Technical

The Winged Bean as an Oil and Protein Source: A Review[1]

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ABSTRACT

Despite high protein contents in its ripe seeds, tubers and fresh leaves (ranging from 29.3-39.0%, 3.0-15.0% and 5.0-7.6% respectively) and the high quality of that protein, the winged bean *(Psophocarpus tetragonolobus)* remained an obscure food source until about 10 years ago. Recently, this legume has received increasing attention from scientists because of its potential multiple uses as a food protein source in the humid tropics. This article reviews the utilization and nutrition literature of winged bean published during the last 10 years. The following aspects are covered: classification of winged bean proteins, nutritional properties and antinutritional components of the protein, protein quality, functional properties, and protein-based food products. The oil content of winged bean seeds ranges from 15.0-20.4%, and use of the winged bean as a potential oilseed crop is discussed. Areas of needed research are identified and described.

INTRODUCTION

Until 1975, the winged bean remained obscure to most scientists, although 2 decades earlier an Oxford University agronomist, Masefield (1,2), had reported on the unusual nodulation potential of this legume in Nigeria and Malaya. Masefield (3) was the first to predict the agricultural potential of the winged bean in 1973. However, the publication of a booklet, "The Winged Bean: A High Protein Crop for the Tropics," by the U.S. National Academy of Sciences (4), focused the attention of scientists on winged bean and led to 2 international seminars in 1978 (5) and 1981.

This review highlights winged bean research publications during the last 10 years. Previously published literature is referred to for historical perspective when necessary. Reviews by Claydon (6,7), Khan and Eagleton (8), Newell and Hymowitz (9), Adimorrah (10) and the FAO handbook authored by Khan (11) should be consulted for the earlier literature.

ORIGIN AND CULTIVATION

The winged bean belongs to the order Leguminosae, family Papilionaceae, sub-family Papilionoidae (Lotoidadea), tribe Phaseolae and genus *Psophocarpus* (12,13). The name *Psophocarpus* is derived from the Greek roots *psophos* ("noise") and *karpos* ("fruit"), referring to the explosive noise created by ripe pods in dehiscence (14). A distinctive flange or "wing" projects from each corner of its quadrangular pod, leading to the popular name of winged bean (4). The plant can be described as a twining, glaborous, perennial herb, botanically, but is cultivated as an annual; the average height of a plant may range from 3-4 m (15,16). Presently, 9 species are recognized of which *P. tetragonolobus* and *P. palustris* are used for food.

Diversity of opinion exists regarding the geographical origin of the winged bean. Whereas some botanists (17,18) point to Papua New Guinea, earlier researchers claimed other areas such as India (19) and Africa (20) as the most likely place of origin. Geographically (Fig. 1), India is the western most limit of the natural range of *P. tetragonolobus* and Papua New Guinea is its eastern-most border. In this range, *P. tetragonolobus* grows naturally in Sri Lanka, Bangladesh, Burma, Indonesia, Malaysia, Thailand, and the Phillippines, and spontaneous occurrence of this species had been recorded only rarely in the African region (17). In the United States, the first news article about the winged bean, in the September 28, 1975, *New York Times*, stimulated much interest among kitchen gardeners, farmers, missionaries, and researchers. Plantings of winged beans at 35 locations in 22 states have generally been unsuccessful (21). Successful planting have been recorded in the sub-tropical states of California, Texas and Florida. In our experience in Illinois, winged-bean plants grew well, but flowering did not occur until September 1, and pod growth was killed by frost well before the beans matured.

According to Crabbe and Lawson (22), winged beans differ from soybeans in that they do not generally require artificial inoculation with specific strains of *Rhizobium*. In 1957, Masefield (2) observed that winged bean nodulated more heavily than any other legumes–including soybean, peanut, French bean *(Phaseolus vulgaris)*, and peas *(Pisum sativum)*. In humid tropical environments where soybean cultivation seems difficult, winged bean could be the preferred legume. The high nodulation and nitrogen fixing capacity of the winged bean have led to the suggestion that it be used as a cover and cash crop in rubber and coconut plantations (23-25).

Winged bean is presently grown only as a field crop in Papua New Guinea during the dry season. According to Thompson and Haryono (26), Indonesia ranks second in production to Papua New Guinea. The best available yield data has been summarized by Khan and Edward (21), who recorded a global-scale survey of areas where the winged bean had been introduced since 1975. Yields of 3,778 kg

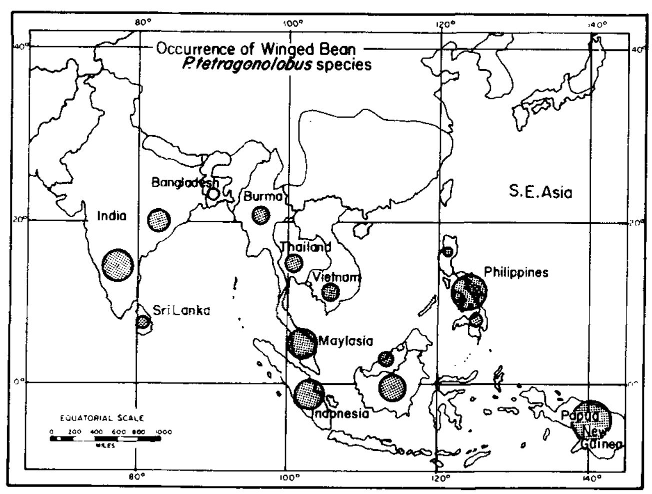

FIG. 1. Occurrence of winged bean, *P. tetragonolobus* species.

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dry beans/ha have been obtained in Costa Rica, and 5,420 kg seed plus 1,960 kg tuber/ha in Papua New Guinea.

COMPOSITION

Overall Proximate Analyses

Seeds. Agcaoli (27), in 1929, recorded the first proximate analysis of the mature seed from the Philippines. Other workers (28-36) have also reported analyses. The similarity of winged-bean seed to soybean in protein and fat content has been well established. Hildebrand et al. (37) evaluated 240 winged bean accessions obtained from 16 countries and obtained seed oil and protein ranges of 7.2-21.5% and 20.7-45.9%, respectively.

Tubers. The tubers of winged bean are also rich in protein with levels of 3.0-15.0% on fresh weight basis (4). However, unlike the seed, the tubers have a comparatively high moisture content (54.9-65.5% by fresh weight). Therefore, spoilage is a problem unless the tubers are consumed immediately or adequately processed and stored (36). Studies of tuber characteristics by Hildebrand et al. (38) demonstrated that only 38 of the 189 winged bean genotypes from 7 countries showed significant storage root formation. UPS-122 from Papua New Guinea had the highest projected storage root yield of 2,629 (kg/ha on a dry weight basis (36,38-40), which is 4-5 times more than that of other commonly consumed tubers such as cassava *(Manihot utilissima)*, African yam bean *(Sphenostylis stenocarpa)*, and Mexican yam bean *(Pachyrrhizus erosis)* (41). The high protein content of the tuber was attributed to its extensive nodulation capacity.

Leaves. Winged-bean leaves, with a protein range of 5.0-7.6% on fresh weight basis, is one of the richest sources of leaf proteins. In comparison, the protein content of other popular leafy vegetables such as *Allium porrum, Alternanthera triandra, Basella alba, Brassica oleracia, Ipmea batatas, Latuca sativa* and *Pastinaca sativa*, consumed in Asia, are in the range of 1.4-2.6% on fresh weight basis (42). In one study from Sri Lanka, the protein content of the winged-bean leaves was found to range from 24.5-31.5% on dry weight basis (43).

Protein. Of the total proteins in winged-bean seed, globulins and albumins accounted for 29-33% and 15-22%, respectively (44). In a series of papers, the Australian researchers Blagrove and Gillespie (45-49) reported on the protein components of winged bean. Electrophoresis on cellulose acetate membranes resolved 3 components of protein, labeled Psophocarpins A, B, and C, in order of increasing mobility. Psophocarpin A is a single protein and is found to be comparatively rich in sulfur-containing amino acids. The other two fractions, Psophocarpins B and C, are each composed of several related compounds. Polyacrylamide gel electrophoretic studies revealed that winged bean contain predominantly low molecular weight subunits (molecular weight less than 80,000 daltons) and may contain certain major components of high molecular weights of about 145,000 daltons.

Table I compares the essential amino acid (EAA) profile of winged-bean seed with those of soybean and peanut. Winged-bean protein is richer in lysine content; however, as in other legumes, the sulfur amino acid methionine is low compared with the reference protein (50,51). Chemical and protein scores based on the figures for sulfur amino acids had been calculated in reference to whole egg protein; chemical scores for winged bean ranged from 42-45, as against 52.6 for soybean, while protein scores ranged from 44-48, with 59.4 for soybean (44). Considerable differences exist in the essential amino acid composition of the major protein fractions of the winged bean. Del Rosario et al. (44) suggest the complimentary roles of albumin and globulin fractions in providing a good amino acid balance in winged bean.

Lipids. Characteristics of the seed oil and fatty acid composition of winged-bean lipids had been reported for the varieties grown in Malaysia (52,53), Nigeria (54-56), India (31), Sri Lanka (34), and Thailand (57). Oil characteristics of winged bean and soybean appear similar. However, the iodine value of 83.2 for winged-bean oil is comparatively lower than 120.3 for soybean oil, while the acid value of 1.6 for winged-bean oil is twice that of soybean oil (52). Palmitic, stearic, oleic, linoleic, behenic, and lignoceric acids are the major fatty acid constituents (Table II) and account for 95-98% of the fatty acids in the free and bound lipids. Three steroids, campesterol (5.6-6.0%), stigmasterol (33.7-37.8%) and β-sitosterol (40.5-42.0%) are the principal components of the unsaponifiable fraction. Though Cerny et al. (29) reported the presence of the toxic fatty acid, parinaric acid, later studies (54,57) did not substantiate these earlier findings. The fatty acid composition of winged-bean oil is more like peanut oil than soybean oil as linoleic and oleic acids predominate in both oils. However, the ratio of polyunsaturated to saturated fatty acids (P/S value) of 1.0 for winged bean oil is lower than that of soybean and peanut oils (Table III).

A series of studies from the Philippines (59,60-62) reported the lipoxygenase activity of winged bean seeds. This work indicated that winged-bean seed lipoxygenase activity is comparable to that of soybeans. However, another report (63) indicated that activity is low compared with other plant sources (Table IV). In our experience with the production of food products from soybean and winged-bean seeds, sensory evaluations suggest that the winged-bean seed possesses an equal, if not stronger, lipoxygenase component than soybeans. Lipoxygenase from mature seeds must be inactivated during processing or off flavors will develop. According to de Lumen et al. (63), Ca^{2+} had a definitive activating effect, while KCN, cysteine and vitamin A inhibited the lipoxygenase enzyme activity. The use of KCN in food products, even in microquantities, is

TABLE I

Essential Amino Acid Content of Winged Bean Seed Compared with Soybean, Peanut, and Hen's Whole Egg (g aa/100 g Protein)

Legume/egg	Ile	Leu	Lys	Met	Phe	Thr	Trp	Val	Arg	His
1. Peanut[a]	3.2	5.6	3.4	0.9	4.2	3.0	1.1	5.0	11.7	2.2
2. Soybean[a]	4.6	7.9	6.3	1.3	5.5	4.0	1.2	4.7	6.9	2.7
3. Hen's whole egg[a]	6.1	8.8	6.7	3.1	5.6	4.8	1.7	7.0	6.4	2.6
4. Winged bean seed[b]	4.8	8.7	7.9	1.2	4.8	4.1	0.9	4.9	7.0	2.9

[a]1-3: ref. (42)—All amino acid data recalculated on the basis of percent protein.
[b]4: ref. (11)—Recalculated for the mean values.

TABLE II

Fatty Acid Profile of Winged-Bean Oil

Fatty acid		References cited (29)[b]	(52)[c]	(54)[e]	(53)[c]	(55)[d]	(57)[f]
Lauric	12:0	n.r.[a]	n.r.[a]	n.r.[a]	0.9	n.r.[a]	n.r.[a]
Myristic	14:0	0.06	0.15	0.09	0.1	0.2	0.06
Palmitic	16:0	9.72	8.4	10.2	10.4	9.1	8.6
Margatic	17:0	n.r.[a]	n.r.[a]	n.r.[a]	n.r.[a]	n.r.[a]	0.08
Stearic	18:0	5.69	5.8	5.8	4.3	5.4	5.08
Oleic	18:1	39.0	33.9	37.2	33.7	41.0	35.4
Linoleic	18:2	27.2	32.8	22.9	29.0	29.5	28.6
Linolenic	18:3	2.0	2.8	3.5	2.1	1.9	1.08
Arachidic	20:0				1.1	2.0	1.7
Eicosenoic	20:1	n.r.[a]	n.r.[a]	n.r.[a]	3.1	2.2	3.23
Behenic	22:0	13.4	10.9	20.1	11.3	7.3	13.4
Erucic	22:1	n.r.[a]	n.r.[a]	n.r.[a]	0.9	n.r.[a]	0.68
Lignoceric	24:0	n.r.[a]	1.6	n.r.[a]	2.5	1.0	2.6
Parinaric	18:4	2.5	n.r.[a]	n.r.[a]	n.r.[a]	n.r.[a]	n.r.[a]
Total saturated		30.0	26.9	37.8	30.6	25.0	31.4
Total unsaturated		70.0	73.1	62.0	69.4	75.0	68.6
% oil		16.7	18.4	n.r.[a]	20.3	16.3	16.4
Iodine value		n.r.[a]	83.2	n.r.[a]	n.r.[a]	91.0	n.r.[a]
Saponification value		n.r.[a]	191.0	n.r.[a]	n.r.[a]	n.r.[a]	n.r.[a]

[a]n.r. = not reported.
[b](29)—One unidentified variety.
[c](52) and (53)—One Malaysian variety.
[d](55)—One Nigerian variety.
[e](54)—Mean of 5 varieties.
[f](57)—Mean of 11 Thailand accessions.

TABLE III

Fatty Acids of Winged-Bean Oil, Compared with that of Other Selected Common Food Oils (as Percent of Total Lipids)

Food lipid	PUFA	Mono-unsaturated FA	Saturated FA	P/S value[a]
1. Corn oil[b]	53	32	11	4.8
2. Soybean oil[b]	59	20	15	3.9
3. Peanut oil[b]	29	47	18	1.6
4. Chicken fat[b]	26	38	32	0.8
5. Egg yolk[b]	12	49	32	0.4
6. Pork fat[b]	09	49	38	0.2
7. Beef fat[b]	03	44	48	0.06
8. Coconut oil[b]	trace	07	86	–
9. Winged bean oil[c]	30.7	39	30.3	1.0

[a]The ratio of PUFA to saturated FA.
[b]1-8: ref. (58).
[c]9: Mean value compiled from ref. (29), (52), (53), (54), (55) and (57).

TABLE IV

Lipoxygenase Activity in Winged Bean, Compared with Other Plant Sources

Plant sources	Lipoxygenase activity units/mg protein Ref. (59)	Ref. (63)
Winged bean	25.2 (20)	37.5 (2)
Soybean	38.9 (3)	816
Cowpea	269.3 (6)	n.r.[a]
Green beans	n.r.[a]	3,507
Celery	n.r.[a]	204
Mushroom	n.r.[a]	178

Figures in parentheses indicate the number of varieties tested and the values represent the mean.
[a]n.r. = not reported.

not an acceptable practice. Lipoxygenase was inactivated by boiling whole beans for 60 min in water, or dehulled beans for 18 min (63).

Carbohydrates, minerals and vitamins. Studies on the carbohydrate composition of winged bean are very meager. The total soluble sugar content of 9.7-13.8% in the seeds consists mainly of sucrose (5.6-8.2%), stachyose (2.2-3.6%), raffinose (1.1-2.0%), and verbascose (0.2-0.9%) (64). Garcia and Palmer (64), analyzing 5 varieties, did not detect the presence of starch by either I_2-KI staining technique or by treating the residue with glucose amylase enzyme. Contrary to this report, Sajjan and Wankhede (65) reported a 32.2% total carbohydrates, over ⅓ of which was starch. Analyses of more varieties are needed to resolve these conflicting data. The oligosaccharide content (4.13-6.18%) may be of concern because of its flatulence-causing potential. Overnight soaking and germination are 2 techniques, which have been used to reduce oligosaccharides in other legume seeds.

Dietary fiber content of the seed is approximately 17% on dry weight basis, of which 72% occurs in the seed hull (66). The lignin contents in the whole seeds and cotyledons are 0.83% and 0.42% respectively (33). Okezie and Martin (33) had reported that fresh winged-bean leaves contained neutral detergent fiber (37.8-43.7%), acid detergent fiber, (19.1-20.8%), and lignin (5.5-8.8%).

The edible parts of winged bean are rich in macrominerals such as calcium, phosphorus, and magnesium, as well as microminerals iron and zinc (Table V). Changes in the mineral composition of seed during development have been reported (67), whereas the levels of calcium, magnesium, iron, and copper did not show any marked changes with onset of maturity; zinc content decreased. In addition, a significant decrease in total phosphorus content was found with a concurrent increase in the proportion of phytate phosphorus throughout the seed development.

TABLE V

Mineral Content in the Edible Parts of Winged Bean mg/100 g Fresh Weight[a]

Minerals	Leaves	Immature pods	Seeds	Tubers
Calcium	113-260	53-330	80-370	25-40
Phosphorus	52-98	26-69	200-610	30-64
Magnesium	54	58	110-255	23
Iron	2.0-6.2	0.2-2.3	2.0-18.0	0.5-3.0
Zinc	1.4	0.2	3.1-5	1.3

[a]ref (4).

Regarding vitamins, leaves of winged bean are one of the richest plant sources of carotenoids, having values in the range of 5,240-20,800 IU/100 g fresh sample (Table VI). High values of ascorbic acid and folic acid are also recorded for the leaves. While folic acid levels present in the seeds are also adequate, rich tocopherol content is noteworthy. Analysis of oil samples from 27 varieties of seeds by de Lumen and Fiad (35) revealed a wide range (80-130 mg) of γ-tocopherol/100 g of oil. The presence of γ-tocopherol in the seed has nutritional significance in relation of the stability of oil to oxidation reactions (35).

FOOD USES

The National Academy of Sciences (4,68,69) has reviewed the food uses of the winged bean in different countries (Table VII). Winged beans are usually cultivated as an annual backyard, home garden crop (4,11). Although the uses of different plant portions are diverse, the winged bean has found a special niche in the food consumption patterns of the natives of Papua New Guinea, the Philippines, Indonesia, Malaysia, Thailand, Burma, Bangladesh, Sri Lanka, Mauritius, and African countries such as Nigeria, Ghana, and Ivory Coast (6,8). Consumption patterns among the natives and consumer acceptability studies have been reported in Papua New Guinea (70), Ivory Coast (71), Tanzania (72), and Sri Lanka (73). Seed yields from Ghana (74) and Puerto Rico (75) have also been reported.

In Tanzania, pods were accepted by the population, but resistance was shown to the mature beans and tubers because of their less desirable taste and smell. However, the addition of spices significantly changed the acceptability of winged bean's appearance, color, taste, and smell. Tubers required boiling for acceptability (72).

Axelson et al. (73), studying consumption and use of winged bean by Sri Lankan villagers, found that the plant is well known and integrated into the foodways of the Sinhalese Buddhists, who form 70% of the population. The plant is generally grown for home use although production as a cash crop is becoming more common. The tender, immature pods and leaves are commonly eaten, but the consumption of tubers and mature seeds was not observed. Additional large-scale studies are needed to evaluate the acceptability of the various parts of the winged bean.

Nutritional Properties

Protein. In vitro digestibility studies of a few cultivars show that mature pods had the highest digestibility (73.8%), while raw seeds had the lowest (67.3%); furthermore, soaking the seeds before cooking, removing the hull, treating the seeds with dry heat, autoclaving, defatting, deactivation of antinutritional factors such as proteinase inhibitors, phytohemagglutinins, and the leaching of tannins into the soaking solution, improved the in vitro digestibility (76,77).

Animal studies. Biological evaluation studies of seeds using experimental animals had been reported by a few workers (29,31,78-82). Based on rat studies, Cerny et al. (29) reported that at the 10% level of protein, both the protein efficiency ratio (PER) and the net protein utilization (NPU) values of the winged bean were superior to those of the peanut (PER 2.14 vs 1.53 and NPU 55.0 vs 46.2, respectively). However, rats fed diets containing raw beans lost considerable weight and died after a few days. High concentrations of antinutritional factors such as trypsin inhibitors (TI), phytohemagglutinins, and amylase inhibitor present in the extracts of raw beans could be the cause of death in the experimental animals. Jaffe and Korte (79) observed that the digestibility value of the beans increased from 61.5 to 81.0% when the seeds were autoclaved at 112 C, which confirms the view that the antinutritional factors responsible for the death of the rats are heat labile.

Weight loss in rats was also considerably reduced when a saline-extracted, winged-bean residue diet was fed. This suggests that some of the growth-depressing antinutritional factors are low molecular weight polar compounds. A bio-

TABLE VI

Vitamin Content in the Edible Parts of Winged Bean[a]

Vitamin		Leaves	Immature pods	Seeds
Vitamin A	IU	5,240-20,800	300-900	
Thiamin	mg/100 g	3.6[b]	0.06-0.24	0.08-1.7
Riboflavin	mg/100 g	2.6[b]	0.08-0.12	0.2-0.5
Niacin	mg/100 g	15.0[b]	0.5-1.2	3.1-4.6
Ascorbic acid	mg/100 g	14.5-128	20-37	trace
Folic acid	μg/100 g	67[b]		25.6-63.5
Tocopherols	mg/100 g	3.5[b]	0.5	22.8

[a]ref. (4).

[b]Values on dry weight basis: all the remaining values are expressed on fresh weight basis.

TABLE VII

Yield Data and Food Use of Winged Bean[a]

Plant part	Greatest yield reported[b] kg/ha	Composition per 100 g fresh wt	Location of consumption	Food preparation consumed
Green pods	34,000-35,500	1.9-4.3 g protein	S.E. Asia, Sri Lanka P.N.G.[c] Ivory Coast	Steam-fried, soups, salads
Tubers	5,500-11,700	3.0-15.0 g protein	Burma, P.N.G.[c]	Steam-roasted, boiled
Seeds	2,000-5,000	29.8-39.0 g protein 15.0-20.4 g oil	Indonesia, P.N.G.[c] Ivory Coast	Parched; in tempeh; preparation in flour that is added to traditional dishes
Leaves	–	5.0-7.6 g protein	Sri Lanka	Steamed; salads
Flowers	–	2.8-5.6 g protein	P.N.G.[c]	Steamed; salads

[a]Data adapted from references (4), (7), (8) and (11).

[b]Tuber yields are from cultivated farmers' plots, and other yields are figures extrapolated from small plots.

[c]Papua New Guinea.

logical evaluation study using chicks arrived at a similar conclusion. In this study from Malaysia (78), a winged-bean diet was compared with a soybean control diet. Results showed that protein from autoclaved winged-bean meal (121 C, 15 lb pressure for 15 min) could successfully replace 50% of the soybean-meal protein in chick rations and the growth rate and feed conversion in chicks were significantly lower when the autoclaved winged-bean meal was used as the sole source of plant protein.

Kimura et al. (81) showed that body weight gain of rats fed a 30% raw winged-bean diet was significantly lower than rats fed a 30% steamed winged-bean diet. The adverse effect of feeding a 30% raw winged-bean diet was accompanied by gastrointestinal tract disorders, including a significant reduction in intestinal sucrase activity. The problems were not improved by methionine supplementation of the raw winged-bean diet. The researchers suggested that the primary cause of the adverse effects of the raw winged-bean diet is disorders in the small intestine caused by phytohemagglutinins or similar substances. Based on these findings (81,82), we can conclude that TI are not exclusively responsible for the antinutritional effects of raw winged beans.

Most of the animal studies have examined the nutritional value of the seeds. Similar evaluations for the other edible portions of winged bean are scarce. However, one study in India (31) suggested that raw tubers were more toxic to rats than were raw beans. Processing at 15 lb steam pressure for 20 min improved the nutritional quality of tubers, but the rats still did not exhibit adequate growth. These workers were not optimistic about the nutritional values of tubers, even though they are in great demand for human consumption in the neighboring country of Burma.

Human studies. Although animal feeding studies are useful in determining the general biological value of the winged-bean protein diets, the extrapolation of these results to human diets has limitations. The importance of human studies cannot be overemphasized, but data in this area is lacking.

Cerny and Addy (83) conducted a feeding trial in a Ghana hospital with 72 children suffering from moderate or severe kwashiorkor. After the children had overcome the most acute phase of the illness by consuming a routine diet based on skim milk and maize flour, mature winged-bean seed flour was introduced as the major source of dietary protein. Their data indicate that the experimental diet of porridge, made by substituting winged-bean flour for skim milk powder, providing 24 g protein, 12 g fat, 16 g carbohydrate and 1,122 of the 4,361 kJ energy was well accepted and tolerated and all children made good clinical progress. In both experimental and control diets, mean daily weight gains were significantly higher in children with previous severe kwashiorkor than in those with moderate kwashiorkor. The increase in total serum protein and the decrease in the amino acid imbalance ratio was similar in both the control and experimental diets at the end of the 30-day experimental feeding.

In a subsequent study conducted by Cerny et al. (84) with Vietnamese infants and toddlers suffering from protein energy malnutrition, two groups of 16 children received 5 servings daily of either the experimental or the control diet for a period of 10 weeks. Owing to the unsatisfactory nutritional status of the children, both diets were complimented with a multivitamin supplement and iron fumarate in doses exceeding the recommended daily allowances. The results of this study revealed that based on the mean gains in weight over the 10-week period, the efficacy of the winged-bean based formula was over 90% of that of the skimmed-milk control diet and, in the malnourished children, an improvement of the biochemical findings related to the nutritional status of the children, such as albumin, transferrin, β-lipoprotein, and hemoglobin were higher than in the control group.

Lipids. Bodger et al. (57) recently reported detailed procedures for extracting and refining winged-bean oil. The oil produced by expeller had a strong, beany aroma but a negligible level of gums and a low level of free fatty acids. Degumming and neutralizing were unnecessary; bleaching produced an attractively colored oil, free from beany aroma. However, the flakes were not as mechanically strong as soybean flakes. The defatted seed meal contained high percentages of protein and carbohydrate ranging from 36-43% and 35-40%, respectively. Acute toxicity tests of the refined winged-bean oil were conducted on mice, and no toxicity symptoms were found in doses up to 20 g/kg body weight for 72 hr (85).

Vitamins and minerals. Bioavailability studies on 2 minerals, zinc and iron, present in mature seed flour had been reported from our laboratory (86). Standard rat bioassay procedures showed that relative bioavailability of winged bean and $ZnCO_3$ zinc were 85% and 93%, respectively, when weight gain and log tibia zinc were the evaluation criteria. The results of the hemoglobin repletion assay indicated that iron in winged bean was 89% as bioavailable as iron from $FeSO_4$.

Among the vitamins, the nutritional and functional significance of the predominance of γ-tocopherol in the seed oil had been reported by de Lumen and Fiad (35). Based on the reported fatty acid profile of seed oil, these researchers calculated the tocopherol to PUFA ratio to be 0.2 mg of d-α-tocopherol equivalents/g of PUFA. This ratio is similar to soybean oil although less than peanut, corn, palm, and cottonseed oils.

Effect of processing. Difficulties in removing the relatively tough hull hindered the development of acceptable winged-bean foods. Apart from prolonging the cooking time needed to soften whole beans, the hull may cause lower net protein use (87). The conspicuous amount of polyphenolics present in the hull could bind the proteins present in the seeds, making them biologically unavailable. Manual dehulling after soaking is extremely time-consuming. Using mechanical dehulling (which is acceptable for soybeans) results in a considerable loss in the yield of nutrients (88).

Varieties differ in hydration behavior and in softening with boiling (89). Boiling for 3-4 hr may be required to significantly soften the tough hull (90). In recent studies, soaking and/or blanching in 0.5-1.0% solutions of $NaHCO_3$ or $(NH_4)_2CO_3$ increased the hydration rate, reduced cooking time by nearly 50% and eliminated the chalky feel of the cooked seed (51,89,91,92) when eaten. The quick-cooking procedure described by Rockland et al. (91) consists of 3 essential steps: blanching of beans in boiling water for 2 min; followed by soaking them in solutions of 2% NaCl, 1% $Na(PO_4)_3$, 0.75% $NaHCO_3$, and 0.25% Na_2CO_3 for 24 hr; and, after draining, cooking in boiling water for 15-20 min. According to these researchers, only minimal differences occurred in proximate composition, riboflavin, and niacin of water-soaked beans cooked for the standard time (210 min) and rehydrated beans quickly cooked for 18 min. However, the thiamin content of the quickly cooked beans was notably lower than that of the water-soaked beans.

The effect of processing on nutritional properties of the protein has also received considerable attention (93,94). Autoclaving increased the availability of sulfur amino acids because TI were inactivated; but lysine, histidine, arginine and glutamic acid levels were decreased. Prolonged heating caused a decrease in protein quality from a loss of available lysine by nonenzymic browning reactions.

The germination of seeds for 3 days improved the nutritive value of beans. When germination was prolonged to 9 days the total fat content decreased (18.5-13%) with an increase in the percentage of polyunsaturated fatty acids (24-37% of fat). The total protein of the seeds slightly increased (29-31%) after 9 days. Lipoxygenase activity gradually decreased from 42 to 26.3 units/mg protein. Among the antinutritional factors, both TI and catalase levels increased (59).

Antinutritional Factors

Proteinase inhibitors (TI and CI). The presence of TI in the seeds of winged bean was first reported in 1954 (95) and in the early 1970's (29). But only in the last few years have in-depth studies been published on TI and chymotrypsin inhibitors (CI). Papers from groups working in the U.S.A. (39,82,96-100), Malaysia (101-103), Australia (104-107), and contributions from other countries (40,108,109) have provided much information about the properties, specificity, thermal stability, and the biological effects.

Comparing TI activity of winged-bean seeds and soybeans shows a distinct difference in the composition of nonprotein TI (100). Whereas nonprotein TI composed 27-55% of the total TI activity in soybeans, it accounted for only 5-14% of the total activity in winged beans. The figures reported for TI levels present in seeds and tubers range very widely because of variations in the samples tested and in diverse assay methodologies that make comparisons impossible among reports (39,40,100,108,109). TI are concentrated in the cotyledon portion of the seed, and boiling for 60 min results in a ca. 50% decrease in the levels (96).

Compared with those from mature seeds, the levels of proteinase inhibitors were approximately the same in the tubers. de Lumen and Belo (39) demonstrated by affinity chromatography that the TI and α-CI from tubers are distinct and do not have overlapping activities. Affinity chromatographic (97,105) studies determined the molecular weights of winged-bean seed TI to be ca. 20,000. The CI isolated from the seeds has a molecular weight of approximately 21,000 (106), and is specific to CI only (107).

Phytohemagglutinins (PHA) or lectins. The occurrence of phytohemagglutinins (PHA) or lectins in the winged-bean seed was first reported in 1948 (110). The activity was found to be nonspecific in nature (111), and all three A,B,O types in human erythrocytes were agglutinated (112,113). However, Bhatia and Allen (114) found that winged bean agglutinating extract did not react strongly with the rare Bombay group that were H-antigen deficient. Apart from these sporadic screening reports, nothing much was known about the PHAs of winged bean until recently. PHA values detected in 1 or 2 varieties of seed have been recorded, but data regarding the ranges of PHA activity by different winged-bean varieties is scarce. An 8-fold variation in hemagglutinating activity was reported among seeds studied in Sri Lanka and Malaysia (115,116). This variation variation is comparable with a 7-fold variation in PHA range reported in soybean varieties (117). The lower PHA activity in the tubers, compared with seeds may be related to the lower protein content.

Pueppke (118) has purified and characterized a seed PHA by affinity chromatography. His studies show lectin, with a molecular weight 46,000 ± 2,000 as determined by analytical centrifugation, is rich in acidic amino acids. A single type of subunit with a molecular weight of 29,000 ± 3,000 was detected by dodecyl sulfate gel electrophoresis.

Tannins. Only a few studies had been reported on the tannin content of winged-bean seed (96,116,119,127). The results reported in these studies are conflicting because of the diverse methods employed (Table VIII). For example, de Lumen and Salamat (96), analyzing 2 varieties, reported that tannins are highest in raw hull, almost 3 times that of raw cotyledon and twice that of raw whole bean, and cooking had a minimum effect on tannin content. These researchers inferred that tannins may play a more important role than the heat-labile proteinaceous TI in heat-processed winged bean. On the contrary, Price et al. (119) failed to detect tannins in 4 varieties. Recently, Tan et al. (116) inferred that none of the 16 varieties surveyed from Malaysia, Papua New Guinea, and Thailand contained amounts of tannin that could be nutritionally harmful. The Folin-Denis reagent method used by de Lumen and Salamat (96) is not specific for detection of tannins (120). Hence, we feel that their inferences regarding the antinutritional effects of tannins has to be critically reexamined.

TABLE VIII

Tannin Content in the Seeds

Varieties analyzed	Assay methodology	Sample preparation	Tannin content (mg/g bean)	Reference
Tpt-1, Chimbu	Folin-Denis reagent	Freeze-dried sample	Hull, raw = 2.88 Bean, whole = 1.58 Cotyledon = 1.08	(96)
Tpt-1, Tpt-2 Tpt-6, Chimbu	Vanillin-HCl reagent	Ground meal[a]	0.0	(119)
16 varieties	Vanillin-HCl reagent	Ground meal[a]	Range = 0.3-7.5 Mean = 4.0	(116)

[a]Details about hulls not provided.

Amylase inhibitor. Only one study (79) has reported the presence of amylase inhibitor.

Phytic acid. The significance of phytate as an antinutritional factor in winged bean has not been studied in detail. Studies in our laboratory have shown that among 14 Sri Lankan varieties, the phytate levels in cotyledons and hulls range from 1.0-1.7% and 0.05-0.2%, respectively (Table IX). These levels are quite comparable to those of soybeans and soy hulls (121). A significant decrease was found in total phosphorus content with a concomitant increase in the proportion of phytate phosphorus throughout the seed development (67).

Cyanides. The presence of cyanogenic glycosides in the tubers have not been conclusively determined. Korte (122) and Poulter (123) did not find these potentially toxic antinutritional factors in the samples they analyzed. However, some researchers believe that cyanides may accumulate to dangerous levels in some of the tuber-yielding varieties. The Nobel Laureate, Gadjusek, who conducted pioneering medical anthropological studies in Papua New Guinea for nearly 25 years, believes that some natives succumbed to cyanide toxicity as the result of consuming excessive amounts of winged-bean tubers (personal communication, 1982).

Other phytochemicals. The presence of several phytochemical principles such as steroids, organic acids, alkaloids, treterpene, gums and glucosides have been qualitatively determined in vegetative parts of the legume. However, most of these are only present in trace amounts (124).

Urease activity. Urease activity in the seeds seems to be absent (99).

FUNCTIONAL PROPERTIES OF PROTEINS

Extraction of Proteins

The identification of suitable methods to extract the constituent proteins is essential in preparing protein concentrates and isolates. Reported studies (44,45,125-128) in the range of 4.5 to 12.0 indicate that the efficiency of the extraction of winged-bean protein is strongly pH-dependent. Proteins are more soluble at very alkaline than at either neutral or acid pH; the point of minimum solubility occurs at pH 4.0, the apparent isoelectric point of winged-bean protein. At a meal-solvent ratio of 1:15, temperature of 40-50 C, and pH 8.0, almost 90% protein yield was achieved in a 60-min extraction. Of the solvents used, including distilled water, NaOH, NaCl and HCl, a 0.1 molar NaOH (pH 12.4) solution was most effective (129).

The sequential extraction of defatted bean meal twice with acetate chloride buffer (pH 4.5), followed by phosphate chloride buffer (pH 8.8), resulted in a 68% protein (N x 5.7) recovery for variety Chimbu (45). For the same variety, Sathe and Salunkhe (77) reported a 91% recovery, employing sequential extraction with distilled water and 2% NaCl. Protein fractionation studies by Sathe and Salunkhe (77) suggested that major differences in the ratio of albumin to globulins may exist among different varieties. According to these researchers, one of the promising varieties, Chimbu, had a ratio of 4.66, while for HF-10 variety the ratio was 1.88. However, we feel that further studies are needed before a generalization can be made related to varietal differences.

TABLE IX

Phytate Content in Winged-Bean Seeds[a]

Seed components	Phytate content g/100 g dry wt	
	Mean	Range
Cotyledon	1.4 ± 0.2	1.0-1.7
Hull	0.1 ± 0.04	0.05-0.2

Source: Hettiarachy and Erdman (1981)—unpublished data.
[a]Determination from 14 Sri Lankan varieties.

Protein Concentrates

Concentrate containing 71.5% protein on a dry weight basis has been extracted from winged-bean seeds using dilute alkali (0.2% NaOH) (127). This concentrate had lower tannins and TI, CI and α-amylase inhibitory activities than full-fat winged-bean flour. The solubility of the protein concentrate was minimal at pH 4. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of the protein concentrate showed the presence of 7 major subunits having apparent molecular weights of 14,200, 16,500, 22,500, 35,000, 56,000, 82,500 and 143,000 daltons. These researchers suggest that the partial hydrolysis of proteins during extraction under alkaline conditions may result in the predominance of low molecular weight protein subunits in the protein concentrate.

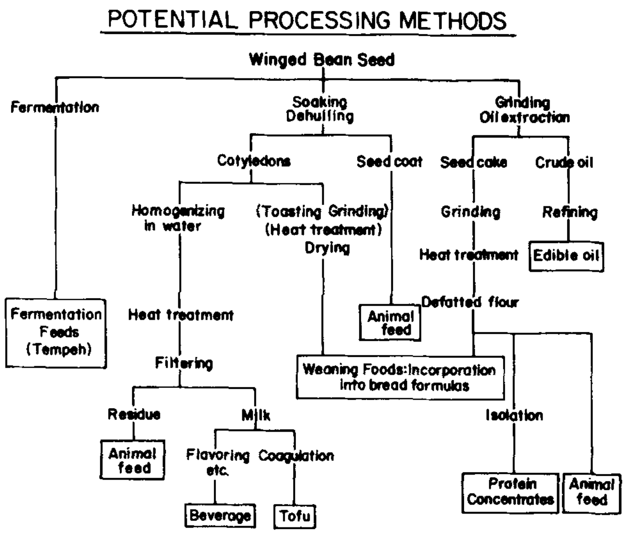
Protein Isolate

Isolates prepared by Dench (130) from winged-bean seeds contained protein in the range of 73-87% and possessed low-bulk densities and high-fat absorption values. While isolates prepared from solvent-extracted flour were whitish or buff in color, those obtained from solvent-extracted, heat-treated, or oil-expelled flours were cream to tan in color. They also showed high (100%) nitrogen dispersibilities and were able to form heat-stable emulsions. Isolates prepared from unheated winged-bean flour formed stiff but unstable foams.

Emulsifying and foaming properties of the protein isolates from seeds were directly related to its solubility. According to Barth and Belo (131), the more soluble the isolate, the greater its emulsifying capacity and volume and stability of its foams.

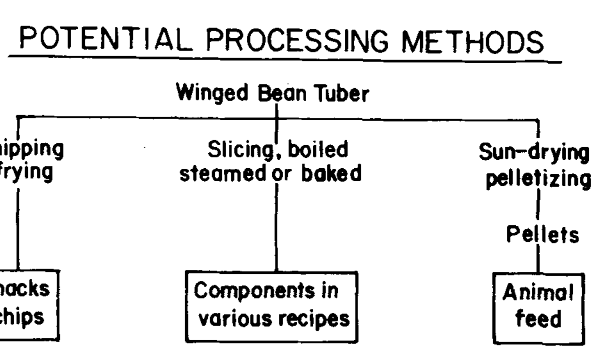
PROTEIN-BASED FOODS

Studies on the processing of mature winged beans were reported at the First International Winged Bean Seminar in 1978. These included preparation of winged-bean tempeh (132), household preparation of winged-bean milk, miso and curd (133), and the formulation of weaning foods (134). Suggestions were also made regarding the potential use of winged bean as livestock feed (135). Potential markets for winged-bean oil were also described (136). At the Second International Winged Bean Seminar in 1981, further reports on the use of winged bean, including production of fermented milk tairu (137) and pellets from seed cake and tubers for animal feed (138), were presented. Figures 2 and 3 show the potential processes that may yield acceptable food products from the seed and tuber. Some of these products have been successfully made in pilot scale.



Adapted From Khan (1982): *Winged Bean Production In The Tropics*: FAO, Rome

FIG. 2. Potential processing methods for the seed.



Adapted From Khan (1982): *Winged Bean Production In The Tropics*: FAO, Rome

FIG. 3. Potential processing methods for the tuber.

Winged Bean Supplemented Bread

Fortification of wheat-cassava composite bread with winged-bean flour was evaluated in Malaysia (139). Increased levels of cassava flour reduced water absorption, development time, and stability of the dough. The incorporation of winged-bean flour improved dough characteristics. Up to 30% substitution with cassava flour (70:30) and 5% fortification with winged-bean flour (75:20:5) yielded an acceptable loaf volume and sensory characteristics. The shelf life of bread made with 9% winged-bean flour (70:21:9) was 4 days before it became stale at room temperature (27 C) or in the refrigerator (9 C).

Three categories of composite flours, wheat/winged bean composites containing 5%, 10%, 15% and 20% defatted winged-bean flour; triticale/winged bean composites containing 5%, 10% and 15% winged-bean flour; and wheat/triticale/winged-bean flours, were studied by Okezie and Dobo (140) for flour stability, dough development, true flour extensibility or strength, and mixing tolerance. Composites prepared by varying the proportions of triticale and winged-bean flours, while keeping the level of wheat flour constant at 50%, showed that rheological properties were adversely affected by levels of winged-bean flour above 15%. Defatted flours exhibited better properties than full-fat flours. The improvement in protein content of the flours ranged from 57%, 78% and 93% for triticale-based, wheat-based, and winged bean-triticale-wheat mix flours respectively. Also, as levels of winged bean flour increased, volume of baked products decreased. Defatted winged-bean flour, when used at levels up to 15%, produced acceptable bread compared with a control using 100% wheat flour. Only 5% and 10% substitution levels of full-fat, winged-bean flour resulted in acceptable breads, with or without sodium stearoyl-2-lactylate treatment. Substitution of 20% winged-bean flour or 15% with triticale increased the protein content of the bread by 65-78% (141). Since World War II, bread has become one of the staple diets of the population in many developing countries. For countries with a malnutrition problem, supplementing traditionally prepared wheat bread with winged-bean flour could be of merit on 2 counts. First, it will minimize the necessities of the large-scale importation of wheat from wheat-producing countries. Second, it could enhance the nutrient composition of the bread significantly.

Weaning Food Formulations

Processing and formulating weaning foods containing winged-bean flour has had limited success (134). Although the seeds can be used as the main source of protein in combination with other cereals in formulating weaning foods, a minimum protein level of approximately 16% on dry weight basis is necessary.

Weaning food made from the dehulled winged-bean seeds and rice, with or without the addition of banana, had been tested in Thailand (142). The resulting product resembles roller-dried flakes. These flakes could be reconstituted in hot water, milk, or soup for feeding the children.

Fermentation Products (Tempeh and Miso)

Household preparation of fermented products, such as tempeh (fermented cake) and miso (fermented seasoning paste), has been tried with winged bean (133). Fermentation studies from Indonesia (132) show that several *Rhizopus* strains ferment the seeds into a tasty product. *R. oryzae* R 128 strain produced a good product in 30 hr. During fermentation, an increase in amino acid nitrogen content and soluble carbohydrates was detected, whereas the total solid content decreased. Although a beany smell could be detected in the product after 24-30 hr, it disappeared after 48 hr.

Milk and Curd (Tofu)

Winged-bean milk, prepared from blending the cotyledons with boiling water, has a beany flavor but can be made more palatable if it is flavored with honey-vanilla, carob, honey, or malt (133). The addition of 1% $NaHCO_3$ during blending minimizes the heavy flavor of the milk. The protein content of ca. 5% for the winged-bean milk compares favorably with that of soy milk (143).

The production of curd (tofu) from winged-bean milk has been reported by several workers (89,133,143-145) who had experimented with various coagulants such as HCl, $MgSO_4.6H_2O$,$CaSO_4.2H_2O$, and glucono-δ-lactone. Earlier studies by Ruberte and Martin (89) reported that winged-bean curd is less acceptable in quality than soy curd. Subsequent studies in our laboratory (143), as well as in Japan (145), showed that although 100% winged-bean curd comparable to soy tofu could not be produced, mixing winged bean and soybean at 50:50 and 25:75% proportions by weight, resulted in acceptable curd products. Differences in the protein subunit structure between winged bean and soybean are suggested as the cause of differences in texture of two types of curds (143).

Pellets for Animal Feeding

The use of mixtures of winged bean and tapioca tubers for the production of animal feed pellets was reported recently in Thailand (146). In this operation, the tubers were cut into small pieces and dried in the sunlight for 2-4 days, reducing the moisture content to ca. 14%. Dried winged bean-tapioca chips were then mixed and fed into a pelletizing machine.

FUTURE PROSPECTS

Tissue culture and organogenetic studies on winged bean might provide additional genetic variation needed for the development of improved varieties. Bottino et al. (147) suggests that the perennial growth habit of winged bean and the fact that it has not been under intense domestication by man are advantageous features that should be explored in tissue culture. Root organogenesis from callus (147) and the production of plants under in vitro conditions (148) have been reported.

Mutation breeding of new winged-bean varieties offers better prospects for the production of desired winged-bean phenotypes. Depending on the needs, different types of winged-bean plant could be developed. Khan and Brock (149) suggested a few alternatives—such as an erect bush type multi-purpose plant, so that labor-intensive trellis-making may be avoided; seed-producing varieties with no tuber formation, and greater yield per area and increased shelling percentage (ratio of seed weight to pod weight); and tuber-producing varieties having greater flower drop and little seed yield.

From the preceding review, that the winged bean has become one of the leading potential plant protein sources for the future is evident. Some of the major drawbacks for large-scale production and processing include the unavailability of sufficient seed stocks and other edible parts for research, the lack of sufficient field trials for variety selection, the labor-intensive nature of crop cultivation, uncertainty over the economies of production and the competitiveness with alternative crops, the difficulty experienced in storing plant parts, particularly tubers and leaves and difficulty in removing the tough hull and the incomplete hydration of the seeds (150).

A significant drawback is the lack of a uniform, worldwide coding system for the winged-bean germ plasm. Varying definitions have been applied to botanical terms (such as varieties, lines, cultivars, cultigens, strains, genotypes, and accessions) in describing germ plasm in the research literature. This variety has resulted in much confusion among researchers.

At present, 2,400 accessions of winged bean are stored in gene banks located in India, Thailand, and the Philippines; long-term storage of nearly 1,400 of the 2,400 is being undertaken in 2 institutions in Thailand and the Philippines (151). New food products are being developed from dried mature seeds or tender seeds in Thailand (142, 152). Tofu, tempeh, and snack foods are being developed on a commercial scale in Thailand, Indonesia, and Ghana. A coffee substitute from roasted seeds and a tobacco substitute from dried leaves are being tested in Indonesia (4).

Presently, winged-bean oil is not available commercially primarily from a lack of bean production. A few reports (52-57) indicate that winged-bean oil is good for cooking and has good nutritional quality. In 1978, Duff (136) predicted that yearly world production of winged bean would reach ca. 10 million tons by 1984, with a gross value for winged-bean oil of 2.5 billion U.S. dollars. Unfortunately, commercialization of the oil is many years away and is dependent on solving some of the problems listed above. The establishment of an International Winged Bean Research Institute in Sri Lanka in 1982 is expected to efficiently coordinate research on winged bean and hasten the prospective uses of this legume.

In conclusion, we are in agreement with Cerny's evaluation that for the winged bean to develop from a backyard, home garden crop, agricultural research has a long way to go (88). However, little doubt exists that the nutritional potential of this legume deserves such an effort.

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