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Starchy legumes in human nutrition, health and culture

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Abstract. Starchy legumes have been consumed by humans since the earliest practice of agriculture and have been ascribed medicinal and cultural as well as nutritional roles. They are an important component of the diet in the developing countries in Africa, Latin America, and Asia where they are especially valuable as a source of dietary protein to complement cereals, starchy roots and tubers. Legumes contain 20–30% protein which is generally rich in lysine and limiting in sulfur amino acids. The nutritional quality of legume protein is limited by the presence of both heat labile and heat stable antinutrients as well as an inherent resistance to digestion of the major globulins. In addition to its nutritional impact, legume protein has been shown to reduce plasma low density lipoprotein when consumed. Legume starch is more slowly digested than starch from cereals and tubers and produces less abrupt changes in plasma glucose and insulin upon ingestion. Starchy legumes are also valuable sources of dietary fiber as well as thiamin and riboflavin. Starchy legumes are a valuable component of a prudent diet, but their consumption is constrained by low yields, the lack of convenient food applications, and flatulence.

Introduction: Historical perspectives

According to Aykroyd et al. (1982), the transition from hunting-gathering to agriculture for the cultural ancestor of western civilization occurred between 11 and 7 thousand years BP (before present) in the fertile crescent of the Near East. Similar events occurred in roughly the same time frame in Asia and Meso-America. Legumes were among the important crops pertinent to that transformation (Table 1). Aykroyd et al. (1982) describe an archaeological site in Halicar, Turkey which has yielded remains of wheat, peas and lentils as well as grinding stones and sickles, dating from 7500 BP. In Turkistan, carbonized (by cooking fires) peas, lentils and vetch seed were found which may be a thousand years older. In the New World, remains of kidney beans, squashes, peppers and gourds dating from 6000 BP were found in caves in Ocampo, Mexico. Evidence indicated that maize consumption at that site came 1000 years later, although the sequence was reversed

Table 1. Archeological record of legume consumption by humans

Domesticate	Nature of remains	Location	Estimated age
Arachis hypogaea	fruits	Huaca Prieta, Peru	2850
Cajanus cajan	seeds	XIIth Dynsasy tombs, Egypt	4000
Cicer arietinum	seeds	Turkey	7000
Lathyrus sativus	carbonized seeds	Jarmo, Iraq	8000
Lens culinaris	seeds	Jarmo, Iraq	9000–8500
Phaseolus acutifolius	unspecified	Tehaucan, Mexico	7000
P. coccineus	unspecified	Tehuacan, Mexico	2200
P. lunatus	fruits and seeds	Chilca, Peru	7300
P. vulgaris	fruits	Tehuacan, Mexico	7000–5500
	seeds	Huaylas, Peru	7680
Pisum sativum	carbonized seeds	Catal Huyuk, Turkey	7850–7600
Vicia faba	seeds	Jericho	8000
Vigna mungo	carbonized seeds	Navdatoli-Maheshwar, India	3660–3440
V. radiata	carbonized seeds	Navdatoli-Maheshwar, India	3660–3440

Taken from Smartt and Hymowitz (1985).

in other locations. Not only have lentils been found in Egyptian tombs of the 12th dynasty (4400–4200 BP), the preparation of lentil soup was depicted in a fresco of that period, indicating a singular importance in the diet. Legume cultivation continued to be of wide-spread importance where agriculture was practiced. The archaeological record from Iron Age Britain some 2500 years ago has revealed the prominent cultivation of Celtic beans along with primitive strains (emmer, spelt, and einkorn) of wheat. At Butser Experimental Archaeological Farm near Stonehenge, these ancient crops are being grown under conditions similar to the historical period being investigated and are producing surprisingly large yields (Murphy, 1985). The simultaneous archaeological occurrence of legumes and cereals provides evidence of legume consumption along with cereals from earliest times.

In addition to archaeological findings, the written record refers to legume consumption in several notable and less notable instances. From Genesis, Chapter 15 (The Holy Bible; religious implications aside, an account of nomadic herdsmen of about 4500 BP) comes the story of Jacob and Esau. Legumes figure prominently in this account of the ascendancy of farmer-herder over hunter. Esau, the elder son of Isaac, being unsuccessful at hunting, turned to his younger brother for more reliable if less savoury food: a mess of pottage-red lentil soup (Aykroyd et al., 1982). The exchange of Esau's birthright for agriculture-derived food could serve as an allegory for the profound cultural changes which were underway at that time. It is also an early example of the subtle or not-so-subtle prejudice against legumes as 'poor man's meat'. Jacob's lentil pottage is unfavourably contrasted with 'savory venison' in the story, amplifying the discrepancy between what Esau got and what he gave up. On the other hand, calling pulses 'meat' at all implies an understanding that they could serve some of the same needs as animal flesh, far earlier than protein and its nutritional role were part of man's intellectual knowledge.

Much later during the Babylonian captivity (The Holy Bible, Daniel, Chapter 1), about 2300 BP, comes the first account of a human dietary experiment (Aykroyd et al., 1982). The test group was comprised of the citizens of Judah, Daniel and his three friends, who convinced their captors that they would thrive better on 'pulse and water' than the 'King's meat'. The control group consisted of other young captives eating the prescribed food and wine. After 10 days, the outward appearance of the test group was reported to be superior to that of the control to the great relief of the King's servant who had countermanded his sovereign's orders so that the experiment could take place. Aykroyd et al. (1982) point out that there is no suggestion of divine intervention in this story, but that 10 days is a rather short time for nutritional impact to be so clearly visible. On the other hand, a diet rich in fat and alcohol might well result in visible deterioration in the appearance of young men over the course of a few days. Even here, although legumes are depicted as wholesome, even righteous foot, there is a definite sense of sacrifice by these virtuous youths. There are doubtless many other examples of legumes in history, literature and culture which space does not permit to be explored. One which I cannot resist mentioning is a sign for the village of 'Pease Pottage' – perhaps related to the old English nursery rhyme – seen while travelling south by bus from London/Gatwick airport to Brighton.

Rationale for inclusion of legumes in diet and culture

Given the apparent ambivalence towards legumes, the question arises: why were they so prominently featured in ancient agriculture? In the absence of clear, written explanations, we must speculate to some degree. Early man undoubtedly ate a wide variety of plant foods, essentially what was available and proved to be healthful. Legumes are among the most adaptable of plants (Adams and Pipoly, 1980) and are found in all climatic zones inhabited by early man. Grivetti (1987) notes that the Tlokwa people of Botswana, a contemporary agro-pastoral-hunter-gatherer society, utilize 130 species of edible wild plants. He further develops the thesis that domestication of plants resulted for mythological-aesthetic reasons, i.e. for ceremonial purposes or for beauty, rather than from the need for food. The

Table 2. Medicinal uses of legumes

Legume	Part of plant	Medicinal uses	
		Number	Examples
Pigeon pea	leaf, roots seeds, flowers	21	sores, bladder stones
Chickpea	leaf, stem, pod	17	aphrodisiac-warts
Lentil	seed	2	constipation, skin ulcers
Lupin	seed	13	diabetes, sores
Lima bean	seed	6	fever, stomachache
Common bean	seed	20	acne, hiccups
Pea	seed	7	emollient, contraceptive
Faba bean	seed	3	diuretic, tonic
Mung bean	seed, roots	6	rheumatism, narcotic
Cowpea	seed	2	sacrifice, boils

Assembled from Duke (1981).

rationale for this conclusion is the abundance of wild grains in the areas where domestication is thought to have arisen. Plants as well as animals have served to appease the gods, predict the future and otherwise impinge on human life in apparently non-rational ways. Grivetti (1987) describes how the sprouting barley was used to confirm pregnancy and even the sex of the fetus in ancient Egypt, a test supported in part by modern research. In southeastern Nigeria, village women pointed out 'male' and 'female' cowpeas to the author, although their significance to the propagation of the species human or *Vigna*, remained unclear. Additionally, the distinction between food and medicine is often blurred in pre-industrial, and sometimes in modern, societies. Many leguminous food plants also have been used in folk medicine (Duke, 1981). A few examples are shown in Table 2. While few modern physicians would likely prescribe legumes as medical treatment (although some non-nutritional health effects have been described), the range of effects claimed by our forebears is remarkable in its scope.

Smartt and Hymowitz (1985) quoting Harlan (1977) agree with Grivetti (1987) that cultivated plants were and are more than mere food sources. Rather, they are part of man's culture and co-evolved with it. However, somewhat at variance with Grivetti (1987), these authors conclude that at the dawn of agriculture, man did not cultivate a random or impractical collection of crops, but only those which met the nutritional needs of the population and their livestock, and those whose production was indefinitely sustainable. Whaterver the original rationale for consuming legumes, the reasons for including them in the agricultural mix, then as now, must have stemmed from their usefulness in human culture including their compatibility in the overall agriculture.

While the pulses currently consumed are doubtless different from their wild and early cultivated ancestors, assessment of their past, present and possible future contribution to man's health and nutriture must derive from their agronomic and compositional characteristics. There are various practical reasons for cultivating legumes. As previously mentioned, legumes are adaptable to a wide range of habitats, more than any plant family except the grasses (Adams and Pipoly, 1980). Thus, various species can be grown from humid to arid tropics to cold temperate zones. Secondly, legumes are compatible with cereal production for a number of reasons including growth season, plant architecture, and the valuable ability of legumes to fix nitrogen for their own use and that of companion plants. Today, as in the past where legumes are important for human food, they are frequently intercropped with cereals (Dovlo et al., 1976). The nutritional complement between cereals and legumes arises from their composition and will be discussed later. Legumes also provide variety and a flavorful complement to bland cereal-based diets in which meat is in short supply. For example, all across West Africa legume dishes contribute to variety in the diet. A particularly popular dish in this region is a fried cowpea batter containing seasonings ('akara' or 'kosai'). This product is usually consumed with cereal or tuber-derived staples. Among the Hausa people of Niger and Northern Nigeria, the staple fermented millet paste, 'toa' is accompanied by a sauce made from cowpea.

Finally, like the dry seeds of cereals, legume seeds are capable of being stored from harvest until the following planting season. Dry legume seed is customarily stored much as cereal grains are, although they may be more susceptible than cereals to insect pests. In West Africa, traditional storage structures include woven or mud and daub structures. Leaves of the neem tree, ashes, or other additives are often mixed with stored cowpea seed to discourage insect pests. Modern concrete buildings and sealed drums are also used.

The number and identity of food legumes which are claimed to be important to humans varies depending on the authority cited. Salunkhe et al. (1985) tabulate 22 major species while Hymowitz (1987) mentions 12, one of which is not on the longer list. The most extensive catalog is shown in Table 3. The production of major food crops in the 1979–81 period is shown in Table 4. The large number and low production of food legumes contrast sharply with the small number and enormous production of stable cereal grains. These figures raise the questions: What are the constraints on legume consumption, that is: Why is there relatively limited cultivation and produc-

Table 3. Most common food legumes

Scientific name	Common names
Arachis hypogaea L.	Ground, Peanut
Cajanus cajan (L.) Millsp.	Pigeon pea, Red gram, Congo pea Arhar, Tur, Gongo pea
Cicer arietinum L.	Chickpea, Bengal gram, Garbanzo, Gram
Glycine max (L.) Merr.	Soybean, Soya
Lablab purpureus (L.) Sweet	Hyacinth bean, Egyptian bean, Val.
Lathyrus sativus L.	Khesari, Chickling vetch, Grasspea
Lens culinaries Medik.	Lentil, Masur
Lupins albus L.	White lupine
Lupinus angustifolius L.	Blue lupine, New Zealand blue lupine
Macrotyloma uniflorum (Lam.) Verdc.	Horse gram, Madras gram, Kulthi
Phaseolus lunatus L.	Lima bean, Butter bean
Phaseolus vulgaris L.	Bean, Common bean, French bean, Field bean, Haricot bean, Pinto bean, Navy bean, Dry bean
Pisum sativum L.	Common or Garden pea, Dry pea
Psophocarpus tetragonolobus (L.) DC	Winged bean, Goa bean, Four-angled bean Manila bean, Princess pea
Vicia faba L.	Broad bean, Faba bean, Horse-bean
Vigna aconitifolia (Jacq.) Marechal	Moth bean, Mat bean
Vigna mungo (L.) Hepper	Urd, Black gram
Vigna radiata (L.)	Green gram, Golden gram, Mung bean
Vigna umbrellata (Thunb.) Ohwi and Ohashi	Rice bean, Mambi bean
Vigna unguiculata (L.) Walp. ssp. *unguiculata*	Cowpea, Black-eyed, Crowder pea
Voandzeia subterranea (L.) Thouars	Bambarra groundnut

Taken from Salunkhe et al. (1985 with permission).

Table 4. World production of major crops (1980)

		(Million Metric Tons)			
Wheat	460	Soybean	90	Dry bean	15
Maize	450	Peanut	20	Pea	10
Rice	415			Chickpea	8
Sorghum	70			Broad bean	7
				Pigeon pea	2
				Cowpea	1.5
				Lentil	1
				Others	5
Total Cereal	~ 1400	Total Oilseeds	~ 110	Total Pulses	~ 50

Assembled from Hymowitz (1987); Salunkhe et al. (1985); and Akroyd (1982).

tion now? and What is the current nutrition and health impact of legume consumption?

Constraints on production and consumption of starchy legumes

A major reason for the relatively small production of legumes compared to cereals is the much lower yield per area of the former. On average, cereal grains produce about 1700 kg/ha while the yield of pulses is less than half that (Aykroyd et al., 1982; Salunkhe et al., 1985). These statistics are somewhat misleading because most cereal grains are produced in developed countries by modern agricultural practice while most pulses are produced in developing countries by subsistence methods. Nevertheless, the yield of legumes is limited by three biochemical characteristics, two of which are also responsible for their value. First, the nitrogen fixation process requires energy in the form of carbohydrate fuel for the *Rhizobium* bacteria responsible for it. This is calculated to reduce potential grain yield by about 10%. Secondly, the synthesis of protein requires almost twice as much energy (as glucose) as does the synthesis of starch. Thus the valuable protein of legumes is synthesized at the expense of greater overall yield. Thirdly, legumes exhibit photorespiration which consumes 30% of photosynthethate and from which there is no known benefit. Cereals such as maize function without this process (Hymowitz, 1987). In addition to these inherent limitations of legumes, cereals have been for focus of much more production-increasing research culminating in the green revolution varieties of wheat, maize and rice. Such efforts have been applied to legumes only in the last decade (Summerfield and Roberts, 1985). Many improved cultivars have been developed in that time but low demand for legumes in areas with advanced agriculture and the understandable conservatism of subsistence farmers where legumes are important have blunted the potential effects of these advances. In addition to economic/production constraints, the low demand in industrialized countries is undoubtedly related to a complex of reasons including the ability to satisfy protein needs with more desirable animal products produced from high-yielding grains; the lack of tasty, convenient legume-based foods; and the adverse physiological reaction to legume consumption arising from various non-nutritional and antinutritional constituents. This last point will be discussed below in assessing the actual and potential health and nutritional impact of legume consumption. The fact remains that legume consumption is inversely related to income (Aykroyd, 1982) and retains the pejorative 'poor man's meat' even in countries where they are the major source of protein.

Table 5. Legume intake in 63 countries of the world

No. of countries	Legume grain intake (g/capita/day)
33	2–13
10	14–24
15	25–35
1	36–46
4	47–57

Country	Legume grain intake from dietary surveys (g/person/day)
Togoland	13–140
India	14–114
Countries south of Sahara	10–150
Guatemala	50
Nicaragua	85
Venezuela	89
Brazil	48

Taken from Bressani (1975).

Impact of legume consumption

The actual impact of legume consumption depends on the *amount consumed*, the *composition* of the species being consumed and any *interaction* between components which may modify digestibility or availability of endogenous nutrients to the consumer. The amount of legume consumption varies widely from region to region (Table 5). Balance sheet type data based on total production and total population gives only the crudest estimate of consumption (Bressani, 1975). A more accurate indication is gained from properly designed surveys in defined populations. These data indicate that persons in many developing countries consume rather remarkable levels of legumes, in excess of 100 g/day in some cases. In contrast, consumption in the U.S. of dry beans and peas has declined 44 and 30%, respectively between 1960 and 1981 to a total of 2.0 kg per year or 5.5 g/day (Kinsey, 1987).

Protein is the nutrient most heavily emphasized when the value of pulses in human diets is discussed. As shown in Table 6, the protein content of legumes differ widely, with as much variation within species as among them (Salunkhe et al., 1985). It is, in any case, 2 to 3 times (dry basis) that of the cereals, starchy roots and tubers which comprise the staple in the semi-arid and humid tropics. The high concentration of protein is, of course, the major reason that legumes have served as a substitute or replacement for meat since earliest times. Legume seeds are characterized by cotyledons which comprise 90% of the total seed weight. The seed coat (8%) and embryonic

Table 6. Protein contents of food legumes

Legume	Range (%)
Chickpea	14.9–29.6
French bean	21.1–39.4
Groundnut	23.5–33.5
Peas	21.2–32.9
Faba bean	22.9–38.5
Cowpea	20.9–34.6
Winged bean	29.8–37.4
Horse gram	18.5–28.5
Pigeon pea	18.8–28.5
Green gram	20.8–33.1
Black gram	21.2–31.3
Lentil	20.4–30.5
Rice bean	18.4–27.0
Cluster bean	19.3–27.8
Soybean	32.2–45.2
Moth bean	21.0–31.3
Lathyrus	22.7–29.6

Taken from Salunkhe et al. (1985 with permission).

axis (2%) comprise essentially the remainder (Aykroyd et al., 1982). Legume proteins are predominantly (~ 70%) globulins which reside in protein bodies of the cotyledons and which are the major repositories of stored nitrogen. There are two major globulins in most legume seeds: the 11s, 300–400 kd, legumin type: and the 7s, 150–175 kd vicilin type. Although these vary in size, number and type of subunits and carbohydrate content, they are both rich in the acidic amino acids and their amides and poor in sulfur containing amino acids. The relative distribution of storage protein as 11s and 7s varies among different species. The remainder of seed protein is comprised of a very large number of enzymes and other functional proteins which are albumins containing relatively more sulphur amino acids than globulins. In addition there are poorly characterized structural proteins which behave as glutelins (Norton et al., 1985).

In considering the nutritional importance of protein from any source, it is necessary to remember that humans (or other animals) have no requirement for protein *per se*, but rather for essential amino acids and amino nitrogen. Thus the value of any dietary protein is, to a first approximation, controlled by its amino acid profile. As is the case with protein content, the essential amino acid composition of legume seeds is quite variable (Table 7). Most attention has been paid to the content of lysine and sulfur amino acids. It is well established that legumes are valuable complements to cereals because legume proteins are good sources of lysine which is deficient in

Table 7. Ranges of essential amino acids in starchy legumes

Essential amino acid	Content in starchy legumes	
	Range	Extremes
Lysine	5.1–8.9	Lentil-Pea
Methionine	0.08–1.9	Lentil-Velvet bean
Cystine	0.7–1.5	Mung Bean-Velvet Bean
Total SAA	(1.2–3.4)	Mung Bean-Velvet Bean
Tryptophan	0.4–1.9	Lathyrus-Cluster Bean
Threonine	2.3–4.6	Lathyrus-Winged Bean
Valine	3.3–6.9	Moth Bean-Green Gram
Leucine	5.9–9.5	Cluster Bean-Pea
Isoleucine	3.1–7.4	Pigeon Pea-Pea
Phenylalnine	3.2–9.0	Rice Bean-Pigeon Pea
Tyrosine	2.0–4.3	Pigeon Pea-Velvet Bean
Total AAA	(6.9–10.3)	Fenugreek-Pigeon Pea
Histidine	2.1–3.8	Lentil-Rice Bean

Based on information in Salunkhe et al. (1985).

cereals, while cereal proteins are reasonably good sources of sulfur-containing amino acids which are limiting in legumes. This fact and the high concentration of protein in pulses are the two most salient features of the cereal-legume symbiosis (Salunkhe et al., 1985; Norton et al., 1985; Bressani, 1975). The third element contributing to the impact of legume protein in the diet is the presence and level of other seed constituents which may modify the availability of amino acids. Protein digestibility in legumes is known to be lower than that of either animal-derived or most cereal-derived proteins. Although the values reported in the literature are variable, they can be lower than 50% for some species, especially for raw seed (Bressany and Elias, 1980). A number of components have been characterized as interfering with the release of amino acids during digestion or their subsequent absorption (Liener, 1975, 1980). Lectins (glycoproteins capable of binding to the gut wall and dispupting its function) and protease inhibitors (proteins which bind to and inhibit the action of digestive enzymes) are the most important modifiers of legume protein quality. Fortunately lectins and enzyme inhibitors are partially-to-totally inactivated during cooking. That lectins interfere with protein digestion has been demonstrated by incorporating isolated lectins into purified (casein) diets. The effect of lectins on protein digestibility was observed to be non-linear, with an increasingly severe effect above about 0.3% lectins in the diet (Jaffe and Camego, 1961). Lectins are implicated in more severe toxicological consequences than interfering with protein digestion, but those effects will not be discussed here. The effects of protease inhibitors have also been confirmed by fractionating legumes so as to remove them, then adding back as a dietary component (Kakade et al., 1972). Removal of trypsin inhibitor is seen to enhance the digestibility of soybean protein somewhat, but can account for only about 40% of the increase produced by heating the soy material. Phytate and tannins are heat-stable factors also implicated in the reduction of protein digestibility (Salunkhe et al., 1982). The content of these compounds is widely variable among legume species. Tannins are known to bind to protein and to interfere with digestion (Romero and Ryan, 1978). Then isolated tannins were added to either bovine serum albumin (BSA) or bean globulin digests, proteolysis was severely inhibited at tannin to protein ratios of about 2 ,g/g in the case of BSA and 0.2 mg/g in the case of phaseolin. Phytate, and the lower phosphate esters of myoinositol have been shown to exhibit some inhibitory effects against digestive enzymes including a-amylase and lipase. Knuckles et al. (1985) demonstrated significant but limited effects against pepsin but less effect against trypsin *in vitro*. *In vivo* studies revealed no protein-related antinutritional effects of phytic acid at levels up to 2% in the diet.

The failure of antinutritional factors to count for the low digestibility of legume proteins implies that the proteins themselves may be an inherently resistant to digestion. This has been demonstrated *in vitro* when legume storage proteins were treated with mammalian proteases. Romero and Ryan (1978) found that the major storage globulin of bean is attached to a far lesser extent by pepsin, trypsin and chymotrypsin than is an animal protein such as bovine serum albumin. Further, while heating dramatically increased phaseolin digestibility it never approached that of BSA. The effect of heating implies that the native structure of the globulin is quite resistant to attach, while denaturing increases susceptibility. Subjecting either protein to a combination of enzymes increased proteolysis, but did not overcome the discrepancy between bean and bovine protein. Nevertheless, the authors felt that the differences between the two proteins were probably not as large as their data indicated based on number of theoretically susceptible peptide bonds. Vaintraub et al. (1979) examined the susceptibility of various legume storage proteins to pepsin hydrolysis. They found vetch and soybean globulins to be almost completely digested while phaseolin was resistant. Subsequent treatment with trypsin increased hydrolysis of bean globulin but not nearly to the levels of the others. Unlike Romero and Ryan (1978), these investigators found that heating resulted in almost complete digestibility of phaseolin. This difference may be due to differences in method for measuring

Table 8. Essential amino acids available from starchy legumes and reference patterns[a]

Essential amino acids	'Available' amino acids g/100 g legume protein	Reference patterns (g/100 g protein) FAO, 1985[b]	
		Adult	2–5 yr
Lysine	2.60–8.28	1.6	5.8
Cystine + Methionine	0.61–3.16	1.7	2.5
Tryptophan	0.20–1.77	0.5	1.1
Threonine	1.17–4.28	0.9	3.4
Valine	1.68–6.42	1.3	3.5
Leucine	3.01–8.84	1.9	6.6
Isoleucine	1.58–6.88	1.3	2.8
Phenylalanine + Tyrosine	3.52–9.58	1.9	6.3
Histidine	1.02–4.00	1.9	–

[a] Calculated from data in Akyroyd et al. (1982). Digestibility for cooked legume protein ranges from 51% for lima bean to 93% for lentil.
[b] FAO (1985).

degree of digestion. Romero and Ryan (1978) used an amino group specific reagent to measure actual bond scission, while Vaintaub et al. measured TCA-precipitable protein. This last technique would not detect polypeptides which are soluble but refractory to further proteolysis.

Using the factors which control the impact of legume protein in human diets, it is possible to estimate the actual range of that impact in terms of essential amino acids (EAA) provided. Table 8 shows available essential amino acids provided by legumes on a g/100 g protein basis calculated from EAA content and digestibility ranges. Thus the lower number is a product of lowest content and lowest protein digestibility while the higher number is the product of highest content and digestibility located in the literature. Even in the worst case scenario, legume protein is adequate in lysine, leucine, and aromatic amino acids for adults. At the other extreme, the combination of maximum EAA content and digestibility give a pattern which exceeds the requirements for growing children. If one carries this idea one step further to include consumption patterns, the ranges of essential amino acids provided to individuals by legumes are from less than 1% to almost 200% of the daily adult requirement (Table 9). The 'typical' column estimates available amino acids to an individual consuming 50 g daily of beans whose digestibility is 75%. This level of intake would provide from about 20% to more than 100% of adult requirements of essential amino acids.

Overall protein quality in actual diets depends on intake levels and requirements of the consuming organism as well as content and availability

Table 9. Essential amino acids contributed by starchy legumes and adult requirements[a]

Essential amino acid	Amino acid contributed (consumption × composition × digestibility)			Requirement (FAO)[b]	
	Low (mg)	High (mg)	Typical (mg)	54 kg female (mg)	70 kg male (mg)
Lysine	6	1530	675	648	840
Cystine + Methionine	1	584	178	702	910
Tryptophan	0.5	327	94	189	245
Threonine	3	791	375	378	490
Valine	4	1186	431	540	700
Leucine	7	1633	713	756	980
Isoleucine	4	1272	394	540	700
Phenylalanine + Tyrosine	8	1770	722	756	980
Histidine	2	739			

[a] Assembled from data in Akykroyd et al. (1982).
[b] FAO (1985).

of amino acids. Biological value is quite variable among and within legume species (Table 10). Bressani and Elias (1980) found that the proportion of consumed nitrogen absorbed from common bean (65%) was significantly lower than from milk or soybean protein while the proportion of absorbed nitrogen retained was 88%. This implies that, despite processing, digestibility was the major factor in the low net protein utilization (NPU). In a sense these results from studies of single source dietary protein are of theoretical interest, as human diets rarely contain a single protein source. A large amount of animal data and a lesser amount of human data have confirmed the complementary effect of combining legumes with staple cereals in the diet. The improvement may be marginal for some cereals and dramatic for others depending on the cereal and legume. The optimal ratio of cereal to

Table 10. Biologic value of some species and varieties of legume grains

Legume grain	Biologic value (%)
Cajanus cajan	46–74
Phaseolus vulgaris (black)	62–68
Vigna sinensis	45–72
Cicer arietinum	52–78
Lens esculenta	32–58
Phaseolus aureus	39–66
Phaseolus mungo	60–64
Pisum sativum	40–49

Taken from Bressani, 1975.

legume is about 70:30 which provides roughly 50% protein from each source. An effect of further supplementation with essential amino acids has been observed in rats at restricted protein intakes, although applicability to humans might be questioned. The fact remains that millions of children and adults around the world thrive on mixtures of cereal and legume when a sufficient amount of that diet is available to them (Bressani, 1975).

Legume protein has been implicated in health-related issues other than purely nutritional effects. An interesting observation has been the effect of legume protein and even blends of amino acids simulating legume protein on serum cholesterol levels. In the study of Nagata et al. (1981), rats exhibited a lowering of serum cholesterol when fed soy protein or its AA mix rather than casein. Similar results have been observed in humans (Meinertz et al., 1989).

Pulses provide, in addition to protein, a significant amount of calories, principally from starch which typically comprises 25–50% of the seed weight (Salunkhe et al., 1985). It has been suggested that legume starch, like legume protein, is less digestible than that from other sources. However, isolated starches from several legumes have been shown to he highly digestible in *in vivo* assays (Reddy et al., 1984). *In vitro* methods give a considerably less favourable picture, but must be considered less reliable than studies with intact animals. Of greater importance is the observation that when intact legumes are given to normal or diabetic humans, both glucose and insulin responses are greatly attentuated compared to the responses to more rapidly digested starch such as that from potato (Trappy et al., 1986).

Along with macronutrients, leguminous seeds contain appreciable amounts of some vitamins and minerals as well as dietary fiber (Table 11). Again considering intake and composition ranges, it can be seen that in many diets, legumes provide significant proportions of these nutrients. The crude fiber content presented here represents as little as 10% of the dietary fiber, much of which is the soluble type. Fiber in legumes would be expected to act along with protein to affect serum cholesterol, both by limiting digestion rates of macronutrients and by binding steroids in the gut.

Although they are important energy sources for germinating legume seeds, oligosaccharides are less desirable constituents from the human perspective. These sugars occur in significant levels in most dry pulses, 3–15% (Salunkhe et al., 1985), and have been correlated to the occurrence of flatulence in monogastric animals including man. However, there is evidence that factors other than oligosaccharides contribute to flatulence (Wagner et al., 1976). Whatever the etiology of this effect, it is a major constraint on legume consumption in Western countries.

Non-protein nutrition and health are both impinged upon by factors

Table 11. Nutrient composition of legumes, potential contribution to diets and requirements

Component	Composition range	Contribution range	Requirement (adult male)
Crude fiber (g/100 g)	1.2–13.5	0–57	
Minerals (mg/100 g)			
Ca	57–290	8.6–1218	800
P	277–546	42–2293	800
Fe	5.1–11.9	0.8–50	10
Mg	92–236	14–991	350
Vitamins			
Carotene (μg/100 g)	0–246	0–1789	1000
Thiamine (mg/100 g)	0.30–0.88	0–3.7	1.4
Riboflavin (mg/100 g)	0.15–0.39	0–1.6	1.6
Niacin (mg/100 g)	1.5–3.4	0.2–14	18

Contribution range based on composition range and consumption range of 15–420 g/day of legumes.

other than those antinutritional ones which affect protein nutrition. The former would include anti-vitamin agents which limit efficacy of vitamins D and E, but are susceptible to heating. Phytin may have a significant effect on mineral absorption, even though its impact on protein digestion is small. Purely toxic components include cyanogens which are present at such large concentrations in some Lima bean varieties that their consumption has been fatal to humans. These compounds may act as iodine antagonists in lower concentrations exacerbating iodine deficiency and leading to goiter. Oligopeptide goitrogens are also found in some legume seeds. Toxic amino acids (canavanine), lathyrogens, and pyrimidine glucosides promote toxic symptoms in man. Isoflavones found in legumes have been shown capable of eliciting an estrogenic response in mice (Liener, 1975, 1980; Nowacki, 1980). It is interesting to speculate that these antinutritional compounds may also be responsible for the practice of using legumes as drugs in traditional societies, given the inevitable toxicity of drugs at intakes greater than their efficacious level.

Summary

In summary, while they share the same history as the cereal grains, pulses have been less favoured by man as a crop because of their low yield and as a food because of problems with digestibility and toxic constituents. On the other hand, they provide nutrients which are valuable because of their concentration, composition and behaviour. In developing countries, the grain-fed meat diet popular in industrialized countries is unlikely to develop due to population pressures, leaving increased pulse production and consumption as the most promising way to meet protein needs. In western societies, replacing some of the refined, high-fat 'king's meat' with its humble cousins is likely to improve overall health. In developing countries more efficient ways to produce the popular, traditional legume-based foods are needed. In western nations, novel and interesting ways of incorporating legumes into the diet could rehabilitate their image and facilitate their contribution to nutrition and health.

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