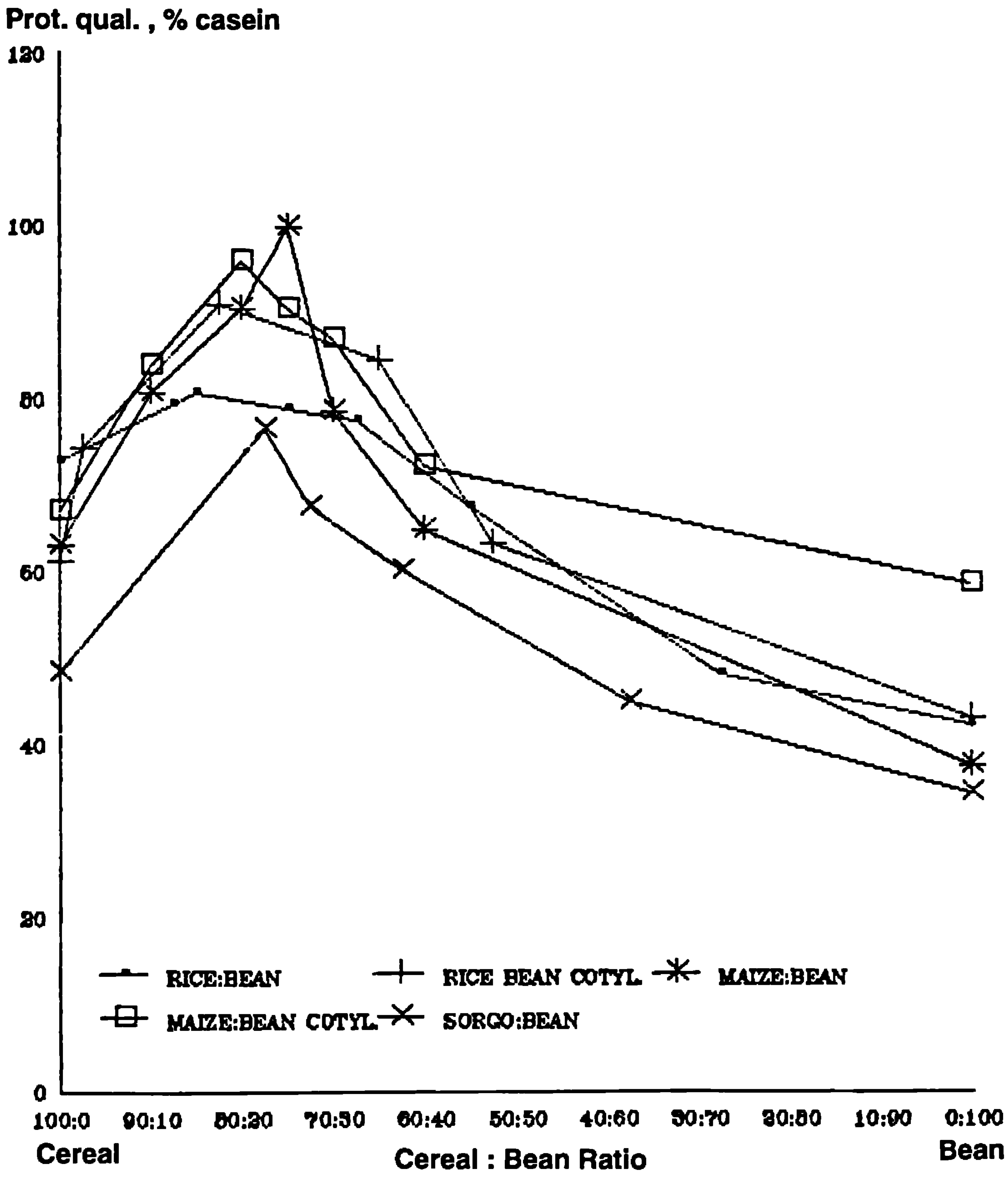

Figure 2. Complementary effect of beans on cereal grains.

This approach has been most useful for food product development, but it is also useful in screening beans for better complementary quality or identifying beans with a higher methionine content (271, 272). As indicated, the amino acids which determine the maximum response between beans and maize are methionine and lysine (263, 264). Figure 3 illustrates both the complementary effect and how the system can be used for purposes of selecting beans of better protein quality. The normal response obtained with a mixture of maize and beans is given

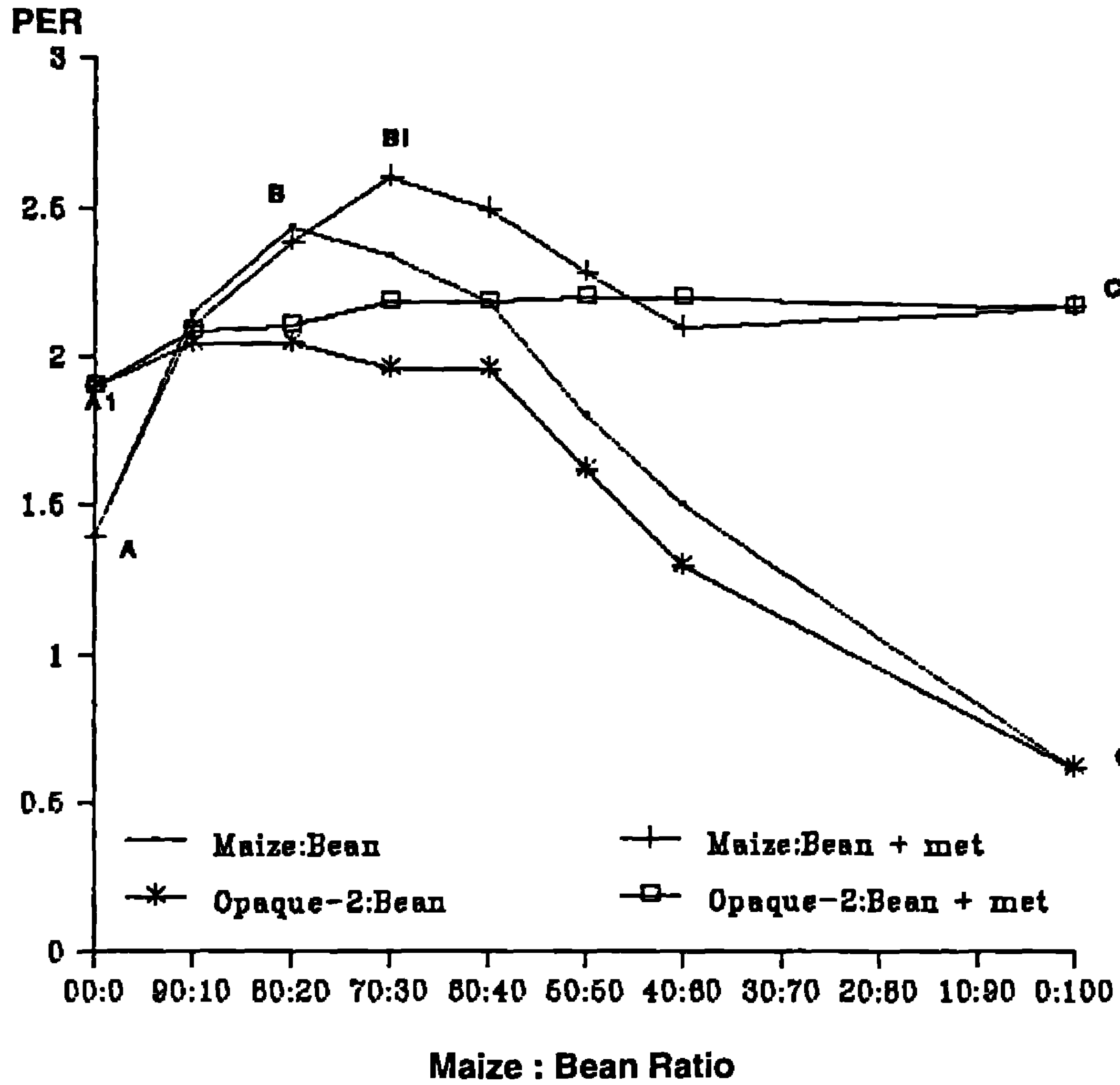

Figure 3. Protein quality of maize with beans, with and without methionine supplementation. —•— maize:bean; —+— maize:bean + met; —*— opaque-2:bean; —⊟— opaque-2:bean + met. (Note: opaque-2, or QPM, is higher in lysine than normal maize.)

by the lines ABC. The AB response is due to lysine. This is supported by results with QPM, a maize (266) which has a higher lysine content than normal maize. Thus, the increase from A to A1 is a lysine effect attributable to the higher lysine content in QPM. The response from C to B is due to methionine supplied by maize. A bean with a higher sulfur amino acid content, in this instance supplied by methionine, will give a response when mixed with maize such as the one shown; that is, AB1C1. The increase from C to C1 illustrates the effect of higher methionine when beans are fed alone, and from C1 to B1 when fed with maize. The B-to-B1 shift either is as shown or may be perpendicular to B. This is a response to higher lysine content in maize due to the low digestibility of bean protein. The studies conducted indicate that the angle ABC is a good way to discriminate between beans with different nutritive values. Although amino acid analysis can be done for the same purpose, the biological approach considers protein digestibility as well (271, 272). Beans with higher sulfur amino acid content will give a higher peak and those with higher levels of lysine will give a higher angle in the response line with higher amounts of maize.

Health-Related Positive Attributes

Common beans, as well as other legume grains, make a valuable contribution to the protein intake and protein quality of cereal diets consumed by people in many developing countries. Recently bean nutritional significance has acquired a new dimension associated with health benefits derived from their consumption. Hellendoorn (273–275) showed that bean consumption has a favorable effect on the body, expressing itself in more rapid intestinal transit time and in lowering of serum cholesterol values. This last effect was first shown by Grande et al. (276). A diet containing legume seeds lowered the serum cholesterol level by 9%. Recent studies have provided some evidence concerning the mechanisms involved and the role of bean dietary fiber (277, 278). Legume grain consumption may also have an impact on several diseases, such as colon and rectal cancer, diverticulitis, appendicitis, varicose veins and hemorroids, coronary heart disease, gallstones, and diabetes mellitus, diseases which have been linked to diets low in dietary fiber (12, 279, 280). Simpson et al. (281) found that when patients were fed with high-carbohydrate portions of grain legumes, after an overnight fast, their blood sugar levels were very much lower after grain legume consumption. The use of grain legume in diabetic diets has been reviewed by Leeds (282) and Hockaday (283). Carbohydrate bean intake induces a low rise in glucose, insulin, and glucose oxidation (284). These findings drew the attention of a number of research groups. Würsch et al. (285) studied the relationship between cellular integrity and the rate of starch hydrolysis in a variety of grain legumes. They confirmed that, whereas cooking alone would ensure the gelatinization of starch granules in white kidney beans, the starch remained encapsulated within intact cell walls.Therefore, the α-amylase could not easily penetrate the gelatinized starch granules, due to steric hindrance. The physical form is important for starch hydrolysis in grain legumes, as shown by various researchers (286–288).

Research on other diseases is underway. Jenkins et al. (289) found legume grain consumption to be useful in the dietary management of hyperlipidemia. Berry (290), using a rat model, found extruded peas to be associated with a lower incidence of diverticulosis. These effects are under intensive research and point to the importance of the relatively high dietary fiber (DF) content of grain legumes. Fiber can have a direct effect, based on its structure and chemical composition, and an indirect effect by blocking the digestibility of starch and protein. Processing effects are also highly important. Legume grains, which contain from 0% to 0.65% saponins, have been associated with the hypocholesterolemic effects of grain food legumes (291, 292).

Negative Attributes: Antinutritional Factors

Common beans as well as all other grain legumes contain antiphysiological substances. The most important are trypsin, chymotrypsin, and amylase inhibitors;

hemagglutinins; tannins; phytic acid; and saponins. The oligosaccharides causing flatulence may also be included among the antiphysiological factors present in food legumes. The significance of these antinutritional factors has been reviewed recently and is not discussed in this document. The causes, relation to diet, and removal of the flatulence factors in beans have been reviewed by Price et al. (10, 292); activity of proteinase inhibitors by Weder (9) and of amylose inhibitors by Lajolo et al. (31); bean tannins by Reddy et al. (7); and antinutritional factors by Van der Poel (10) and by Deshpande and Damodaran (5).

Nutrient Bioavailability

Bean Protein Quality—Sulfur Amino Acid Deficiency

Little attention has been given recently to the protein quality of common beans, since it is well known and well documented that sulfur amino acids limit the quality of bean protein (22, 120, 293–297). The belief that protein quality of beans is not a real problem in mixed diets, particularly with cereal grains, may also contribute to this lack of interest. Although protein quality in common beans is limited by the deficiency of methionine and cystine, higher levels of total sulfur amino acids would be desirable even for cereal grain–bean diets, and more so for diets based on starchy foods and tubers. Not only is the total amount of sulfur amino acids low in beans, but their availability may also be low (198), even though *in vitro* studies (298) indicate that heating improves the rate of their release.

Most of the published studies indicate that the addition of 0.69 g of DL-methionine to a bean with 23% protein (equivalent to 0.3% in 10% bean protein diets) induces a significant increase in protein quality (120, 293, 294, 296, 297). This level may, however, be higher than needed, based on results of studies (300) shown in Table 7. Analysis of the data suggests that black beans require around 0.3% methionine (10% protein in the diet), while red and white beans need only 0.2% (10% protein in the diet). Using linear regression analysis, the values for

Table 7. Effect of Methionine Supplementation on the Weight Gain and Protein Quality of Beans

Level of supplemental DL-methionine, %	Color bean					
	Black		Red		White	
	NPR	Av. wt. gain, g	NPR	Av. wt. gain, g	NPR	Av. wt. gain, g
0	1.59	9	1.78	12	1.96	16
0.1	2.44	36	2.87	40	3.12	47
0.2	2.62	42	3.46	52	3.58	53
0.3	2.71	49	3.17	53	3.45	62
0.4	2.73	47	3.39	53	3.50	54

black, red, and white beans are: 0.24%, 0.15%, and 0.15% methionone. Taking into consideration the total available sulfur amino acid content in beans, and the amounts of supplemental methionine required to significantly increase their protein quality, it is estimated that beans should contain between 0.66% and 0.76% total sulfur amino acids. Levels as high as 0.88% have been reported (295, 301–303). Therefore, it appears feasible to select for beans with a higher content of sulfur amino acids. Availability of the sulfur amino acids may, however, be a problem since bean protein digestibility is low. Nitrogen balance studies with adult humans (304) show that a level of intake of 0.65 g of bean protein per kilogram of body weight per day is not enough to maintain nitrogen equilibrium, due to the low digestibility and low methionine content. These workers (304) estimated that an intake of 0.9 to 1.0 g of bean protein/kg/day is necessary for nitrogen balance in male human adults. Thus methionine deficiency constitutes a problem in bean protein utilization. Blanco and Bressani (305) reported that essential amino acid (EAA) digestibility from beans was less than nonessential amino acid (NEAA) digestibility (41 ± 19 versus 54 ± 13). There were no significant differences between black, red, and white beans. Consequently, the high levels of supplementary methionine required to increase protein quality may be due to the low protein digestibility of beans.

Bean color seems to be related to the effect of methionine addition on protein quality, possibly by interaction with tannins. Braham and Bressani (94), for example, found that addition of 0.3% methionine to 10% bean protein diets increased protein quality 99% for white beans, 131% for black beans, and 153% for red beans when the cooking broth was not included with the cooked beans. The improvement was 125%, 185%, and 245%, respectively, when an equal weight of cooking broth was added to the beans, as shown in Table 8. The cook-

Table 8. Effect of Methionine Supplementation of Beans of Different Colors in the Absence or Presence of Cooking Broth

Cooked bean sample	Color bean					
	Black		Red		White	
	− Met	+ Met	− Met	+ Met	− Met	+ Met
Beans − cooking broth	1.13 ± 0.19	2.61 ± 0.35	0.90 ± 0.29	2.28 ± 0.16	1.48 ± 0.20	2.95 ± 0.21
Beans + 1 cooking broth	0.80 ± 0.14	2.28 ± 0.17	0.66 ± 0.16	2.28 ± 0.28	1.25 ± 0.16	2.81 ± 0.18
Beans + 2 cooking broth	0.59 ± 0.20	2.03 ± 0.15	0.53 ± 0.25	1.86 ± 0.18	1.23 ± 0.16	2.63 ± 0.23
Beans + 3 cooking broth	0.49 ± 0.16	2.12 ± 0.16	0.37 ± 0.16	1.78 ± 0.34	1.14 ± 0.19	2.74 ± 0.22

From Ref. 94.

ing broth is rich in tannins, and an interaction between tannins and the sulfur amino acids may explain the results. Polyphenolic compounds also decreased protein quality in the absence and presence of methionine. It is of interest that in the studies reported by Braham and Bressani (94), methionine addition, although it improved protein quality, did not improve the digestibility of the protein, as was to be expected. Studies on the effect of methionine addition to beans, as measured in human subjects, are very few. Essenbaugh et al. (306) showed an increase in nitrogen balance when peas (*Pisum sativum*) were supplemented with methionine, with no change in protein digestibility.

Graham et al. (307) fed beans to 10 children recovered from calorie/protein malnutrition at 6.4–6.7% dietary protein calories. They reported very high wet stool weights with beans as compared to casein, a very low protein digestibility (65.6%), and a low nitrogen retention (9.8 ± 6.1%) as compared to casein with a digestibility of 87.5%, and nitrogen retention of 34.5%. Methionine increased nitrogen balance, although it was not statistically significant. There was, however, an increase in free plasma methionine. A longer-term study by Graham et al. (307) showed a clear effect due to methionine addition. However, these workers concluded that the poor protein digestibility of beans is the first limiting factor in bean utilization.

Blanco and Bressani (305) found that digestibility for individual amino acids ranged from 29% to 61% for black beans, from 29% to 51% for red beans, and from 26% to 65% for white beans. Usually, the highest value was for phenylalanine and the lowest for valine. True amino acid digestibilities were higher. Values for black beans range from 60% to 89% (valine/lysine), for red beans the values were 64% to 86% (valine/lysine), and for white beans 56% to 87% (valine/phenylalanine). Sulfur amino acid digestibility was not established.

A second limiting amino acid in some grain legume proteins may be tryptophan (294, 295); the results of Blanco and Bressani (305) on amino acid digestibility of bean proteins offer further evidence of this. They showed that apparent tryptophan digestibility was only slightly higher than the digestibility of valine. These values were 33.0%, 29.0%, and 29.3% for black, red, and white beans, respectively. For valine the values were 29.1%, 32.6%, and 25.6% for black, red, and white beans, respectively. The methionine deficiency is important when beans are consumed with farinaceous foods (308, 309) and with cereal grains, when bean provides more than 50% of the dietary protein.

Protein Digestibility

The positive nutritional components of grain quality need improvement, and the negative attributes should be minimized. Those which are positive for bean utilization should be preserved in breeding programs and during storage and processing. Those which are negative and decrease the biological utilization of beans should be corrected. Among the latter, the poor protein digestibility of

Table 9. Apparent Protein Digestibilities of Common Beans and Other Grain Legumes

Legume grain	Process[a]	Other variable	No.	Prot. dig., %	Ref.
Phaseolus vulgaris					
Black beans	PC; 20 min, 121°C	Without broth	1	64.1 ± 3.1	94
		With broth	1	61.9 ± 2.5	94
		With 2× broth	1	60.5 ± 2.9	94
Black beans	AP; 80–215 min	15-h soak + broth	3	68.1 ± 71.7	83
		15-h soak − broth	3	67.0 ± 75.4	83
Black beans	PC; 30 min, 121°C	—	4	69.0 ± 72.0	354
	PC; 30 min, 121°C	18-h soak + broth	10	66.6 ± 74.5	313
Black beans	PC; 45 min, 121°C	Without broth	1	69.9 ± 6.2	189
		With broth	1	70.5 ± 2.9	189
		Without broth and hulls	1	75.4 ± 4.2	189
		Cotyledons only	1	81.3 ± 1.2	189
Black beans	Extrusion cooking	Recent harvest	1	68.0 − 77.6[b]	139
	Extrusion cooking	Hard-to-cook	1	71.8 − 81.5[b]	139
	PC; 25 min, 121°C	16-h soak: soft	1	69.0 ± 3.3[b]	139
	PC; 25 min, 121°C	16-h soak: hard	1	67.4 ± 5.8[b]	139
Black beans	PC; 30 min, 121°C	8-h soak + broth	21	71.5 ± 3.3	311
	PC; 30 min, 121°C	18-h soak + broth	1	62.8 ± 6.5	354
Black beans	PC; 15 min, 121°C	8-h soak + broth	10	72.4 ± 0.6	91
	PC; 30 min, 121°C	18-h soak + broth	5	67.4 − 74.9	46
Black beans	PC; 15 min, 121°C	18-h soak + broth	1	73.0 ± 1.6	121
	PC; 30 min, 121°C	18-h soak + broth	1	75.8 ± 2.9	121
	PC; 45 min, 121°C	18-h soak + broth	1	74.2 ± 9.0	121
Black beans	PC; 20 min, 121°C	18-h soak + broth	1	72.5	313
	PC; 30 min, 121°C	18-h soak + broth	1	68.2	313
Red beans	PC; 30 min, 121°C	8-h soak + broth	23	72.4 ± 2.9	311
			2	65.7 − 71.3	46
	PC; 30 min, 121°C	18-h soak + broth	4	76.1 ± 1.2	91
		18-h soak + broth	1	72.1	313
	PC; 15 min, 121°C	18-h soak + broth	1	69.2 ± 3.1	94
		− broth	1	71.8 ± 2.3	94
	PC; 30 min, 121°C	+ broth	1	66.8 ± 4.3	94
		2× broth	1	69.0 − 71.2	313
	PC; 20 min, 121°C	18-h soak + broth			
	PC; 20 min, 121°C				
	PC; 20 min, 121°C				
	PC; 20 min, 121°C				
White beans	PC; 20 min, 121°C	18-h soak + broth	1	71.4 − 74.1	313
		18-h soak + broth	1	75.4	313
	PC; 30 min, 121°C	18-h soak + broth	3	76.3 − 77.4	313
		− broth	1	74.3 ± 5.1	94
	PC; 30 min, 121°C	+ broth	1	72.7 ± 5.1	94
	PC; 20 min, 121°C	+ 2× broth	1	73.1 ± 4.2	94

Table 9. Continued

Legume grain	Process[a]	Other variable	No.	Prot. dig., %	Ref.
	PC; 20 min; 121°C				
	PC; 20 min, 121°C	− Methionine	2	77.0 ± 1.4	121
				77.1 ± 1.0	
	AP; 8.5 h, 100°C				
		+ Methionine	6	76.4 ± 1.3	121
				86.1 ± 0.8	
	AP; 8.5 h, 100°C				
		18-h soak + broth	3	79.5 ± 1.0	91
	PC; 15 min, 121°C				
Brown beans	PC; 15 min, 121°C	18-h soak + broth	3	73.9 ± 1.3	91
	PC; 30 min, 121°C	18-h soak + broth	3	66.4 − 73.7	313
Vigna sinensis, cowpea	PC; 10 min, 121°C	18-h soak + broth	1	74.3	313
	PC; 20 min, 121°C	18-h soak + broth	1	76.0	313
	PC; 15 min, 121°C	18-h soak + broth	1	77.5 ± 1.4	121
	PC; 30 min, 121°C	18-h soak + broth	1	77.5 ± 4.3	121
	PC; 45 min, 121°C	18-h soak + broth	1	74.3 ± 2.0	121
	Raw	Whole peas	1	73	188
	Raw	Decorticated	1	75	188
	Steamed	Decorticated	1	78	180
	PC; 20 min, 121°C	18-h soak + broth	1	63.2 ± 4.1	140
				72.0 ± 0.9	
Cajanus cajan, pigeon pea	PC; 15 min, 121°C	18-h soak + broth	1	80.4 ± 1.8	121
	PC; 30 min, 121°C	18-h soak + broth	1	78.6 ± 0.6	121
	PC; 45 min, 121°C	18-h soak + broth	1	78.1 ± 0.5	121
	PC; 20 min, 121°C	18-h soak + broth	1	73.7 − 76.4	313
Cicer arietinum, chickpea	Boiled		1	73.3 ± 1.6	160
	PC		1	73.8 ± 2.9	160
	Boiled	2-day germinated	1	76.2	160
	PC		1	77.5	160
	Boiled	4-day germinated	1	78.9	160
	PC		1	80.3	160
Chickpea	Various processes		1	87.5 − 92.8	340
Faba beans			1	77.7 − 83.5	340
Lentils			1	73.7 − 80.3	340

[a]AP: atmospheric pressure; PC: pressure cooking.
[b]True protein digestibility.

most grain legumes is a major problem. The protein digestibility of a number of grain legumes is shown in Table 9. With few exceptions, the digestibility is low, particularly for *Phaseolus*. The variability within one species is of interest. Some varieties are apparently more digestible than others, suggesting genetic effects. However, the variability could also be due to differences in bean age, handling after harvest, and processing. The frequency with which low values are reported for *Phaseolus* does suggest that it is a true characteristic.

Antunes and Sgarbieri (219), for example, showed that beans stored under poor conditions of temperature and relative humidity had an initial digestibility of 62.4%; after 6 months of storage, the digestibility decreased to 54.4%. There is also in interaction between soaking time and cooking time. In general, soaking times from 0 to 24 h followed by cooking times of 15 to 75 min decreased protein digestibility. However, there appeared to be an increase in digestibility with soaking, at low cooking times (310).

Studies with rats, utilizing 57 cultivars of black, red, white and brown beans, gave an overall digestibility of 72.7%. Black bean digestibility was 71.5%; red bean, 72.4%; white bean, 76.6%; and brown bean, 70.7% (311). When young growing dogs were fed 4 g prot/kg body wt/day from either red, black, or white beans, protein digestibility was 60.1%, 73.4%, and 70.3%, respectively (312). Using a multiple enzyme assay, the *in vitro* protein digestibility of 18 bean cultivars ranged from 67.8% to 76.6%. The *in vivo* values in rats ranged from 66.4% to 77.4% (313). All these studies consistently showed that white beans have a higher protein digestibility than black or red beans, and that beans with a brown testa have the lowest protein digestibility.

Studies have been conducted with human subjects (189, 306, 307, 314–316). Table 10 summarizes the results. The apparent protein digestibility of all beans is low, although white beans gave higher values than black or red. Protein level of intake may increase the digestibility value, but this needs to be demonstrated in human studies. Such an increase has been shown by nitrogen balance studies with young growing dogs fed common beans, dry beans, cowpeas, and pigeon peas (312). However, the increase was not large. Dogs were fed 0.675 g prot/kg/day (0.108 g N), equivalent to an intake of about 3.1 g beans/kg/day (22.5% protein). This is equivalent to the consumption of 195 g of beans (for a 65-kg person), an intake value much higher than currently consumed. In a comparative study with humans, rats, and *in vitro* assay, all protein digestibility values were highly correlated, indicating that *in vitro* and *in vivo* assays with rats can predict assays with humans (189). In all these studies, human digestibility values tend to be lower than rat values, a difference not yet explained.

The low protein digestibility of beans influences the protein digestibility of diets in which beans are a part. A summary of values of protein digestibility in humans fed bean/cereal diets or bean/starchy foods is shown in Table 11. Calloway and Kretsch (317) found that protein digestibility of a typical rural Guatemalan diet containing tortillas and beans in a 83.5/16.5% ratio was 69%. This diet induced fecal dry matter, nitrogen, and energy excretions nearly four times as high as an egg formula used as control. Results of similar studies (314, 318, 319, 320, 321) with children or adults fed beans in combination with other foods also demonstrate that there is a significant influence of bean protein to lowering protein digestibility. Of interest are the results of Vargas et al. (321, 322), which show that an addition of 10% skim milk to a rice/bean diet increases protein digestibility from around 59.4% to 64.9%, and also improves protein quality.

Table 10. Bean Protein Digestibility in Humans

Food legume	Process	Subjects (no.)[a]	Digestibility[b]			Ref.
			NI, kg/day	APD, %	TPD, %	
Peas	Cooked	A (6)	5.47	78.8	—	306
Peas + met	Cooked	A (6)	5.95	80.0	—	306
Common beans	Cooked	C (7)	6.4–6.7	65.6	—	307
White beans	Cooked	A (12)	5.8–5.9	62.0	74.5	316
White/black 50/50	Cooked	A (12)	5.8–5.9	57.4	69.4	316
Red beans	Cooked	A (12)	5.8–5.9	55.7	68.2	316
Black beans	Cooked	A (12)	5.8–5.9	49.6	61.7	316
Black beans	Cooked	A (12)	5.8–5.9	53.4	65.7	316
Black beans	Cooked	A (12)	5.8–5.9	60.2	74.9	314
Black beans	Cooked	A (12)	5.8–5.9	54.6	75.9	314
Black beans	Cooked	A (6)	5.8–5.9	57.8	79.1	314
Black beans	Cooked; ground	A (8)	5.8–5.9	48.4	75.5	314
Black beans	Cooked	A (9)	5.8–5.9	51.2	—	304
Red	Cooked	A (12)	5.8–5.9	51.8	—	304
White	Cooked	A (12)	5.8–5.9	57.3	—	304
Black beans	Cooked − cooking liquor	A (8)	5.8–5.9	67.1	—	189
Black beans	Cooked + cooking liquor	A (8)	5.8–5.9	68.7	—	189
Black beans	Cooked − seed coat − cooking liquor	A (8)	5.8–5.9	73.4	—	189
Black beans	Cooked cotyledon	A (8)	5.8–5.9	72.3	—	189

[a]A: adults; C: children.
[b]APD: apparent protein digestibility; NI: nitrogen intake; TPD: true protein digestibility.

The foregoing data and data obtained by others (189, 306, 308, 309, 314–316) prove that bean protein digestibility is low, and it would be desirable to improve it, independently of any relationship to protein quality. In other words, a higher protein digestibility does not necessarily imply that a higher protein quality will result (311), since absorption of the limiting essential amino acid methionine, which determines protein quality, may be similar in beans with either low or high protein digestibility.

It would be desirable, then, to study in greater detail the factors responsible for the low digestibility of bean protein. These factors include tannins, phytic acid, dietary fiber, residual enzyme inhibitors, carbohydrates, nitrogen compounds, and protein structure. These factors can be classified into three groups,

Table 11. Protein Digestibility of Diets Containing Beans

Diet	No. of subjects[a]	Nitrogen, intake, mg/kg/day	Digestibility[b] APD, %	TPD, %	Ref.
Guatemala; rural diet	6	140.0	69	—	317
Beans (13%); tortillas (87%)	6	127.6	61	86.7	314
Beans + cassava	10	105.7	55.7	79.8	309
Beans + plantain	10	117.1	50.4	81.0	309
Beans (15); rice (85), 45 kcal	10	102.1	59.1	70.8	321, 322
Beans (15); rice (85), 50 kcal	10	102.4	59.6	71.3	321, 322
Beans (15); rice (85) + 10% milk	10	104.5	65.3	76.8	321, 322
Beans (15); rice (85) + 10% milk	10	104.4	64.6	73.3	321, 322
Beans-rice (diet)	9	96.0	59.4	75.5	319
Beans (13); maize (87)	6 (C)	200.0	72	—	321
Bean-rice (diet)	12 (C)	190–198	56.9–72.7	—	318

[a]C: children.

[b]APD: apparent protein digestibility; TPD: true protein digestibility.

as shown in Table 12: the chemical compounds pertaining to the seed, both in the seed coat and in the cotyledon; the effects resulting from poor storage conditions; and the effects of processing.

Chemical Compounds: It is difficult at the present time to indicate which of the possible chemical entities listed above have a greater effect in affecting bean

Table 12. Factors of Interest Intervening in the Protein Digestibility of Edible Legume Grain

Factors in the seed coat
Tannins
Dietary fiber
Factors in the cotyledon
Tannins
Dietary fiber
Enzyme inhibitors
Protein structure
Phytic acid
Starch
Soluble carbohydrates
Storage and processing factors: chemical reactions
Tannins × protein
Protein × carbohydrate
Dietary fiber binding

protein digestibility. Therefore, the order in which they are presented does not imply a greater or lesser effect.

Tannins: The role of polyphenolic compounds in bean protein digestibility has been studied intensively. A negative correlation between polyphenols and *in vivo* protein digestibility has been reported and reviewed by many authors (90, 94, 323–332). Aw and Swanson (331) showed the influence of tannin on *P. vulgaris* protein digestibility and quality, using an enzyme bioassay (*Tetrahymena thermophila*). They reported that condensed tannins complexed readily with black bean globulin G1 to form insoluble precipitates between pH 2.0 and pH 8.0. These complexes were resistant to pepsin digestion at pH 2.0.

In another approach, it was shown (37, 38, 90, 94) that bean cotyledons, which are very low in tannin content, had a higher protein digestibility than the whole bean, whether white, black or red. Similar findings were reported by De Godinez et al. (189) in studies with humans. The influence of tannins on protein digestibility in humans was also studied by Bressani, Hernández, and Braham (316). A high significant positive correlation was found between catechin intake and fecal nitrogen excretion; and as a consequence, a negative correlation with protein digestibility. The same relationship was observed for tannic acid.

The effect of feeding different levels of dried cooking broth added to cooked whole beans on protein digestibility in rats, was studied by Braham and Bressani (94). The effect was directly associated to polyphenolic intake. These studies indicate that tannins do indeed decrease bean protein digestibility. The effect on digestibility has been estimated to be on the order of 8–10%. An important observation (94, 331) was that protein quality was also decreased by tannin intake, an observation which merits research, since it cannot be explained solely by the decrease in protein digestibility.

Mechanism of Tannin Effects: The negative effects of tannins have been reviewed by Price and Butler (327), Deshpande et al. (333), and Butler (328). These effects can be classified into three different groups, which may help explain their mode of action in digestion and metabolism. One group of effects includes those changes which take place upon bean processing, such as a redistribution of the tannins in the cooking liquor, seed coat, and cotyledons (90); formation of greater amounts of condensed tannins upon cooking (96); and formation of complexes between tannins and proteins and with other organic/inorganic compounds (334–336). The second group of effects take place upon food consumption, since the presence of tannins decreases food intake (94, 325, 334). It is possible that tannin + dietary protein complexes are formed during the chewing and digestion process (328, 337, 338). Within the gastrointestinal tract, the tannins may bind enzymes and intestinal tissue, thus increasing endogenous nitrogen excretion (327, 328). Bender and Mohammadiha (339) and Sandaradura and Bender (340) reported increased fecal excretion of DNA and N from rats fed cooked beans, and attributed the increases to an increased rate of mucosal cell turnover. Fairweather-Tait et al. (341) concluded from their studies that the high nitrogen excretion was due to indigestible carbohydrate, which increases the activities of the intestinal flora, leading to greater fecal nitrogen concentration. Recently, Lanfer-Marquez and Lajolo (342), using N- and S-labeled beans, reported that the ingestion of whole bean caused the highest N and S excretion, mostly from exogenous sources. Whole beans and, to a lesser extent, albumins also increased metabolic fecal nitrogen excretions, which represent around 20% of total N elimination. Isolated bean globulins were well digested. The authors concluded that other nonprotein components present in whole beans may be involved in the increase of both exogenous and endogenous fecal nitrogen. As previously indicated, beans contain from 8.3% to 14.5% of NPN, which if factored into the digestibility equation, will increase nitrogen digestibility.

These two groups of effects have a direct influence on the digestion process. The third group of effects are associated with the utilization of the absorbed nitrogen, since as tannin intake increases, protein quality decreases (94, 316). This effect may be due to two possible actions. One is that polyphenols may be absorbed and the body must metabolize them as a defense mechanism. Such a defense mechanism, according to Butler (328) and to Mehansho, Butler, and Carlson (343) is provided by salivary proline-rich proteins which have a high affinity for tannins. The lower quality could also be the result of phenolic compounds binding lysine or other amino acids in plasma, similar to the role of gossypol in cottonseed (344, 345). Finally, it has been shown that supplementation of tannin-rich diets for poultry with free methionine overcomes the antinutritional effect of tannin (346), although the mechanism is still not known. The digestibility and quality of the protein in beans can also be affected by reactions of tannins and legume starches (338, 347).

Phytic Acid: The phytic acid in the cotyledons of grain legumes represents about 98.5% of the total phytate in the seed. Phytate may complex dietary essential minerals in grain legumes, rendering them poorly available to monogastric animals. Zinc appears to bind phytic acid in the physiological pH range more strongly than other minerals (348). According to Sathe and Salunkhe (112), phytates also interact with proteins, resulting in reduced protein availability. Camus and La Porte (349) showed phytate/protein complexes to inhibit pepsin. Others (95, 350, 351) found that phytates inhibit α-amylase and trypsin activity. Vaintraus and Bulmaga (351) observed that the inhibitory action of phytate is manifested only when the phytate is bound with the protein substrate *in vitro*. Considerable inhibition of trypsin activity was observed only at high phytate concentration (350), and Reddy et al. (352) found no inhibitory effect of phytate on trypsin hydrolysis in great northern beans. Phytate can affect carbohydrate digestibility, according to Thompson and Yoon (338).

From the literature reviewed, it would appear that phytate plays a role in affecting bean protein digestibility by binding to digestive enzymes or to protein. However, the question is still open since no direct evidence is available on phytate content in beans and protein digestibility.

Residual Enzymatic Inhibitors: The presence of enzyme inhibitors in beans and the effects they have on the animal organism are very well documented. It is also accepted that appropriate heat processing will decrease or completely destroy the inhibition activity in beans (33, 353). Some concern has been raised about the presence of heat-stable trypsin/chymotrypsin inhibitors in common beans (354–357). Van der Poel (10), in his review, cited reduction in hemagglutinins from 74% to 100%, and inactivation of TI in *Phaseolus vulgaris* from 29% to 100%. However, for estimating a more precise bean protein nutritional value (186, 369) after processing, more detailed information is required on residual antinutritional factor (ANF) activity, based on functional ANF assays in various target animals.

Lajolo et al. (31) reported different degrees of thermal stability of α-amylase inhibitors at 80°C in 150 bean varieties; Hernández and Jaffé (358) obtained similar results in 87 of 95 bean selections. These studies indicated that the α-amylase inhibitor is quite stable. It is fully active after heating for 30 min at 60°C, but it is destroyed after 10–15 min heating at 100°C. In spite of the residual levels reported, Van der Poel (10) concluded that there was little correlation between residual activity of antinutritional factors in heat-treated beans and *in vivo* protein nutritional value.

Conventional cooking as practiced in bean-consuming countries inactivates all proteolytic inhibitors and lectins. However, cooking of ground raw bean flour does not result in a complete inactivation. Korte (359) showed that ground flour often used as a porridge, even if cooked, shows residual activity, particularly of lectins. This is important since bean flour is being used in mixtures which may have residual antinutritional effects (360).

Dietary Fiber: Dietary fiber is a group of cell wall polysaccharides which in recent years has received increasing attention due to consumer awareness of its health benefits (282, 361). Different types of fiber elicit different physiological responses such as decreasing gastrointestinal transit time, lowering blood cholesterol, slowing nutrient absorption, reducing hyperglycemia, and decreasing diverticulitis. Cell wall polysaccharides may also affect nutritive values by reducing intestinal availability of nutrients, particularly minerals (362–368).

Hellendoorn (273–275) pointed out that because of the high fiber content, dry beans can be a valuable component of the diet, by stimulating intestinal transit and lowering serum cholesterol. Acevedo and Bressani (369) reported values of 24.6%, 25.9%, and 26.8% TDF in cooked white, red, and black beans, on a dry weight basis. Their contributions to TDF in the total diet were, respectively, 6.4%, 6.7%, and 6.9%. No other food contained these high levels. Values for raw beans have been obtained, and they range from 15% to 25% (186, 369). These studies have also shown an increase in TDF upon cooking. For example, white cooked beans had 24.6% TDF, but when refried, the value increased to 27.3%. For red beans, the corresponding values were 25.9% and 31.4%; and for black beans, the values were 26.8% and 30.2%, respectively (369). On the basis of a daily bean intake of 55 g/person, dietary fiber intake from beans would be around 15 g.

The two main physical fractions of common beans are the seed coat, which represents 8–10% of the weight of the kernel, and the cotyledons, representing around 85% of the seed weight. The seed coat contains high levels of total dietary fiber, varying from 61% to 68% in raw beans, while the TDF of the cotyledons varies from 11% to 17%. These levels, as shown in Table 5, increase upon cooking, from 68% to 77% in the seed coat, and from 16% to 24% in the cotyledons (186). According to Srisuma et al. (370), the cell wall of the seed coat is rich in cellulosic structural polysaccharides (58.7–65.0%) and lignin (1.4–1.9%). On the other hand, the cell wall of the cotyledon is composed principally of matrix polysaccharides and is rich in hot-water-soluble polymers (25.7–32.5%) and hemicellulose B (14.6–19.2%). The TDF of beans contained from 15% to 20% protein (336), while the cell wall of the cotyledon contained from 11% to 14% (370). This protein was resistant to proteolysis and/or inaccessible to proteolytic enzymes. Saura-Calixto (335) found that the composition of DF contained appreciable amounts of tannins and protein, and Moron, Melito, and Tovar (371) indicated that *in vitro* the indigestible residue from black beans inhibited trypsin and α-amylase activity.

Dietary fiber apparently decreases protein digestibility (372). Similar results have been reported by other authors (373–376). Although most of these studies were not conducted with beans, due to their relatively high levels of DF, it can be inferred that their DF is a factor in causing low protein digestibility. In nitrogen balance studies with adult humans fed mixtures of beans and cereal grains, or beans and starchy foods, the digestibility of the protein was closer to that of beans than of cereals. This is taken as an indication that the complex DF nature of beans has a negative influence on protein digestibility (308, 309).

The mechanism is not well understood. It may be due to an increase in transiet time (273–275). Others have suggested that the effect is due to enzyme inhibition, both proteases and amylases (371). Another possibility is that the DF traps proteins directly or through tannin/protein complexes, making the protein unavailable to enzymatic digestion (369, 370).

The low digestibility of bean protein because of its DF poses an interesting dilemma in terms of bean nutritional quality. For populations consuming vegetable diets from cereal grains and vegetables, bean consumption represents the best protein complementary source. Unfortunately, beans also contain a component which decreases digestibility and alters the availability of other nutrients. Furthermore, it appears difficult to decrease DF in beans through genetic manipulation, since the DF is a very important structural component of the seed. If, in fact, DF is responsible for the low protein digestibility in beans, the answer to this constraint, then, lies in the improvement of the protein quality of the nitrogen from bean protein that is digested, and this digested nitrogen in food legumes is deficient in sulfur amino acids. Thus, it appears that if beans are to be a better protein supplement in people's diets of vegetable origin, they should contain higher levels of the sulfur amino acids, with as high a protein digestibility as possible.

Protein Structure: A factor often cited as being responsible for the low protein digestibility of grain legumes is the structure of its protein, particularly phaseolin (5, 330, 354–356, 377). This topic has recently been reviewed by Nielsen (378). These studies show that processing causes no significant changes in the secondary structure of phaseolin but significantly disrupts the tertiary and quaternary structures, which results in a large improvement in phaseolin digestibility. Although these studies are important in helping us understand the causes of the low digestibility of grain legumes, they have limitations since they are isolated systems and the influence of other factors is absent.

The available literature seems to indicate that the problem of low digestibility in beans is due to a combination of chemical components present in the seed, not to any single factor.

Effects Due to Poor Storage Conditions: As indicated in a previous section of this review, poor storage conditions result in an increase in the cooking time of beans (210–216, 220–225). This increase in cooking time results in a decreased protein digestibility as reported by Antunes and Sgarbieri (219). However, a bean sample cooked for 74 min at sea level had the same digestibility as that of beans cooked for 5 h at 2500 meters above sea level (58). This problem requires further research. It cannot be assumed from the few data available that protein digestibility decreases due to prolonged cooking time, assuming other factors remain constant.

Effects of Processing: The effects of processing on protein digestibility have also been discussed in a previous section.

The low protein digestibility of common beans and of other legume grains is far from being solved or understood. The accompanying diagram (Fig. 4) may be useful in planning research strategies. This diagram, based on available data, represents protein digestibility. It shows raw beans to have a low but not well established value, primarily due to the presence of enzyme inhibitors. For purposes of discussion, the value assigned is 30% (379). Upon cooking, the common enzyme inhibitors are inactivated, and as a result, protein digestibility increases. The increase depends on bean color possibly due to tannins. Using data from Table 10, the digestibilities of black, red, and white beans have been set at 54%, 56%, and 60%, respectively. Tannins and probably phytic acid are still active in the cooked samples. Tannins are mainly in the red and black beans, and possibly only phytic acid in white beans, which do not contain high levels of tannins. Dehulling before cooking increases digestibility to 73%. This increase may be due to removal of the DF from bean hulls. The effect could also be explained by the removal of the tannins in the hull, which therefore cannot

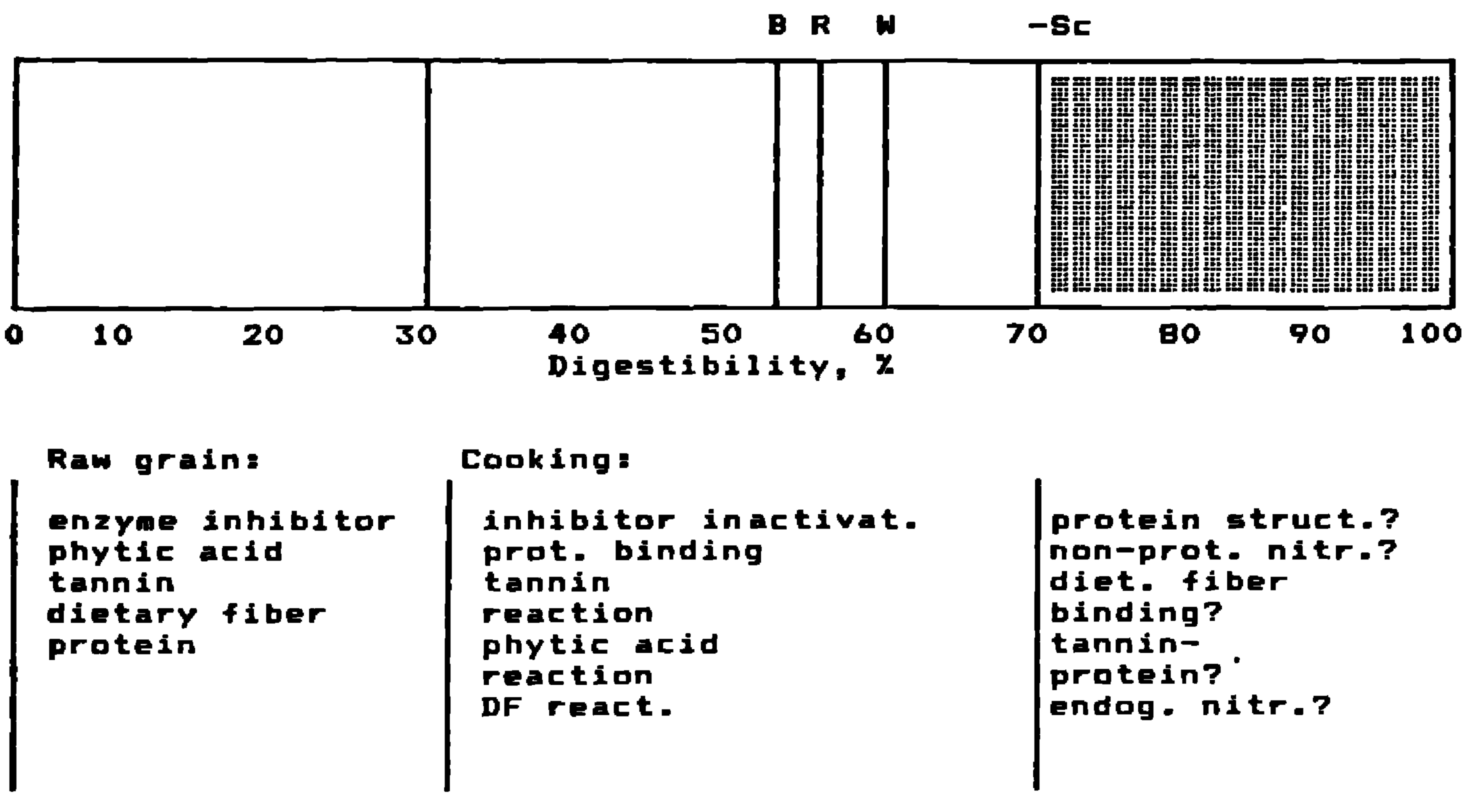

Figure 4. Graphical representation of factors involved in protein digestibility of legumes. B: black beans; R: red beans; W: white beans; – SC: without cotyledon.

react with other compounds while beans are being cooked. This diagram (Fig. 4) shows some 27% nondigestible protein. A slightly lower value for undigested protein would result if the ingested N were true protein nitrogen rather than total nitrogen. This undigested protein could be protein trapped by DF in the cotyledons of beans, protein structures not easily digested, and/or endogenous fecal nitrogen. This is an area that requires additional research.

Carbohydrate Digestibility

Common beans have been considered as foods containing relatively high levels of protein. However, the most abundant chemical components are the carbohydrates, which amount to 50–60% on a dry weight basis. However, since beans are a small portion of the total diet, they are not considered as carbohydrate sources, particularly in comparison to cereal carbohydrate intake. However, being present in a relatively high concentration, it is probable that they influence the nutritional value of beans. Of significance in this respect is the digestibility of legume starches, both *in vitro* and *in vivo.*

According to Reddy et al. (6), food legumes contain between 4% and 15% of total sugars. The variability depends on the species and variety. Although glucose is the most abundant, much attention has been given to the oligosaccharides of the raffinose family of sugars. These sugars are found in relatively high amounts in mature food grain legumes and make up from 30% to 80% of the total soluble sugars. These nonreducing sugars include raffinose, stacchyose, and verbascose. Their large intake causes flatulence in humans and animals. Reddy et al. (6) reported *P. vulgaris* to contain from 0.2% to 0.9% raffinose, 0.2% to 4.0% stacchyose, and 0.1% to 0.5% verbascose. These heat-stable sugars of the raffinose family cannot be digested by humans, nor can they pass through the intestinal wall. Due to these characteristics and to the formation of flatus, efforts have been made to eliminate them during processing. Reddy et al. (380) found that significant amounts of flatus-producing sugars are extracted when beans are soaked and the water is discarded. Iyer et al. (381) reported losses of 70–80% raffinose oligosaccharides when beans were soaked for 18 h at 72°C. Similar losses were reported by Iyenger and Kulkarne (382). Germination of the grain legume also results in a significant removal, around 70%, of the raffinose family oligosaccharides (78, 162–165). Fermentation is also effective in reducing raffinose oligosaccharides from grain legumes (173, 174, 176).

The size and shape of starch granules vary between grain legumes (383–385). *In vitro* studies using mammalian amylases show that the starch from maize and other cereal grains is more easily digested than the starch from legume grains (285, 385, 386, 390, 391). The yield of starch varies between 28.5% and 31.5% in bean varieties (387), and the starch granules are larger in legumes than in maize. These workers found that in comparison to maize starch, bean starch has a similar water absorption capacity and forms stable gels at lower concentrations. The swelling and solubility are both temperature and pH dependent. The same workers also reported that the retrogradation tendency of maize starch was much higher than that of the bean samples. The damaged starch content, water absorption, and swelling were higher for isolated starches from hard-to-cook seeds than for the controls (388, 389). According to Sathe et al. (386), there is a wide range in the amylose content of legume starch, from 10% to 45%. The complexity of the carbohydrate fraction in beans is probably responsible for the differences between *in vitro* and *in vivo* digestibility results (180, 387, 388). The *in vitro* digestibility of legume starch, using α-amylase from animal sources, is higher than legume starch digested with α-amylase from microbial sources, according to Ganesh Kumar and Venkataraman (171) and Geervani and Theophilus (170). Furthermore, starches with a higher amylose content are of lower digestibility than starches with lower levels of amylose. Other factors probably responsible for lower starch digestibility include the physical isolation of starch by the cell wall (285, 286, 392, 393). Tovar et al. (393, 394) reported that red kidney bean and lentil precooked flours contained intact cells filled with gelatinized starch and retrogradated amylose. Of the total starch ingested, about 8% from beans and 12% from lentils appeared in the feces of rats. This indicated a relatively low starch digestibility, around 89–92%. The *in vitro* digestibility of food legumes increases with processing—in particular when subjected to boiling, pressure cooking, roasting and parching, germination, fermentation, and extrusion cooking. This increase is probably due to an increase in the swelling and rupturing of the cell and of the starch granules, and to inactivation of α-amylase inhibitors. Although some studies indicate that grain legume starch influences protein metabolism (395–397), the evidence is not strong enough to conclude that legume carbohydrates in general, or starches in particular, have an adverse effect on protein digestibility.

FOOD PRODUCTS

Neither bean production nor daily bean intake per person has changed significantly in countries where beans are a popular food, during the last 10–15 years (398). Any increase in production is absorbed by increases in population. In Africa and Latin America any increase in production has been due more to area expansion rather than to yield increases. According to Janssen (398), by the year 2000 Africa will have to increase production 72% above present levels; and Latin America, about 42% over present levels. Market forces and profitability will determine the future of bean production. Bean-producing farmers would probably benefit more economically, and would increase production, if value-added products could be marketed.

During the last few years, attempts have been made in different countries to diversify bean use based on their relatively high protein and lysine content. This, as indicated, makes them a good protein supplement to cereals. There is also a need to produce high-quality foods such as weaning foods. Food product development may lead to practical ways of utilizing beans which have become hard-to-cook due to improper storage, and to the reduction of postharvest losses. The following section briefly reviews the research which is underway on utilization of beans and their preparations as an ingredient in food product development.

Preparation of Bean Ingredients

Dehulled Flour

The processing of beans to develop bean ingredients for food product formulation is done either by dry or wet techniques. The dry technique involves the separation of the seed coat, as a first step. The beans are used either raw or after roasting, and bean flour of an attractive physical appearance is produced. The removal of the seed coat results in a product of slightly higher protein content, higher protein digestibility, and very good rehydration properties (155, 399).

The wet technique starts with raw-dehulled beans. A legume flour is obtained, either by regular wet cooking and drying, or by extrusion cooking. These types of flours have been tested in a number of applications.

Protein Concentrates and Isolates

Bean protein concentrates and isolates have been obtained by either air classification or protein extraction. For air classification, the bean flour is finely ground and separated into fractions by a special air stream (190–192). According to Sosulski et al. (192), concentration of the protein is possible because of the differences in size, shape, and density of the heavier starch granules from the lighter protein-containing particles. The preparation usually contains 40–50% protein.

Protein concentrates and isolates can also be prepared by extraction and precipitation of the protein from the extract. The basic process consists of extracting the raw-dehulled bean flour with an alkaline solution, followed by precipitation at the isoelectric point (155, 400–405). An alternate procedure is to extract the protein with a salt solution and then precipitate the protein by dialysis or heat denaturation. These preparations not only contain high protein but are also free of undesired components. Murphy et al. (403) reported on the preparation of a protein concentrate, from common beans, without flatulence activity. Sathe et al. (406–408) observed in their protein isolates, absence of hemagglutinin activity and flatulence factors, as well as lower activity of trypsin inhibitors. However, Deshpande and Cheryan (404) reported that their protein concentrate had high trypsin inhibitor activity. Sathe and Salunkhe (112) indicated that prolonged treatment of the protein with alkali could result in a decrease in protein solubility and amino acid crosslinking with sugars.

Utilization in Food Products

Weaning Foods

Bean flours, as well as bean protein concentrates and isolates, are good nutrient sources when combined with cereal grain flours in the preparation of infant and weaning foods. Ballesteros et al. (409) and Valencia et al. (410), using linear programming, developed infant foods from cereal and food legume flours, which were similar in terms of nutritional protein quality to infant foods developed using cereal grains and common beans (263–267). The quality of these products was superior when the bean flour used had the seed coat removed (107). Marero et al. (411) developed a technology for preparing weaning foods from germinated cereal and grain legumes. Others have developed weaning foods from cereal/legume mixtures prepared by malting and then roller drying (412, 413).

Composite Flours

The high-fiber fraction resulting from dehulling has been used successfully as a source of dietary fiber in cookies and quick breads (414, 415). Whole bean flour and bean protein fractions have been used to increase the protein of white bread and of chemically leavened quick breads and cookies (131, 416, 417). Aguilera et al. (132) developed food ingredients from navy beans processed by roasting, followed by milling and air classification. Some of these ingredients have been used in cake doughnuts (101, 133).

Bean products have been used as components of composite flours in a number of different food products (418–421). These composite flours have been evaluated for their acceptability in bread and bread products (417, 422–424). Other food products made from cereal grains and bean flours include cookies (425, 426) and various types of snacks (427, 428), as well as pasta products (373, 418, 419, 429, 430). In all these studies, the addition of bean flour at levels up to 25% increased protein content, lysine content, and protein quality. However, losses in functional properties were observed, yielding products of lower acceptability. The functional properties of these composite flours are of great importance (405–408, 416, 418, 419, 424).

The concept is without doubt good, but additional research is needed to develop processes for using bean flour and retaining desirable functional characteristics. The physicochemical characteristics and the rheological properties of bean flours and other bean-derived constituents are of the greatest importance in determining their utility in food applications.

SUMMARY

Food grain legumes represent the main supplementary protein source in cereal- and starchy foods-based diets consumed by large sectors of the population in developing countries. Their availability and nutritive value is, therefore, of the greatest importance. Grain legumes are also becoming more important in the diets of populations in developed countries due to their health-related attributes, which include hypocholesterolemic and hypoglycemic effects. This paper discusses the importance of maximizing grain quality characteristics in food grain legumes, an activity that requires the integrated participation of geneticists, biotechnologists, agronomists, food scientists, and nutritionists. Grain quality characteristics in grain legumes include a great many desirable attributes related to production and postharvest biochemistry and technology. It is of importance, therefore, to identify and define them in terms of the physical, chemical, technological, and nutritional properties of the grain—properties that are not necessarily related to each other, nor to yield. This review attempts to identify the grain quality components of food grain legumes, other than yield. These have been classified into two main groups: (*a*) the acceptability and (*b*) the nutritional components. These depend on the genetic makeup of the grain and on agronomic practices but may be significantly affected by postharvest technology and pro-

cessing methods. The effects of processing techniques on nutritive quality are presented. These include: moist cooking at atmospheric conditions and under pressure; dry cooking, including roasting and extrusion cooking; and fermentation, germination, milling, and irradiation. The problem of bean acceptability is then reviewed, including the physical aspects of the grain and the development of the significant increase in cooking time, known as the hard-to-cook characteristic of beans, which develops under inappropriate storage conditions. Among the grain quality nutritional components, the document reviews the significance of protein, lysine and methionine contents, as well as factors such as tannins, phytic acid, and dietary fiber that limit the biological utilization of the nutrients in food grain legumes, particularly that of protein digestibility of beans alone and as a diet component. In this last respect the document summarizes human protein digestibility data and presents in schematic form the effects of individual factors in beans that may, alone or together, influence protein digestibility. The last section discusses the need to diversify the use of grain legumes in food product development, as a way to stimulate production and consumption of food grain legumes.

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