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Legumes and a Cereal with High Methionine/Cysteine Contents

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The amino acid and chemical composition of seeds from three lesser known legume species and an African cereal with high Met + Cys contents is presented. Mesquite (*Prosopis spp.*): 41% protein, 2.5% Met + Cys. Djenkol bean (*Pithecellobium lobatum*): immature seeds, 32% protein, 2.8% Met + Cys; mature seeds, 16% protein, 3.9% Met + Cys. Tamarind seeds (*Tamarindus indica*): 18% protein, 3.5% Met + Cys. Acha (*Digitaria exilis*): 8% protein, 7.3% Met + Cys. Threonine is the first limiting amino acid for mesquite and tamarind while leucine is for Djenkol bean. The overall chemical scores are as follows: mesquite, 55; Djenkol bean, (immature) 31, (mature) 38; tamarind, 80. Tamarind seed protein has a very favorable amino acid balance and deserves further study. These legumes can not only complement cereals but supplement legumes with lower Met + Cys contents as well. The exceptionally high Met + Cys content of the cereal Acha makes it an excellent complement to legumes.

INTRODUCTION

Legumes, as protein-rich crops, are becoming increasingly important sources of plant proteins for human food and animal feed. In 1972–1974, legumes contributed 7% to the total protein supply worldwide (Hoshiai, 1980). With the ability to fix nitrogen from the atmosphere and a much higher efficiency to produce protein per unit land area than animals, legumes hold a promise of meeting protein needs of an increasing world population. However, legume proteins are of lower quality than animal protein due to the limiting amounts of Met + Cys, poor digestibility, and the presence of antinutritional factors.

The low levels of Met + Cys are usually corrected by supplementation with methionine, as in animal feed, or complementation with cereals, as practiced by various human populations. However, there are good reasons for improving the amino acid balance of legumes without resorting to these practices. Addition of methionine to foodstuffs may result in off-flavors caused by bacterial degradation and release of volatile sulfides (Damico, 1975; Bookwalter et al., 1975). Certain populations consume edible roots such as cassava and other starchy foods such as plantain as their chief carbohydrate sources instead of cereal (Bressani, 1973). Due to the very low protein content and a deficient amino acid profile of these starchy foods, which are not complementary with legumes, such population groups can benefit from legumes with improved amino acid balance.

Our objective in this study was to identify lesser known legumes and other plant seeds with high Met + Cys contents. Traditional plant breeding techniques have so far failed to improve the amino acid balance of legumes and other plant foods. Thus, there is a continuing need to identify legumes with relatively high Met + Cys to provide the genetic base for traditional plant breeding methods or the genes for the rapidly developing tools of genetic engineering. On the molecular level, the genes coding for the (Met + Cys)-rich proteins can be studied with the tools of molecular biology with the aim of enhancing the biosynthesis of such proteins. In our search, we include a cereal of reported high Met + Cys content. We present, in this paper, the amino acid and chemical composition of some lesser known legumes and an African cereal with high Met + Cys.

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MATERIALS AND METHODS

Legumes and Cereal Samples. *Prosopis velutina*, *Prosopis alba*, and *Prosopis pubescens* seeds were collected by one of us from mature trees in the Sonoran Desert of Southern California while *Prosopis chilensis*, *Prosopis tamarugo*, and *Prosopis strombulifera* seeds came from mature trees in the Atacama Desert near Pica, Chile. Sample code numbers indicate the field number of the tree and year of collection. Seeds of tamarind (*Tamarindus indica*) were from the Philippines, seeds of Djenkol bean (*Pithecellobium lobatum*) from Indonesia, and seeds of the African cereal Acha (*Digitaria exilis*) from Senegal. The seed coats of Djenkol bean and tamarind were removed before grinding the cotyledon to 80-mesh size. Seeds of *Prosopis spp.* and Acha were ground whole to 80 mesh in an Udy Mill.

Proximate Analysis. All proximate analyses were carried out according to AOAC methods (AOAC, 1980).

Amino Acid Analysis. Ether-extracted milled samples were heated in 6 N HCl under vacuum for 24 h at 110 °C. After filtering, the HCl was removed by evaporation and the amino acid composition of the acid hydrolysates determined with a Durrum amino acid analyzer, Model D-500, by the modified Spackman et al. (1958) ion-exchange method. Cysteine and methionine were determined separately as cysteic acid and methionine sulfone after per-

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Table I. Chemical Composition of Some Tropical Legume Seeds and *Digitaria exilis*[a]

	moisture, %	protein,[b] %	fat, %	ash, %	carbohydrate, %
Prosopis tamarugo	9.6	44.8	6.5	3.5	45.2
Prosopis chilensis	10.0	39.6	4.7	3.5	52.2
Prosopis velutine					
FN 1-82	10.0	46.1	6.5	3.9	43.5
FN 1-83	9.1	46.9	5.9	3.6	43.6
FN 1-84	9.4	41.4	6.3	3.5	48.8
P. velutina					
FN 12-82	8.0	44.5	4.5	3.8	47.2
FN 12-83	8.4	43.6	5.9	3.8	46.7
FN 12-84	8.7	44.0	5.2	3.8	47.0
P. velutina					
FN 25-84	8.3	44.3	5.6	3.6	46.5
Prosopis alba					
FN 24-83	8.4	41.0	5.1	3.6	50.3
FN 24-84	8.4	45.0	4.1	3.6	47.3
Prosopis pubescens	10.0	26.2	4.1	3.1	66.6
Prosopis strombulifera	8.2	30.0	5.2	3.7	61.1
Pithecellobium lobatum (Djenkol bean)					
immature	63.8	32.2	1.1	3.2	63.5
mature	29.4	15.8	1.4	1.7	81.1
Tamarindus indica (Tamarind)	9.7	17.7	9.6	2.6	70.1
Digitaria exilis[c] (Acha)	10.9	8.2	3.0	1.7	87.1

[a] Average of duplicate analysis; results reported on moisture-free basis. [b] Protein = 6.25 × Kjeldahl nitrogen. [c] Carbohydrate by difference.

formic acid oxidation as in Moore (1963). Results are averages of duplicate determinations except as indicated. On samples where the analysis was repeated, the results varied by no more than 0.1 g/100 g of protein for, at most, three of the amino acids determined.

RESULTS

The chemical composition of the legumes we studied are shown in Table I. The 13 accessions of *Prosopis* had a mean protein content of 41.3 ± 6.0%. Eleven of the samples ranged from 39.6 to 46.8% protein, which is somewhat higher than the values reported by Becker and Grosjean (1980) for *P. velutina* (32.8%) and *Prosopis glandulosa* (34.2%) but near values from del Valle et al. (1983) for *Prosopis juliflora* (37%) and Zalfaghari and Harden (1985) for *P. glandulosa* (39.3%). The two lowest protein values of 26.2 and 30.0% are in *P. strombulifera* and *P. pubescens*, both section Strombocarpae, series Strombocarpae (Burkart, 1976), suggesting the six other species in this series may also have relatively low protein contents.

Much of the carbohydrate content of the seeds has been shown to be mucilage (Becker and Grosjean, 1980). The carbohydrate data in Table I and viscosity measurements of heated seed flour solutions (data not shown) indicate *P. strombulifera* and *P. pubescens* seeds contain more mucilage than seeds from other series.

The fat content ranged from 4.1 to 6.5% and ash from 3.1 to 3.9% in the *Prosopis* species. There was surprisingly little variation in the composition of the seed from a specific tree over the 3-year period studied.

The immature seeds of Djenkol bean have twice the protein content (32%) of the mature seed (16%). However, on a fresh basis, the two types of seeds, both consumed in Indonesia, have the same amount of protein. The protein content of the mature Djenkol bean is similar to that reported by Felker and Bandurski (1977). Tamarind seed, with the hulls excluded, has a protein content of about 18%, very close to a previous analysis (FAO, 1970). Interestingly, tamarind has a relatively high oil content of 10%. We included Acha, a tropical African cereal, in our studies because it has been reported to have a very high Met content (FAO, 1970). Its protein content of 8% is typical of cereals.

The amino acid composition of the legumes is given in Table II, and the calculated chemical score for each of the essential amino acids is presented in Table III. The average Met + Cys content of *Prosopis* is 2.5%, giving it a chemical score of 71% for the sulfur amino acids. This score is very similar to soybean and winged bean and higher than cowpea, chickpea, dry bean, and broad bean, all of which have Met + Cys as the first limiting amino acids. It is worth noting that the Met + Cys content of *Prosopis* is on the high side of the range of values for legumes (Table II) and higher than most legumes. The first limiting amino acid of *Prosopis*, however, is threonine (mean content 2.2%, chemical score 55), giving it an overall chemical score lower than soybean and winged bean and similar to dry bean.

Both samples of Djenkol bean have unusually high Cys content, although the Met content is low, the sum of the two sulfur amino acids gives them a high chemical score (80, 111) for these amino acids. However, Djenkol bean is seriously limiting in the rest of the essential amino acids. Djenkolic acid, a dimer analogue of Cys that is not metabolized like Cys is very high in Djenkol bean (2.2% of the seed) and imparts a strong sulfury odor (Armstrong and Du Vigneaud, 1947; Sastrapradja, 1984). The unusually large amount of Cys probably serves as a pool of Djenkolic acid precursor.

Tamarind seed has a very good balance of essential amino acids. Except for the first limiting amino acid threonine (chemical score 80) and valine (chemical score 98), all the essential amino acids are as high or higher than the FAO reference protein. Its favorable chemical score of 80 is higher than other legumes. The content of sulfur amino acids of 3.5%, equally divided between Met and Cys, is unusually high for legumes while its high lysine content, similar to that of soybean and winged bean, is expected for legumes.

We confirmed that Acha has a high Met content (4.8%) and a very high Met + Cys content of 7.3% (FAO, 1970). Like other cereals, it is complementary to legumes with low Met content.

DISCUSSION

The objective of this study was to identify lesser known legumes and other plant seeds with relatively high Met + Cys contents. Our data on *Prosopis*, Djenkol bean, and tamarind demonstrate the wide range of Met + Cys in legumes. On the basis of their Met + Cys contents, Djenkol bean and tamarind are high in their chemical score (80 and higher). *Prosopis* seeds are in the low 70s, putting them in the same group as soybean and winged bean, which are still higher than other legumes such as cowpea, chickpea, dry bean, and broad bean with chemical scores in the low 60s and below. However, since the first limiting amino acid of *Prosopis* seed is threonine, its overall chemical score of 55 puts it below cowpea and chickpea. Our data demonstrate that sulfur amino acids are not always the first limiting amino acids in legumes. Threonine is first limiting in *Prosopis* and tamarind, which both belong to the subfamily Mimosaceae. Djenkol bean, although high in Cys is seriously limiting in leucine and isoleucine and the rest of the essential amino acids. In the search for high Met + Cys legumes, it is therefore important to analyze the complete amino acid composition to determine imbalances in essential amino acids.

Tamarind seeds deserve further studies because of their very favorable amino acid composition. Unfortunately, tamarind seeds are not eaten in Asia, as far as we know,

Table II. Amino Acid Composition of Some Tropical Legumes (g/100 g of Protein)[a] and *Digitaria exilis*[c]

	% N recd	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys	Val	Met	Ile	Leu	Tyr	Phe	His	Lys	Arg	Met + Cys	Met + Cys/100 g of sample[e]
Prosopis tamarugo	79	7.7	2.2	3.9	17.0	4.8	4.9	3.5	1.1	3.7	1.1	2.7	5.5	2.2	3.5	2.4	4.1	11.8	2.2	0.94
Prosopis chilensis	82	8.0	2.5	4.4	17.5	5.1	5.2	3.7	1.1	3.9	1.2	2.9	5.8	2.4	3.7	2.4	4.2	11.8	2.3	0.94
Prosopis velutina																				
FN 1-82[b]	82	7.5	2.2	4.1	18.0	5.4	4.4	3.9	1.6	3.9	1.0	3.0	6.7	2.6	3.6	2.8	3.7	11.8	2.6	1.29
FN 1-83[b]	84	7.8	2.3	4.2	18.4	5.6	4.6	4.2	1.4	4.1	1.0	3.0	6.6	2.5	3.5	2.8	3.8	12.3	2.4	1.14
FN 1-84[b]	80	7.4	2.1	4.1	17.2	5.2	4.6	3.7	1.5	3.7	1.1	2.9	6.3	2.3	3.4	2.7	3.7	11.8	2.6	1.07
Prosopis velutina																				
FN 12-82[b]	82	8.3	2.1	4.0	17.6	5.4	4.7	3.7	1.5	3.8	0.6	2.9	6.3	2.6	3.5	2.7	3.7	11.0	2.1	1.05
FN 12-83[b]	84	8.2	2.2	4.2	18.1	5.7	4.9	3.9	1.7	4.0	1.0	3.1	6.7	2.6	3.5	2.8	4.0	11.9	2.7	1.18
FN 12-84[b]	83	9.1	2.2	4.2	18.0	5.5	5.1	3.8	1.6	3.8	1.0	3.0	6.4	2.5	3.4	2.7	3.8	11.4	2.6	1.12
Prosopis velutina																				
FN 25-84[b]	83	7.8	2.3	4.2	18.2	5.6	4.9	3.9	1.6	4.0	1.1	3.1	6.6	2.6	3.6	2.6	4.0	12.2	2.7	1.20
P. velutina																				
mean	83	8.0	2.2	4.1	17.9	5.5	4.7	3.9	1.6	3.9	1.0	3.0	6.5	2.5	3.5	2.7	3.8	11.8	2.5	1.17
±SD	1	0.6	0.1	0.1	0.4	0.2	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.4	0.2	1.23
Prosopis alba																				
FN 24-83[b]	86	7.8	2.4	4.4	18.5	6.0	5.0	4.1	1.8	4.1	1.1	3.3	7.0	2.5	3.6	2.7	4.2	12.2	2.9	0.64
FN 24-84[b]	81	7.6	2.2	4.1	16.7	5.7	4.6	3.8	1.7	3.8	1.1	3.8	6.4	2.4	3.4	2.5	3.8	11.7	2.8	0.59
Prosopis pubescens	78	9.2	2.4	3.6	19.0	5.5	6.1	3.9	1.2	5.1	1.0	3.1	6.1	2.6	4.0	2.7	5.3	12.7	2.2	1.02
Prosopis strombalifera	74	8.6	2.1	3.6	14.5	4.5	4.6	3.6	1.0	3.5	1.0	2.5	5.0	2.1	3.3	2.1	4.1	11.0	2.0	0.67
Pithecellebium lobatum (Djenkol Bean)																				
immature	61	5.9	1.6	3.0	5.0	12.8	1.5	1.7	2.5	1.8	0.3	1.3	2.2	0.9	3.0	4.1	2.5	2.9	2.8	0.58
mature	53	4.6	1.9	2.3	5.5	5.5	2.0	2.7	3.4	2.3	0.5	1.6	2.7	2.1	3.2	3.4	3.2	2.7	3.9	
Tamarindus indica (Tamarind)	88	12.3	3.2	5.6	16.9	4.6	5.3	5.0	1.7	4.9	1.8	5.0	8.5	4.6	5.1	2.3	7.6	7.2	3.5	
Digitaria exilis[c] (acha)	78	7.2	3.9	5.0	18.8	6.4	3.8	8.4	2.5	5.5	4.8	3.8	9.8	3.1	5.2	2.3	3.1	4.7	7.3	0.67
legumes (general)[d]		2.5–5.0							0.2–1.1	3.8–7.8	0.5–1.8	5.1–9.9	3.2–10.9	3.2–10.9	1.0–3.8		5.4–11.4			

[a]Tryptophan was not analyzed in our samples. Protein = 6.25 × Kjeldahl nitrogen. [b]Single determination. [c]Tropical cereal from Senegal. [d]Range of values from Bressani (1973). [e]Dry-weight basis.

Table III. Chemical Scores of Essential Amino Acids of Some Legumes[a]

legume	amino acid							limiting amino acid	
	Thr	Val	Met + Cys	Ile	Leu	Phe + Tyr	Lys	first	second
Prosopis spp.[b]	55	76	71	75	90	105	71	Thr	Met + Cys, Lys
Djenkol bean (*Pithecellebium lobatum*)									
immature	40	36	80	32	31	65	45	Leu	Ile
mature	48	46	111	40	38	88	58	Leu	Ile
Tamarind (*Tamerindus indica*)	80	98	100	125	121	161	138	Thr	Val
soybean[d] (*Glycine max*)	96	97	74	114	110	133	117	Met + Cys	Thr, Val
winged bean[c] (*Psophocarpus tetragonolobus*)	107	99	79	122	128	148	147	Met + Cys	Val
peanut[d] (*Arachis hypogaea*)	65	84	68	84	91	146	65	Lys, Thr	Met + Cys
cowpea[d] (*Vigna spp.*)	90	91	64	96	100	128	126	Met + Cys	Thr, Val
chickpea[d] (*Cicer arietinum*)	94	92	63	111	106	142	126	Met + Cys	Val
dry bean[d] (*Phaseolus vulgaris*)	99	93	54	105	108	127	132	Met + Cys	Val
broad bean[d] (*Vicia faba*)	84	89	44	100	101	124	119	Met + Cys	Thr

[a] Calculated according to the provisional amino acid scoring pattern (FAO/WHO, 1973). The overall chemical score for the legume is the lowest score for any of the essential amino acids. [b] Calculated from the average amino acid values of 13 *Prosopis* accessions listed in Table II. [c] Newell and Hymowitz, 1979. [d] FAO, 1970.

although the pulp, which is sour–sweet, is widely used for snacks. Our analysis is the first complete amino acid data reported and differs from an incomplete analysis reported previously (FAO, 1970). However, more samples need to be analyzed. Its protein content of 18% is in the low range for legumes but still high for plant foods. The protein yield per pod can be high, however, since the seeds are big and make up as much as 50% of the pods. Amino acid analysis of more samples, feeding studies on animals, and analysis for toxic and antinutritional factors are needed for a complete nutritional evaluation of tamarind seeds.

Our amino acid data on a large sample of *Prosopis* species show a relatively high range of Met + Cys, contrary to the very high Met content reported by Pant and Tulsiani (1969) and de Valle et al. (1983). Our analysis of del Valle's samples of *P. juliflora* showed Met + Cys values similar to our present data. Differences in the amino acid content of the *P. velutina* seeds reflect yearly climatic and tree to tree variations. The very high value of 5.6% Met reported by FAO (1970) for *Prosopis africana* remains to be verified, since we have been unable to obtain samples of this species. The interesting food uses of *Prosopis* in Mexico, Central America, and Southwestern U.S. and its high protein content make this legume worth studying further.

Felker and Bandurski (1977) reported a high chemical score for Djenkol bean (*P. lobatum*) and a generally favorable amino acid composition, contrary to our data. It is disappointing that a legume with such a high level of total sulfur amino acids has a poor balance of the other essential amino acids.

The Met content of Acha of 4.8% we are reporting is lower than the value 6.1% reported by FAO (1970). However, this Met level is still higher than any cereal included in the same report. Compared with isolated corn protein fractions of high Met contents, Acha is 30% higher than glutelin (3.7%) but 30% lower than the alcohol-soluble reduced glutelin (6.3%) (Paulis, 1982). We expect that the proteins contributing to the high Met content of Acha would have higher than 4.8% Met. The total sulfur amino acid content of 7.3% is exceptional and makes Acha a very good complement to legumes. Feeding studies are in order to verify this.

The lysine content (3.1%) of Acha is expectedly lower than that of the FAO reference protein. It is similar to wheat, lower than rice, barley, and oats and higher than maize and sorghum (Doll, 1984).

These legumes and cereal we are reporting present some uses. The legumes can be used not only to complement cereals but to supplement other legumes with lower Met + Cys content. Again, Acha should be a very good complement to legumes. Also, they can be used as a genetic base to improve the protein quality of other plant foods through traditional plant breeding or molecular biology techniques, as it is expected that the high Met + Cys contents of these crops are due to (Met + Cys)-rich proteins.

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