Antioxidant Activity of Chia Seed Components

The antioxidant indices (AI) of bands from hydrolyzed and nonhydrolyzed extracts eluted from cellulose plates (developed in 15% acetic acid) are summarized in Table III. The antioxidant activity is expressed by the equation:

$$AI = \frac{\text{Bleaching time (hours) of } \beta\text{-carotene surrounding test spot}}{\text{Bleaching time (hours) of } \beta\text{-carotene surrounding control spot}}$$

As may be seen in Table III, the flavonol aglycones possessed the greatest antioxidant activity. Myricetin is primarily responsible for this activity. Myricetin possesses ca. 1.5 times the activity of quercetin and several times that of kaempferol (2,14). Since the ratio of myricetin to quercetin is 15:1, little doubt exists that myricetin is the primary flavonol antioxidant.

Caffeic acid also makes a significant contribution to the antioxidant activity of chia seed. In the hydrolyzed extract, caffeic acid concentration is ca. 4 times that of flavonols and must be considered as a major antioxidant source. Chlorogenic acid possesses about the same activity as caffeic acid in chia seed (as determined from the nonhydrolyzed extract). Concentrations of caffeic and chlorogenic acid are approximately equal. The caffeic acid moiety of chlorogenic acid is responsible for antioxidant activity.

Caffeic acid, perhaps, offers greater potential as an antioxidant from chia seeds than myricetin or other flavonols. Caffeic acid is easily derived and has not been shown to be a mutagen, as have myricetin and quercetin.

TABLE III

Antioxidant Indices of Components of Chia Seed

Band	AI	Antioxidant principal
		Hydrolyzed
I	6.5	Myricetin, quercetin, kaemferol
II	6.2	Caffeic acid
III	2.9	Not identified
IV	2.2	Not identified
V	1.1	None
		Nonhydrolyzed
I	6.0	Flavonol glycosides
II	4.2	Caffeic acid
III	4.8	Chlorogenic acid
IV	1.1	None

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Semiarid Legume Crops as Protein Resources

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ABSTRACT

Worldwide population pressures and accompanying increased demands on water supplies and tillable land has forced a reevaluation of traditional agricultural techniques and crops. Under-used semiarid lands are becoming candidates for crop production that uses stress-tolerant plants. Desert legume trees and shrubs, e.g., species of *Prosopis, Leucaena, Acacia, Geoffroea* and *Olneya,* fix nitrogen and could be sources of seed protein, forage or biomass. Seeds from desert legume perennials have a high potential as protein producers.

INTRODUCTION

The United States is currently facing the problem of overproduction of food, its main export commodity, and efforts to enhance agricultural production by cultivation of desert lands might appear illogical. However, long-term national objectives and international considerations combine to dictate that a high priority, intensive research effort be directed toward the goals of water and soil conservation as exemplified by minimum irrigation farming and development of crops and technologies to farm our arid and semiarid lands.

Today, ca. 1/3 of the earth's land mass is desert, compared with ca. 12% in 1882. Worldwide, 20% of the land is generally considered arid and 13% semiarid (Table I) (1,2) when arid zones or dry lands are defined by relating available precipitation to potential evapotransporation (3,4,5). These desert lands represent a diversity of soils and climates and are a home for a variety of cultures (6).

Ca. 8% of US land is arid and 22% semiarid. Three percent of North American land is arid and 11% semiarid. The Americas (North, Central and South) have ca. 14% of the world population, but 16% dry land. Of these countries, Mexico probably has the worst problem with 46% of its land dry and a population of ca. 70 million. Central America is generally tropical, but South America also has large desert areas.

Africa is 69% arid or semiarid. Egypt is essentially all desert, except for land along the Nile. Algeria, Tunisia, Niger and Ethiopia also have a severe lack of agricultural land.

To make a bad situation worse, deserts are expanding. In the Sudan, the desert is advancing at a rate of 5 km per year; in the Sahel 100,000 ha per year are lost; worldwide, 5 million hectares per year (or 0.35% of the world's arable lands) are estimated to have become desert because of man's mismanagement (6). Between 100,000-250,000 people are believed to have died of starvation in the Sahelian region alone between 1960 and 1974, and the toll would have been higher if $200 million had not been spent on emergency relief during that period.

The Middle East is 68% arid and 16% semiarid, and supports 3% of the world's population on land ranging from the hyperarid Sahara Desert regions to the semiarid areas in Turkey.

Asia has less dryland, but is burdened by 56% of the world's population, mainly in China, India and Pakistan.

Most countries with large amounts of drylands are food importers. The US is an exception in that it exports ca. 40% of the food it produces, but productivity of key crops is beginning to peak or flatten out. Export demand is expected to continue, especially because food production must double in the next 40 years to meet population projections.

We should, therefore, be interested in developing these dryland reserves, both domestic and international. One of the best ways to start is by finding plants native to the desert areas that might have commercial potential.

DRYLAND AGRICULTURE

Agricultural practices appropriate for fertile land often bring disaster when applied to marginal land. Plowing the natural grasslands of the Great Plains of the United States during the 1930's and the "virgin lands" of south-central Russia in the 1950's, when combined with natural droughts, produced conditions virtually guaranteeing severe wind erosion. The resulting serious soil losses were controllable only by reestablishing the grass cover (7).

TABLE I

Percentage of Drylands in Selected Countries and Their Populations[a]

Country	Arid (%)	Semiarid (%)	World Population—1981 (%)
The Americas	4.2	12	13.9
United States	8	22	5.1
Bolivia	10	15	0.13
Chile	27	7	0.25
Mexico	26	20	1.6
Peru	1	6	0.40
Africa	49	20	8.6
Algeria	85	10	0.43
Egypt	100	0	0.95
Ethiopia	20	50	0.71
Kenya	20	55	0.38
Niger	70	30	0.12
South Africa	35	25	0.67
Tunisia	75	15	0.14
Middle East	68	16	3.0
Iran	7.2	32	0.87
Iraq	74	15	0.30
Jordan	93	6	0.07
Saudi Arabia	98	2	0.21
Turkey	0	18	0.97
Yemen (N&S)	81	14	0.17
Asia	12	14	58.2
China	13	10	22.3
India	4	17	15.5
Soviet Union	9	11	5.9
Australia	49	16	0.32
Europe	0.1	2	15.5
World	20	13	

[a]Based on total world land mass of 52,006,000 square miles, which does not include Antartica (9.6% of total land mass).

Even today, land-use patterns developed in the sixteenth century, and culturally perpetuated by peasants living close to the absolute margin of survival, have severely degraded plant resources in many countries, from the upland semiarid areas of Chile (8) to the Sahel area bordering the Sahara Desert (9) and the Rajasthan Desert of India (10).

For example, the Indian desert, by far the most populous of the world's deserts, has a population of 48 persons per sq km (0.19/acre or 124/sq mi) and receives 100-500 mm annual rainfall. Demand for local trees and shrubs as fuel increased from 1.64 million t in 1951 to over 3 million t in 1971 as the result of a population increase from 9.4-15.5 million during the same period. Based on this, the native plant population is expected to last for only another 6 decades (10). In addition to using the plants for fuel, the inhabitants eat the pods and seeds, further handicapping natural regeneration.

Cultural and religious factors are also important. Years ago, to protect grasslands and forests, Rajput princes decreed that all desert villages would set aside an "oran" (protected forest) and a "gochar" (grazing land). Serious punishments were prescribed for using an ax in the oran, and only deadwood could be collected for fuel. In certain orthodox Indian areas, the orans are still honored and the forests are surviving whereas adjacent areas have been stripped. To protect hill flora, half the hill was also dedicated to the deity "Jogmaya." Today, the well-forested Jogmaya side can be found with the other half absolutely barren and denuded (11). Without these practices, the area would undoubtedly be in much worse condition.

A 40-fold increase in nitrate losses occurs in soils denuded of forest vegetation (12). Potassium losses are 15-fold greater, calcium and magnesium are 4-fold and sodium is 2-fold greater than from unstripped soil. To erode 8 inches of untilled topsoil in midwest America is estimated to take 2234 yr. When subjected to noncontour tillage, the same 8 in. of soil would be lost in only 37 years (13), with similar losses expected for African lands (14). Because of similar ongoing erosion processes, desert lands are characteristically low in organic matter (0.5-0.8%) and fertility, and usually lack moisture storage capacity (15).

Desert lands also can have extreme temperatures, ranging from below freezing to over 50 C. High temperatures, combined with commonly occurring winds and low humidities, often are severely dehydrating. Some plant species have evolved a crassulacean acid metabolism (CAM) that enables stomata to close during the heat of the day and reduce water transpiration losses.

The solar intensity of the desert can be a mixed blessing. It enables high photosynthesis rates and multiple crops, but can combine with other environmental factors to induce plant stress. It can also reduce human activity unless tolerances are developed.

Water quantity and quality are usually the limiting factors in most arid zones. Precipitation can range from no rainfall for 7 years in the Atacama Desert of Chile to over 400 mm annually in some semiarid zones.

For agricultural purposes, water quality is determined by salt content. In general, water with less than 600 mg/L total dissolved solids may be used to irrigate almost any crop. Water with 1,000-1,500 mg salt/L is widely used on all but the most salt sensitive crops if leaching and drainage are adequate. If frequently irrigated, water with 1,000-2,000 mg salt/L can be used for crops of moderate tolerance. Water with 3,000-5,000 mg salt/L will produce high yields only from highly tolerant crops. The most common salt tolerant crops can withstand about 12,000 mg salt/L, although eelgrass (*Zostera* spp) produces an edible grain and large amounts of biomass in full sea water (16). (Seawater has a total salt content of ca. 35,000 mg/L.) The relative concentrations of sodium to calcium and magnesium, and the anion concentration (chloride or sulfate) may also be important. Additional factors are plant age, soil type and irrigation methods (17).

The accumulation of salts in the soil is one of the problems accompanying irrigation of agricultural land. In many desert areas, evaporation exceeds precipitation by up to 1500 mm (60 in.) per year and is the major factor responsible for the salt buildup in the soil (18). A second problem occurs when good water percolates through saline soils as irrigation runoff. This runoff water is often high in leached salt (up to 3,000 ppm solids) and must be collected and removed to prevent soil salinization and contamination of low salt groundwater supplies (18).

The amount of saline soil in arid and semiarid areas worldwide was estimated in 1977 by Ponnamperuma (19) at 381 million ha, although estimates vary and some of this land may not be suitable for agriculture for reasons other than salinity. Others (20) estimate that 1/3 of the world's irrigated land (47 million ha) is affected by salt. Soil salinization can be a direct cause of creating deserts and contributes to the decreasing productivity of farmlands worldwide. Salinity is the most important problem in irrigation agriculture and combating it is among the most costly problems facing the farmer (18).

Productivity decreases of existing farmland associated with salinity can be combated by introducing salt tolerant lines of conventional crops or the introduction of other salt tolerant plants with an equivalent, or better, economic value.

LEGUME TREE SEEDS AS NEW CROPS

Desert legume trees are particularly well suited to meet the stringent requirements of dryland agriculture. In a recent review (21), they were described as the ideal crop for reducing capital and energy expenditures in these special environments. These woody dicotyledonous trees or shrubs from the family Leguminosae (order Rosales) comprise most of the subfamily Mimosoideae and some of the subfamily Caesalpinoideae. Most species examined nodulate and fix nitrogen (22) with reported rates between 200 and 580 kg N/ha/yr (23,24). The soil under leguminous trees has been shown to have levels of nitrogen and organic matter several times higher than surrounding soils (25-28) or soils under nonleguminous trees (27). Legume trees require minimal tillage and their subsurface roots retard erosion (21).

Seed compositions of some commonly used dryland legume trees are shown in Table II. Seed protein content ranges from 17% in a *Gleditsia* species to 37% in *Leucaena lanceolate*, with most being 20-30%. The amino acid chemical score of 38 for Desert Ironwood seed protein is less than the score of 47 for dry beans. The scores of 77 and 66 for *Prosopis* seed protein are higher than that found in soybeans (29), which is shown for comparison. Fat content in the seeds ranged from ca. 2% in several species, as high as 49% in Chanar, which will be described later.

Yields from dryland or minimum irrigation cultivation practices are highly variable, so the calculated values used in the tables are, in many cases, arbitrary (Table II). The correlation between protein content of legume tree seeds and yield is not known. A negative relationship has been shown between protein and methionine content of field beans, and raising soil phosphorus may increase protein content (30), but little is known of the effects on the nutritional value of these proteins.

TABLE II

Dryland Legume Tree Seeds

Plant name			Composition (%)		FAO protein chemical score	Yield, kg/ha	
Common	Botanical	Ref.	Fat	Protein		Lipid	Protein
Mesquite	*Prosopis glandulosa*	34	1.6	22	–	40	550
	P. velutina	34	5.7	29	30	142	725
Algarrobo	*P. chilensis*	a	9.2	31	77		
Tamarugo	*P. tamarugo*	a	3.6	27	47	–	675
Screwbeans	*P. pubescens*	a	–	36	66	–	792
Leucaena	*Leucaena leucocephala*	16	10	28			
	L. lanceolate	16	7	37			
Acacia	*Acacia moniliformis*	20	–	(55)[b]			
	A. auriculaeformis	20	–	(38)[b]			
	A. spp		–	21			
Honey locust	*Gleditsia triacanthos*	a	1.9	17			
African	*Parkia clappertoniana*	20	–	(16)[b]			
locust	*P. roxburghii*	20	–	(41)[b]			
Djenkol	*Pithecellobium lobatum*	20	–	(16)[b]			
	P. sonorae	20	–	(44)[b]			
Dhaincha	*Sesbania* spp	16	2.9	31			
Carob	*Ceratonia siliqua*	49	2.8	20			
Ironwood	*Olneya tesota*	52	35	31(26)	27	577	511
Chanar	*Geoffroea decorticans*	51	49	29	66		
Palo verde	*Cercidium microphyllum*	a	8.3	25	–	33	100
Blue p.v.	*C. floridum*	a	7.2	26			
Mexican p.v.	*Parkinsonia aculeata*	16	3.8	21			
Beans	*Phaseolus vulgaris*, US, 1981		1.6	22	47	25	348
Soybeans	*Glycine max*, World, 1979		18	34	62	805	934
	US, 1979					955	1804

[a]Becker, Sayre, and Saunders, unpublished observations.

[b]Composition of trichloroacetic acid precipitable fractions from seed embryos (20).

PROSOPIS

Forty-four *Prosopis* species are known, occurring in North and South America, Africa and eastern Asia (31). Examples of useful species have been found that fix nitrogen, are frost hardy, tolerate extreme heat and survive in some of the hottest and dryest of the earth's deserts (31). One of the highest CO^2-fixation rates known for trees (30 mg $CO^2/dm_2/hr$) was observed on a *Prosopis* species in Death Valley, California (32). *Prosopis* trees are thought to have CAM, enabling them to close their stomata during the day and fix CO_2 at night.

Prosopis trees produce indehiscent pods that are palatable to humans and animals (31). Pods of many species, e.g., *Prosopis glandulosa, P. velutina* and *P. chilensis,* are rich in sugar, containing 13-41% total sugar in the pericarp, of which over 90% is sucrose (33) (Table III). Most of the pod protein occurs in the seed, which is 15-25% of the pod. The cotyledon, where the seed protein is concentrated, constitutes 7.9-14% of seed weight, the remainder being seed coat and endosperm mucilage material (33,34). Amino acid analysis of protein from these seed samples in each case demonstrated that the sulfur amino acids methionine and cysteine were limiting when compared with the FAO standard. The protein content of the trichloroacetate (TCA) precipitable fraction of seed embryos ranges from 56-60% in *Prosopis* species and 16-58% in other tree legume seeds (21) (Table II).

The protein efficiency ratio (PER) was determined to be 0.71 and 0.61 for uncooked and cooked *P. velutina* pods, 0.69 and 0.63 for the uncooked and cooked seeds and 0.32 for the pericarp, similar to other common legumes. *P. pubescens* pods had a PER of −0.32, which was depressed to −1.35 by autoclaving, indicating it is not a desirable feed. For both species, lowering of the PER after cooking was probably caused by increased solubilization and accompanying increased water absorption and bulking effects of the seed gum when heated. A similar effect was observed when *P. velutina* pods were fed to poultry; the metabolizable energy dropped from 1.65 to 0.70 after heating (35).

Pods from mesquite trees have traditionally been used by desert dwelling cultures worldwide for animal feed, and in processed form for food products. Established food technology principles have been recently applied to pod processing in attempts to create modern nutritious products from what until now has been an underused food source (36).

The pods were dry milled and separated into 4 fractions: exo-mesocarp (58%), endocarp (26%), seed coat plus gum (6%) and seed cotyledon (5%). The exo-mesocarp fraction was rich in sugar and contained most of the typical mesquite taste components; it may be useful as a fermentation substrate or as a flavor and sweetening ingredient in food products. The endocarp fraction was high in fiber content. The seed coat and mucilage fraction contained large amounts of a galactomannan gum, with properties similar and in some applications superior to guar gum. The seed cotyledon fraction was richest in protein and contained most of the seed lipids. This fraction had a characteristic legume nutlike flavor and aroma, and can probably be used in typical legume applications.

Prosopis pods and seeds are known to contain varying quantities of antinutrients, e.g., tannins and related phenolics, trypsin inhibitors and cyanogenic compounds (33). Kinds and amounts of these compounds may vary with species, accession and perhaps agronomic factors, but so far have not been found to present unsurmountable difficulties.

In South America, the predominant *Prosopis* species are tamarugo *(P. tamarugo)* and algarrobo *(P. chilensis).* Tamarugo is being used in an attempt to reclaim parts of the Chilean Atacama desert. Most areas there are generally denuded of all plant life except for shrubs that are low in palatability to goats or useless as firewood. The botanical desolation increases in direct proportion to nearness to villages (8). In a recent forestation project involving 10,875 ha (37), tamarugo seedlings were planted in 40-50 cm deep holes cut in the salt crust and irrigated until the roots reached groundwater, which is often only 2-10 m below the soil surface. The mature trees were pruned to permit livestock access and the agro-forest maintained as a fodder source for goats, sheep and some cattle.

Groundwater under the forested areas is less salty than under adjacent barren areas. The forest is thought to lower

TABLE III

Proximate Composition of *Prosopis* Fruit[a]

Acession Number	Species	Part analyzed	H_2O (%)	Protein (%) N X 6.25	Fiber (%)	Ash (%)	Sugar (%)
		Trees grown on experimental plots					
F0001	*P. glandulosa*	Whole pod	2.2	14	20	3.4	34
F0020	*P. velutina*	Whole pod	1.6	11	30	4.4	13
F0025	*P. velutina*	Whole pod	2.1	14	19	3.1	28
F0032	*P. velutina*	Whole pod	2.6	17	24	4.4	19
		Mature wild or ornamental trees					
B0060	*P. velutina*	Whole pod	4.3	12	31	4.1	19
B0201	*P. velutina*	Whole pod	4.2	12	23	3.4	28
B0078	*P. velutina*	Whole pod	2.2	12	23	4.8	22
B0078	*P. velutina*	Pericarp	6.0	7	23	5.5	32
B0078	*P. velutina*	Seeds	2.4	29	7	3.8	4
B0024	*P. glandulosa*	Whole pod	7.5	11	22	3.3	26
B0024	*P. glandulosa*	Pericarp	8.5	7	27	3.4	32
B0024	*P. glandulosa*	Seeds	7.1	31	7	3.4	4
F0377	*P. glandulosa*	Pericarp	8.1	8	30	–	13
F0372	*P. glandulosa*	Pericarp	8.3	5	23	–	41
B0219	*P. pubescens*	Whole pod	5.9	11	17	3.8	25
B0219	*P. pubescens*	Seeds	7.4	26	–	–	–

[a]From reference 36.

the groundwater level, thus reducing surface evaporation and its salt-concentrating effects. The forested salt flats and soils have a lower mean annual evaporation rate (309 m^3/ha) than the unforested areas (1590 m^3/ha). Under conditions of high humidity, tamarugo reportedly absorbs water through its foliar system, deposits it in the microrhizosphere and reabsorbs it as water (37).

In the extreme western parts of the Indian desert (200 mm annual rainfall), village fuel is supplied by miscellaneous shrubs, including Khejri *(Prosopis cineraria),* which has a density of only 1-5 trees/ha (10). For religious reasons, the Khejri trees are not usually cut down, but are only lopped during midwinter to provide branches for fuel and air-dried leaves for livestock feed. These trees are thought to be slow growing, or more likely stunted by the yearly lopping, so that 100-year-old trees are only 8-10 m high. The usual meager seed production is often consumed by the population.

In the US, mesquite *(P. velutina, P. glandulosa)* is found in ca. 90 million acres of the Southwest (50 million of which are in Texas). Here, it is generally considered an invasive pest that captures moisture that might otherwise sustain grasses. Mesquite is not currently used in the US; however, it is a strong candidate for biomass culture. *Prosopis* forests have been proposed as a fuel source, enabling the production of a million BTU's of energy at a fuel cost of $1.50, compared with $3 for natural gas and $6 for crude oil (38).

LEUCAENA

Leucaena is the common name given to *Leucaena leucocephala,* but it as well as other varieties may have local names, e.g., ipil-ipil, lamtoro, yaje, kao kaole or tan-tan. Fifty-one species of leucaena have been reported, but only ca. 10 of these are valid, the remaining being synonyms resulting from a confused taxonomy. The most commonly exploited species is *Leucaena leucocephala,* although other species may have value throughout the tropics (39).

Leucaena is commonly grown in the tropics or subtropics to provide windbreaks, firebreaks, shade, ornamentation and as a food and forage crop, but it is not grown in the US. It grows best in areas of high rainfall (600-1700 mm annually), but also grows well even in areas with long, severe dry seasons. It survives in its native Mexico habitats in Yucatan and Guerrero (west-central Mexico, where no rain may fall for 8½ months a year), and in cooler parts of the Sonoran desert, and is the dominant vegetation on Honolulu's Diamond Head, where only 250 mm (10 in.) of rain falls annually. The varieties range from short bushy types of 5 m height (Hawaiian), tall plants to 15 m (Peruvian), to treelike plants with heights to 20 m (Salvadoran) (40).

Leucaena's drought tolerance, hardiness and nitrogen-fixing ability combine to make it a promising candidate for increasing milk and meat supplies throughout the dry tropics. The large quantities of foliage it produces are highly palatable, digestible and nutritious to beef and dairy cattle, water buffalo, sheep and goats. The seeds have been used as a source of galactomannan gum and as pig and chicken feed (41,42).

Leucaena leaves and seeds contain from 2-6% of the amino acid minosine, with up to 10% in the growing points (40). When ingested by nonruminants (monogastric animals), especially horses, it may cause depilation, growth reduction and general ill health. In poultry, it may cause a reduction of egg production. When more than half of the diet is leucaena and the diet is continued for more than 6 months, cattle may experience general ill health with loss of tail and rump hairs, excessive salivation and poor growth. These effects are probably caused by malfunctioning thyroids (goiters) because of rumen bacterial transformation of mimosine to 3,4-dihydroxypyridine (DHP), an acknowledged goitrogen. Goiter in cattle can be detected at early stages and the effects reversed by removal from leucaena pastures. Mimosine has no known effects on the meat or milk of ruminants that can be detrimental to man (40), although leucaena-fed dairy cattle produce off-flavored milk (removable by pasteurization), poultry shows reduced egg production and pigs experience fetal resorption, reduced birth weights and teratogeny (41,42).

ACACIA

Acacia species are another underexploited dryland leguminous tree (43-45). Their main value is as a forage plant in areas with a prolonged dry season, although the wood and pods have uses similar to other legume trees. Acacia species possess the attributes common to many of the other leguminous trees previously described: they fix nitrogen, are drought and heat hardy, the foliage is a valuable fodder for all types of livestock and the trees produce palatible pods (135 kg pods/tree in the Sudan). The trees are usually found in riparian communities, although many are the dominant species in more arid areas. In many instances, acacia trees stand isolated in otherwise treeless arid environments or are the last surviving woody plant to form stands on sandy soil adjoining the desert.

Acacias also have many of the worse characteristics of legume trees; they often are thorny and invasive because they propagate from suckers and the seeds are spread by animals. They often form impenetrable thickets and pioneer the invasion of grasslands by brush and other forms of thickets. Eradication of some species can be extremely difficult, so introduction should be carefully considered (44).

CAROB

Carob (*Ceratonia* spp, subfamily Caesalpiniodeae) is one of the oldest known cultivated plants. Noted for its drought resistance, it has contributed for centuries to the economy of the Mediterranian basin and may well be suitable for cultivation in the dry subtropics elsewhere. The pharaohs fed their cattle on it, the seeds and sweet pulp are supposedly the locust and wild honey eaten by John the Baptist in the wilderness (hence the name St. John's Bread) and Wellington used it to sustain his horses during the campaign against Napoleon in Portugal and Spain. The tree is used for fodder and for its wood, but the main product is the carob pod (46), which contains more sugar than sugar beet or sugar cane. The pod is often used as a chocolate substitute and the seeds roasted and substituted for coffee. The seeds contain about 21% protein but are usually only about 10% of the pods. The ground whole pod is about 7% protein, 30% sugar, 9% fiber, and 1-2% fat with a comparatively low energy value of 180 calories/100 gm (46).

CHANAR

Chanar (*Geoffroea decorticans,* subfamily Papilonoldeae) grows in the South American deserts of Chile and Argentina as shrubs or trees 5-7 m high (47). The tree fixes nitrogen and tolerates saline water (2,000 mg/L). It produces plum-sized fruit used locally as a beverage and for fermentation. The fruit pericarp contains 48% sugar, most of which is sucrose. The fruit seed, which is only ca. 5% of the fruit, is 29% protein and nearly 49% fat. The limiting amino acids in the seed protein are lysine and the sulfur amino acids. The seed protein has a FAO chemical score of 65, which is in the range of groundnuts, 65; millet, 63; polished rice, 67. The oil is rich in oleic and linoleic unsaturated fatty acids and smells and tastes like peanut oil.

Whole chanar fruit has a negative PER (−3.97), indicating the presence of an antinutrient, probably hemagglutinin, although small amounts of cyanogenic compounds were found and the high fiber content may also contribute.

If species could be found with a higher seed-to-pod ratio to enhance exploitation of the fat and protein, and the plant's invasiveness could be controlled, chanar might have potential as a new crop (47).

DESERT IRONWOOD

Many plants throughout the world with very hard, dense wood are called ironwood. In North America, the name Desert Ironwood has been given to *Olneya tesota,* a leguminous tree common to the Sonoran and Coloradan deserts. Desert Ironwood trees are often found in dispersed stands with *Prosopis, Cercidium* and *Atriplex* species, although it will tolerate more arid conditions than *Prosopis* species. *Olneya* trees annually produce single-seeded pods that, on maturing, fall to the ground and split open to release the seed, which is eagerly eaten by local inhabitants (desert-dwelling Indians and wild animals). These seeds are 17-21% protein, 33-30% lipid and have a pleasant nutty taste after cooking. Unfortunately, the seeds contain as much as 5% canavanine (a structural analog of arginine), which is a potent antinutrient and could hinder protein exploitation. The lipid is rich in palmitic, stearic, oleic and linoleic acid and tastes much like peanut oil. Workers have collected 8 kg seeds from 1 tree. If trees were planted on 7 × 7 m plots and similar yields were obtained, a yield of 571 kg/ha lipid and 424 kg/ha protein could be expected without fertilizing and with minimum tillage (48).

OTHER TREE LEGUMES

A number of other tropical legumes are sufficiently drought tolerant to be considered for semiarid dryland agriculture (44). Honeylocust (*Gleditsia* species) produces pods with up to 40% sugar in reported yields of 230 kg pods/tree/yr after the 4th or 5th yr, but little is known of its performance under stress conditions. Little is known of African Locust (*Parkia* spp) and the Djenkol bean (*Pithecillobium* spp) and their drought hardiness, but they may also merit further research. *Sesbania* species are tropical leguminous trees common in Asia, India and Australia and should be tested in dryland areas (43).

Palo Verde (*Cercidium* and *Parkinsonium* species) are also found in the desert and have historically been used as food and feed by desert dwellers. Some of these beans are quite tasty, especially when harvested green and blanched. Their occurrence in some of the more inhospitable areas of the desert and their significant seed protein content suggests that they may be exploitable as arid land protein resources (21).

ANNUAL LEGUMES

Desert annual legumes have a potential for development as a protein resource that is equal to or greater than legume trees. Annual legumes are easy to plant, they usually produce a crop in a short time, need little fertilization because they fix nitrogen and may be drought hardy and disease and insect resistant. The beans are usually high in protein, with amounts generally equal to or greater than the protein found in common commercial beans. Typical of most legume seeds, the protein is low in the sulfur amino acids and would be expected to contain heat-labile antinutrients (trypsin inhibitors and hemagglutinins). The beans listed in Table IV all have a history of being consumed by local inhabitants and all are normally prepared for consumption in much the same way, usually by boiling.

TEPARY BEANS

Tepary beans (*Phaseolus actifolius*) are ideally suited for the desert, as documented in a recent review (49). They require more moisture to germinate and flower than other desert ephemerals, but beyond that they grow and produce fruit rapidly (60-90 days) with little water, sometimes permitting 2 crops. They thrive in arid and semiarid desert regions, withstanding heat and low humidity, to produce edible dry beans in climates often too arid for even the hardiest pinto bean.

Native to North America, wild species have been found from Guatemala to central Arizona and from sea level to a 1650 m summit and on an extremely arid, volcanic scoria slope. The most useful variety, the broad-leaved *P. latifolius,* is commonly found climbing into the overstory in shady shrub thickets on floodplain alluvia. The narrow-leaved variety, *P. tenuifolius,* prefers grassy slopes or woodland openings and vines on the ground or twines on grasses or forbs.

Wild teparies reportedly produce 20 kg/ha seed under natural conditions. Domestic white teparies produced 2,020 kg/ha in irrigated fields in the Sonoran desert and 4,633 kg/ha seed with minimal irrigation from areas near Fresno, California, where the climate is less extreme. They equal or surpass the average Arizona bean yield of 560 kg/ha in wet years and produce some beans in dry years when other crops completely fail. The pods explosively dehisce when dry so harvesting is usually during the morning, before the dew is dried.

Teparies may also have potential as a forage crop. They are better at evading drought (because of their short life cycle) and tolerating drought than *Phaseolus vulgaris* species.

The protein content of tepary seed ranges from 22-25% (a high of 39%) with the sulfur amino acids as a limiting factor. Fat ranges from ca. 1-2% and large quantities of carbohydrate (65%) are present (49).

Around the turn of the century, agronomists in the arid southwestern US were promoting teparies for dryland

TABLE IV

Dryland Pulses

Plant name		Percentage		Yield, kg/ha	
Common	Botanical	Fat	Protein	Fat	Protein
Tepary	*Phaseolus acutifolius*	1.5	24	24	400
Bambara groundnut	*Voandzeia subterranca*	9	20	202	450
Lablab	*Lablab purpureus*	1.4	25	56	1000
Marama	*Tylosema esculentum*	36	34	–	–
Guar	*Cyamopsis tetragonoloba*	4	32	40	320

farming, and by 1915 a tepary boom had begun. Tepary cultivation on marginally productive land in Arizona, New Mexico and California was initiated, and by 1918 expanded onto 41,000 ha. In the marketplace, they were cheaper than other dry beans. They were also smaller and less attractive than the navy or pinto bean, had a stronger flavor and were reportedly more flatulent. They could not gain acceptance in restaurants and soon the bottom fell out of the market. Gasoline-powered pumps were introduced and groundwater irrigation became popular at the same time. Dryland farms were irrigated and converted to many of the cash crops seen today: alfalfa, vegetables, small grains and fruits. Indians began working for wages and abandoned their traditional agricultural fields and their barter and gift economy was replaced by a cash economy. Soon, only the unemployed Indians farmed teparies. Agricultural techniques of the era made tepary fields susceptible to severe wind erosion, and the 1930's dust bowl made farmers wary. Today teparies are grown only by a few farmers for marketing on trading posts and reservations, usually bringing prices better than pinto beans because of their scarcity.

BAMBARA NUT

The National Academy of Sciences has suggested several African legume annuals that may be useful in desert areas (44). The bambara groundnut (*Vigna subterranea*, subfamily Papilionoidea) is little known in areas outside its native Africa. Named for the Bambara district near Tombouctou (Timbuktu) in the southern edge of the Sahara Desert, the plant grows from Senegal to Kenya and from the Sahara to South Africa and is one of Africa's most popular pulses. It tolerates harsh conditions and variable rainfall better than peanuts, corn or sorghum and, as a *Rhizobium* symbiont, does well in poor soils.

It grows much like the peanut; the plant being either erect or prostrate with pods on or just beneath the soil surface. The pods contain 1-2 round seeds (ca. 1.5 cm diameter), which are very hard when mature or dried. The seeds are usually harvested while soft and sweet, mature seeds being too hard to be eaten unless roasted or boiled. Bambara groundnut seeds contain 14-24% protein, 6-7% fat (not a good oilseed) and ca. 60% starch, making them useful as a nutritious flour for baking. The protein reportedly is richer in the sulfur amino acids than other grain legumes. They do not seem to be grown in the US.

LABLAB BEANS

Lablab beans *(Lablab purpureus)* are generally thought of as a tropical plant; however, they reportedly will tolerate semiarid climates with annual rainfall of 200-400 mm. The plant is used as forage and hay for cattle, sheep, goats and pigs; the leaves and flowers can be cooked and eaten as a vegetable; the sprouts are tasty; the pods are used as a table vegetable and the dried seed have the usual legume seed uses (cooked or processed for tofu or tempeh). The seeds contain ca. 25% protein, 2-3% fat and considerable starch (44) but reportedly hydrate poorly and contain significant amounts of heat-labile trypsin inhibitor. The plant has a long taproot, which contributes to the drought hardiness of established plants.

MARAMA BEAN

Another underdeveloped leguminous African plant is the Marama bean (*Tylosema esculentum*, subfamily Caesalpinioideae) (44). It grows uncultivated in the Kalahari and neighboring sandy areas of southern Africa and is a dietary staple in many of the native cultures. The low-lying vines produce pods containing 1-6 seeds, which are normally roasted before eating and taste much like roasted cashew nuts; Africans also boil them whole or grind them as a flour. The plant also produces an underground tuber which is also edible.

Not much is known about yield as the plant has not been cultivated. Analysis of the dry seed indicates ca. 30% protein and 36-43% oil (soybean has 34% protein and 18% oil). Marama protein is reportedly high in lysine (5%) and limiting in methionine (0.7%).

GUAR

Guar is one crop that has been successfully introduced in many arid areas in the US and is beginning to establish a place for itself in the market (50). Introduced from India in 1903, Guar *(Cyamopis tetragonoloba)* was recognized as a source of an industrial gum, animal feed and for its protein. World production is now concentrated in India, Pakistan and on the plains of Texas and southwestern Oklahoma. In the US, 12,000-80,000 ha have been planted (20,000 ha in 1978-1979), yielding 437-896 kg/ha seed. Even so, almost 43,000 mt were imported in 1977, the price often being inversely tied to production conditions on the Indian subcontinent.

The seed contains 50% endosperm and yields 40% gum. The protein content of guar seed ranges from 27-37% with ca. 4% fat also present. The seed protein is low in methionine, traces of hydrocyanic acid were present in mature seed and trypsin inhibitor but no hemagglutinin activity has been observed.

RESEARCH NEEDED

The plants described here are obviously only a sampling of potentially useful new protein sources. As more interest is focused on these topics, other useful plants will undoubtedly be identified and additional mechanisms for their exploitation developed.

Some of these plants are already items of international commerce. Leucaena fodder is a well-developed industry in the tropics. Carob is established in the Mediterranean area and guar in parts of Asia and North America. Lablab beans are grown as a tropical crop.

In the US, of the plants mentioned, only guar has become commercially competitive as a semiarid crop. Other plants, e.g., jojoba, are being actively marketed and appear to have a commercial future.

As mentioned, Tepary beans tried and failed to become an established crop. Circumstances have changed since then, so they may now be another good candidate for exploitation. The other plants have an even longer and more difficult path to acceptance in the US market.

Most current work has been focused on identifying and growing new stress-tolerant plants. Future research should also include a critical evaluation of the potential commercial usefulness of the plants. Many of the plants being investigated are wild species whose quality could perhaps be significantly improved by breeding, but these breeding studies should be aimed at a compromise of best stress tolerance and best product characteristics. Even though grown on previously unproductive land, the products will still have to compete in the marketplace with established crops of known characteristics.

If a specific stress-tolerant crop does not have a single commercial characteristic of sufficient high quality to make the crop economically competitive, multiple products should be considered. For example, mesquite trees could be used for forage, biomass and erosion control while being grown with little water or fertilizer. The pods could be collected and milled into fractions rich in protein, sugar and galactomannan gum. None of these attributes may economically justify growing the trees by itself, but collectively they may make a new crop attractive. The same argument could be applied to the other plants being considered. Unfortunately, plants that are thought to be stress tolerant may not prove to be so. Also, the plant may tolerate the stresses but at the expense of yield or product quality. If one argues that a low yield in a hostile environment is better than nothing, then the range of accepted conditions must be defined, and such a range would probably differ for each plant and in each agronomic situation.

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