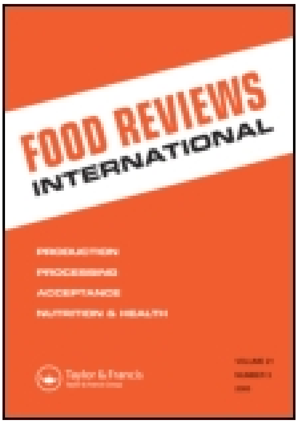

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Pod Mesocarp Flour of North and South American Species of Leguminous Tree *Prosopis* (Mesquite): Composition and Food Applications

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*Flour from the mesocarp of pods of the tree legume known as mesquite (*Prosopis *spp.) in North America or algarrobo in South America was one of the most important food staples for desert people. Contemporary milling techniques produce a flour similar to that of indigenous peoples that is about 40% sucrose, 25% dietary fiber, and that has a variety of volatiles, such as 2,6-dimethylpyrazine, γ-nonalactone, methyl salicylate, and 5,6-dihydro-6-propyl-2*H*-pyran-2-one, that contribute to a chocolate and coconut-like aroma. Flour made from the mesocarp contains no stachyose or raffinose, sugars that are responsible for flatulence in other legumes. High-performance liquid chromatography (HPLC) analyses of sugar (sucrose) and citric, malic, and ascorbic acids found considerable ranges in acid/sugar ratio that may be responsible for the wide variations in organoleptic perception. Due to the absence of gliadin, peanut, and soy allergens, the flour is useful in gluten-free formulations. Optimum concentrations for incorporation ranged from 5% for biscuits, 10% for breads, 15% for pancakes/muffins, and 50% in chapatti and drum-dried wheat flour. At these concentrations, considerable browning occurs, which is generally considered to be desirable.*

Keywords Algarrobo, Allergens, Aroma, Browning, Celiac, Desertification, Fiber, Gluten-free, Legume, Semiarid

Global Perspective of *Prosopis*

Mesquite is the common name in the United States and Mexico for about half a dozen species of *Prosopis*, which is a genus of nitrogen-fixing trees especially adaptable to arid lands. Worldwide, there are 44 *Prosopis* species native to North America, the Caribbean, South America, Africa, the Middle East, and South Asia.(1) In some cultures and ecosystems, such as Texas, mesquite is disliked by ranchers because it aggressively invades grasslands, often establishing initial densities greater than 10,000 stems ha^{-1}, which competes with grass forage production for cattle.(2) In Haiti(3) and the Rajasthan desert of India,(4) *Prosopis* is highly revered, as it provides the bulk of energy (in terms of firewood and charcoal) to the local population. In Argentina in the province of the Chaco, more than 100,000 tons of *Prosopis alba* logs were harvested annually for fine furniture, flooring, and architectural components,(5) albeit with very little replanting. In Argentina, the timber harvest has been decried as being unsustainable with genetic erosion of the

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tallest straightest trees.[1] The evolution of *Prosopis* in arid, saline, hot ecosystems has resulted in some *Prosopis* being able to grow in 10 times greater salinities than annual legumes such as soybeans,[6] the ability to photosynthesize at leaf air temperatures of 45 °C in Death Valley, California, where it is native,[7] and the ability to fix atmospheric nitrogen at leaf air temperatures of 45 °C and leaf water potentials of 35 mPa,[8] which are environmental parameters far too severe for common annual legumes. Due to low annual N inputs into arid lands (ca. 2 kg N ha^{-1} $year^{-1}$) from rainfall and lichens, the ability of *Prosopis* to fix 30–40 kg N ha^{-1} $year^{-1}$ may well be responsible for its strong competitive ability against non-N-fixing grasses on low-N arid ecosystems.[2] Increased soil organic N stimulates an approximate 10-fold increase in soil organic C, resulting in enhanced water-holding capacity, nutrient-binding capacity, and increased C sequestration in the soil. Even with a low amount of soil C sequestration per ha (2 ton ha^{-1}), it has been estimated (due to the extensive nature of the worlds arid/semiarid lands that occupy 30 million km^{-2}) that mesquites and closely related N-fixing trees of the genus *Acacia* could sequester approximately 6×10^9 tons of C, which compares favorably to the 2000 total world carbon emissions of 6.9×10^9 tons of carbon. There is great genetic diversity in the genus *Prosopis*, allowing the possibility for genetic selection and in the future better varieties through hybridization. Some outstanding clones have been obtained from progeny trials.[9,10] However, the potential for food production from *Prosopis* in truly arid regions such as the Horn of Africa where *Prosopis* has become widely naturalized has not been touched.[11] As with any crop species, *Prosopis* clones or seedlots that are new to a region must be tested in multiyear, replicated trials by professional plant breeders or foresters in collaboration with evaluation by local people before being released for widespread use.

History as a Human Food

Prosopis species are widespread in semiarid regions of the Western Hemisphere and were a major food staple for indigenous peoples in North America[12–17] and South America[18–21] before the arrival of Europeans. The Asian *Prosopis cineraria* was similarly important as a human food for early peoples in the Indian peninsula.[22]

North American indigenous peoples distinguished trees that produced bitter pods from those that produced sweet nonastringent pods; in some tribes, individual families maintained ownership of these selected trees.[14] In South America, *Prosopis* was so important to indigenous peoples that it was referred to in the Quechua language as "taco," which was translated into Spanish as "El Arbol" meaning "The Tree." However, some of the pods were known to indigenous peoples to be bitter, which was referred to as Patalca in the Quechan language.[15]

Surprisingly, food preparation techniques for North and South American peoples were remarkably similar; the pods being ground in a mortar, the small hard seeds being discarded, and the sweet flour from the mesocarp being prepared for long-term storage.[12,20] Often the high-sugar-content mesocarp flour was slightly moistened and fashioned into balls or a shape akin to a modern day loaf of bread, allowed to dry and stored until the next year's crop. Alternatively, the pods were not immediately processed and were stored on the roofs of homes in large baskets of about 350–500 L.[14]

Ethnobotanists have surmised (R. Felger, pers. comm., 1990) that indigenous peoples could get their approximate 50 g daily protein requirements from small animals, birds, or reptiles, whereas the high-sugar *Prosopis* pod flour served to provide their daily 2000-calorie energy requirements.

Over the last 15 years, various preparations of *Prosopis* pods have begun to enter the U.S. food industry in a variety of applications. It is the intent of this communication to review the refereed literature and unpublished work at the U.S. Department of Agriculture (USDA) Western Regional Research Center to suggest uses for *Prosopis* flour that are nutritionally valid and functionally useful.

Composition

Fig. 1 illustrates the diversity of pod morphology of *Prosopis* species from North and South America. The species that have been routinely used as food by indigenous peoples include

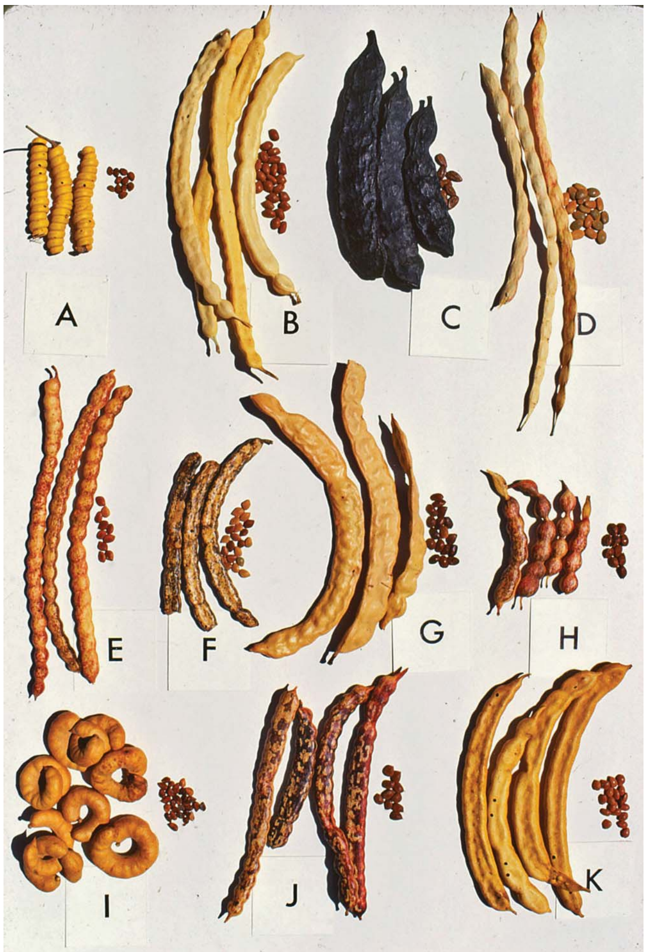

Figure 1. *Prosopis* pods of various species and origins. Screwbean from California, *P. pubescens* (A); mesquite from California, *P. glandulosa* var. *torreyana* (B); itin from Argentina, *P. kuntzei* (C); mesquite from Baja, California, *P. articulata* (D); algarrobo from Catamarca, Argentina, *P. flexuosa* (E); algarrobo negro from Argentina, *P. nigra* (F); algarrobo blanco from Santiago del Estero, Argentina, *P. alba* (G); mesquite from New Mexico, *P. glandulosa* var. *glandulosa* (H); tamarugo from the Atacama Desert, Chile, *P. tamarug*o (I); Mesquite from south Texas, *P. glandulosa* var. *glandulosa* (J); and mesquite from Senegal, *P. juliflora* (K) (color figure available online).

P. glandulosa var. *torreyana* (B) from California, *P. flexuosa* (E) from the interior deserts (Catamarca) of Argentina, *P. nigra* (F) from Argentina, *P. alba* (G) from Argentina, *P. glandulosa* var. *glandulosa* (H) from west Texas (El Paso region), and *P. glandulosa* var. *glandulosa* (J) from south Texas (Kingsville). *P. pubescens* (A) has been eaten by indigenous peoples but has little edible mesocarp and is bitter. The mature pods of the leafless *P. kuntzei* (C) from Argentina, whose wood has a specific gravity of 1.2, are so hard that metalworking tools are required to extract the seeds. The pods of *P. tamarugo* (I) from the salt flats of the Atacama desert have very little sugar and are only eaten by livestock. The pods of *P. juliflora* (K), originally from the Caribbean and extensively naturalized in the world's arid regions from Dakar, Senegal, to Delhi, India, have much higher concentrations of citric acid (ca. 2%), which makes them so strongly acidic that the flavor of the pods is undesirable. The pods of the tropical *P. pallida*, native to Peru with highly desirable low-acid sweet pods, are not shown. The pods of *P. pallida* are similar in color to those of *P. juliflora* but are straight rather than being slightly curved.

Fig. 2 illustrates the location of the sugary mesocarp, leathery fibrous endocarp, and hard seeds within a pod of *Prosopis alba* from Argentina. The small whole seeds are typically about 30% protein, but after the hard, nondigestible seed coat is removed, the true seed contains about 55–60% protein.[23] As the whole seeds are typically about 10% by weight of the entire pod, extraction of the pod for a high-protein seed fraction is not a good option. The variation in total pod protein (from 10% to 17%) and total pod sugar (from 10% to 40%)[24] is due to varying thicknesses of this sugary mesocarp.

Dr. Saunders' group at the USDA in Albany, California, pioneered the translation of indigenous methods of mesocarp preparation from pods into prototype dry milling procedures (25–27). This work led to the production of the following four fractions from *Prosopis* pods: (a) a mesocarp flour containing high sugar ca. 48%, 9.5% protein, 2.0% fat, and 16% crude fiber; (b) a high-fiber fraction from the endocarp surrounding the seed with 6% sugar, 6.5% protein, 1.3% fat, and 45% crude fiber; (c) a high-galactomannan-gum fraction (82%) from the inside of the seed coat that was low in protein (4%), fat (0%), and fiber (7%); and lastly, (d) a fraction that was high in protein (61%), low in fiber (4%), and with some fat (8%). Among various species, typical ranges of these fractions of the total pod weight are (a) high-sugar fraction (50–55%), (b) high-fiber fraction (15–20%), (c) galactomannan gum

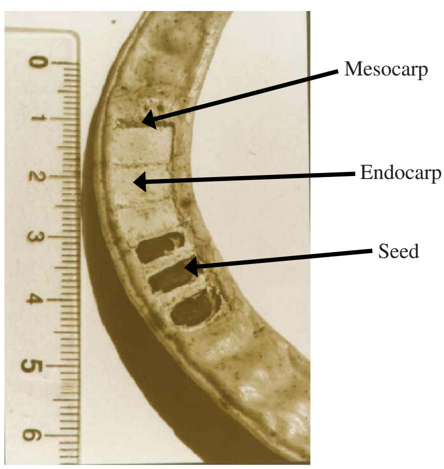

Figure 2. Partially dissected *Prosopis alba* pod illustrating pod mesocarp, endocarp, and seeds (color figure available online).

fraction (10–15%), and (d) germ fraction (10–15%). An economic analysis of production of mesocarp flour from *P. alba* from Argentina and *P. pallida* from Peru has been reported.[28]

Grados and Cruz[29] and Cruz[30] at the Universidad de Piura, Peru, which is in the center of the distribution of *P pallida*, have developed a strong program on human food utilization of the pods of *P. pallida* with products such as flour, algarrobina (a syrup from the pods), galactomannan gums from the seeds, and a caffeine-free coffee substitute made from high-temperature roasting of the flour. Prokopiuk[31] recently completed a doctoral thesis on characteristics of *Prosopis* flour as a coffee substitute.

The vast majority of commercial *Prosopis* flour sold in the United States is "Fraction a" derived from the mesocarp (Felker, unpubl. observ.). A comparison of the mesocarp fraction of various *Prosopis* species is provided in Table 1. The most notable characteristic is the high sugar content, ranging from 31% for North American mesquites *P. glandulosa* and *P. velutina* to 46–48% for *P. pallida* from Peru and to 59% for *P. alba* from Argentina. Virtually all of this sugar is sucrose.

The small amount of reducing sugar in the mesocarp flour is possibly the trisaccharide raffinose[32]; they did not find hexose sugars without autolysis (indicating invertase activity). They found considerably higher raffinose contents, 1.70% and 1.85%, in the seeds than in the pods of *P. glandulosa* and *P. velutina*, respectively. This is important because raffinose is one of the trisaccharides responsible for flatulence formation with common legume seeds such as soybeans.[33] However, using high-performance liquid chromatography (HPLC), it was not possible to detect (<0.01%) raffinose or stachyose in *P. alba* mesocarp flour (Felker, unpubl. observ.). It is possible that the lack of these sugars in *P. alba* flour is genetic or that *P. alba* and *P. pallida* do not have those sugars in their mesocarps. The other possibility is that since the Becker and Grosjean[32] work was done before efficient dry milling separation techniques were developed (their coffee mill scarified the seeds indicating some damage to seeds containing these sugars was done), their flour potentially had contamination of these sugars from the seeds. Bravo et al.[34] found low concentrations of glucose, fructose, and xylose in syrups made by prolonged heating of water extracts of *P. pallida* pods. However, the sugars could have resulted from sucrose hydrolysis caused by prolonged heating. Cardozo et al.[35] prepared water and alcohol extracts of whole pods and reported that sucrose concentration was 42% of total pod weight for *P. alba* and 27% for *P. nigra*. Values for glucose and fructose of 1.38% and 0.72%, respectively, were obtained from colorimetric methods rather than HPLC.

Brand et al.[36] conducted glycemic index measurements from *Prosopis velutina* pods that were shipped from Arizona to Australia. During the long transit time, undoubtedly there was a substantial buildup of seed eating bruchid insects, which have been shown to destroy 75% of the seeds after 4 months.[37] Upon arrival in Australia, the pods were heated to destroy bruchid insect larvae and then ground with a mortar and pestle with the seeds being discarded. The remaining flour was mixed with water to enhance its poor palatability. The authors reported a low starch digestibility (9%) and a low glycemic index.[25] Since *Prosopis* pods contain no starch,[32] this value is questionable. As commercial *Prosopis* flour contains about 45% free sucrose (above) and since "many clinicians and researchers, especially in the United States, have questioned the relevance and practicality of the glycemic index,"[38] until replicated trials prove otherwise, it is wise to counsel diabetics not to consume significant quantities of commercial mesquite flour due to the high concentration of free sucrose.

A second major attribute of *Prosopis* mesocarp flour (Table 1) is the presence of high fiber ranging from 23% in *P. velutina* to 32% in *P. alba* and *P. pallida*. As the majority of this fiber is insoluble fiber and as fraction (b) above resulting from the endocarp surrounding

Table 1
Major nutrients in mesocarp flours from *Prosopis alba, P. glandulosa, P velutina* and *P. pallida*

Content	*P. pallida*[a]	*P. pallida*[b]	*P. alba*[b]	*P.alba*[c]	Mean 16 California trees[d]	*P. velutina*[e]	*P. glandulosa*[f]	*P. velutina*[f]	Commercial *P. alba* flour[g]
Major components (mean g 100 g^{-1})									
Moisture		3.39	2.57	7.17			8.53	6.04	
Protein	8.11	8.11	7.17	7.03	8.6	9.5	6.81	6.88	11.2
Fat	0.77	0.77	2.17	0.71	1.92	2	2.79	2.24	
Cholesterol									
Ash		3.6	3.13	2.58	4.5	4.5	3.44	5.52	
Fiber (unspecified)						16	26.57	23.48	
Crude fiber		3.4	2.43	2.07	14.1				
Insoluble dietary fiber	30.6	30.6	20.09	24.68					
Soluble dietary Fiber	1.62	1.62	6.47	7.92					
Total dietary fiber	32.2	32.22	26.5	32.5	35.3				
Total carbohydrates		82.6	84.9	82.5					
Raffinose							1.17	0.54	
Stachyose							0	0	
Xylose				0.2			0	0	
Fructose				9.1			0	0	
Glucose				2.6			0	0	
Sucrose	46.35			38.2	42.4		27.02	32.08	
Reducing sugar	2.14	2.14	2.76		4.7		3.04	1.42	
Total sugars		48.5	59.1		47.1	48	31.6	31.6	
Pectin	0.8								
Energy value (kcal kg$^{-1)}$		362	378	356					

Condensed tannins		0.41	0.57	0.583				
Total soluble polyphenols	0.82	0.013	0.006	0.014				
Caffeine				0				
Minerals (mg 100 g^{-1})								
Calcium	75.9	76	127	200		420	630	250
Phosphorous				140				190
Potassium	2650			360		1030	1610	1540
Sodium	113			136		80	40	20
Magnesium	90.4			81		60	90	100
Minerals (mg kg^{-1})								
Iron	33	33	45	10		18	49	82
Zinc				21		10	10	18
Copper				1.3		3	6	6
Manganese				1		6	8	12

[a]Grados and Cruz (1996)[29]; [b]Felker et al. (2003)[28]; [c]Prokopiuk (2004)[31]; [d]Meyer (1984)[25]; [e]Becker and Grosjean (1984)[32]; [f]P Felker, unpubl. observ., 2011. Data not available for empty cells; [g]Commercial *P. alba* flour from Argentina measured by Precision Agri Lab, Madera, CA 2011, Felker, 2011 unpub obs.

the seed had 45% fiber, it would seem reasonable that the insoluble fiber in the mesocarp flour is at least partially derived from the high-fiber endocarp. Dietary fiber is important but lacking in many gluten-free products.(39) In Case's(39) review of fiber contents of gluten-free products, *Prosopis* flour, along with flax seed meal (27%), corn bran (79%), and rice bran (33%), was among the flours with the highest fiber content.

As can be seen in Table 1, there is a low level of pectin (0.8%), low levels of condensed tannins (0.41–0.58%), low levels of soluble polyphenols (0.006–0.82%), and no caffeine in *Prosopis* mesocarp flour. The latter is important, since *Prosopis* mesocarp flour has been promoted as a caffeine-free coffee substitute in Peru(29) and Argentina.(31) As regards minerals, *Prosopis* is low in Na (20–136 mg 100 g^{-1}) and high in K (360–1540 mg 100 g^{-1}) and Fe (10–82 mg kg^{-1}). Preliminary analyses of the sugars and organic acids of mesocarps of *Prosopis alba* and *P. pallida* found that flours with greater concentrations of citric acid were more "bitter" and that the almost unpalatable *P. juliflora* had 3–4 times higher acid/sugar ratio than the other two species (Takeoka and Felker, unpubl. observ.). Only one study(29) reported vitamin contents of *Prosopis* mesocarp flour, which were (in mg 100 g^{-1}) vitamin A 0, vitamin E 0.5, vitamin B1 0.19, vitamin B2 0.06, vitamin B6 0.235, nicotinic acid 3.1, vitamin C 6.0, folic acid 0.018, and calcium pantothenate 1.05.

Felker and Bandurski(23) measured the amino acid composition of the seeds and pods of several *Prosopis* species by gas chromatography/isotope dilution after extracting and precipitating the proteins with trichloroacetic acid and found that the extracted pod protein was of higher quality than the seed protein and that the only limiting amino acids were methionine and cysteine (with tryptophan being adequate in the pod but limiting in the seed). Meyer et al.(26) measured the amino acid concentrations by HPLC after perchloric acid oxidation (to obtain food values for the sulfur amino acids) and found all essential amino acids to be below the Food and Agriculture Organization (FAO) provisional scores, with methionine + cysteine the most limiting.

P. alba and *P. nigra* flour have a total free phenolics concentration of 0.18–0.41 g gallic acid equivalents (GAE) 100 g dry weight $(DW)^{-1}$.(35) This concentration range is similar to the total phenolics contained in wheat bran of 0.126–0.316 g GAE 100 g^{-1}(40) and 0.27–0.35 g GAE 100 g^{-1}(41) and higher than the total free phenolics reported in white wheat flour of 0.0044–0.014 g GAE 100 g^{-1}(40) and 0.028 g ferulic acid equivalents (FAE) 100 g^{-1}.(42) Antioxidant capacity of *P. nigra* and *P. alba* flour (aqueous extract) was found to be 6161 $\pm$ 32 and 5706 $\pm$ 50 μmoles Trolox 100 g DW^{-1}, respectively, using the ABTS [2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)] assay.(35) Total flavonoid content of *P. nigra* flour (0.07–0.13 g quercetin equivalents [QE] 100 g DW^{-1}) was higher than *P. alba* flour (0.01–0.03 QE 100 g DW^{-1}).(35) Cardozo et al.(35) reported phytic acid levels of 1.19% and 1.39% in *P. nigra* and *P. alba* flours, respectively. These results were similar to the levels of 1.20% to 1.22% found in wheat flour.(43) Using the VCEAC (vitamin C equivalent antioxidant assay) antioxidant technique,(44) C. Y. Lee (Cornell University, pers. comm., 2005) found *Prosopis alba* mesocarp flour to have a value of 650 $\pm$ 34 mg 100 g^{-1} of total antioxidants as gallic acid and 1239 $\pm$ 71 vitamin C equivalents.

To help understand the flavor/aroma profiles of mesquite flour, Takeoka et al.(45) determined the chemical identities and percentages of more than 100 volatiles in *Prosopis pallida* from Peru, *Prosopis alba* from Argentina, and a mixed blend of unknown origin probably from northern Mexico/southwestern United States. Among the most important compounds imparting flavor to mesquite flour was 2,5-dimethyl-3-ethylpyrazine (4.83% of the total volatiles), which has cocoa, chocolate, burnt almond, and filbert-hazelnut aroma notes and a low odor threshold of 0.4 ppb. γ-Octalactone (0.39%) and γ-nonalactone (1.62%), with odor thresholds of 7 and 30 ppb, respectively, are possible contributors to coconut aroma of mesquite flour. γ-Octalactone has a sweet, creamy, dairy, coconut aroma, whereas γ-nonalactone has strong, sweet, soft coconut aroma and is used in the formulation of synthetic coconut flavors.[46] Another likely contributor is 2-methoxyphenol or guaiacol. This compound, which constituted 0.88% of the volatiles, has a relatively low odor threshold of 3 ppb and a sweet, smoky odor. 4-Vinylguaiacol has a spicy, clove-like odor and an odor threshold of 3 ppb. This compound ranged from 0.03% to 1.3% in the mesquite flour samples and is another possible contributor to the odor.

The Takeoka et al.[45] sample from Mexico/southwestern United States, which contained whole ground seeds, had an abundance of aldehydes, with hexanal being the major volatile. Hexanal is often used as an indicator of rancidity. Although the lipid contents of the seed and pod were similar, evidently the seed fat is more predisposed to oxidation to produce hexanal than is the fat in the mesocarp.

In a previous study,[45] it was not possible to identify an unknown that was the major volatile in *P. alba* (17.61%) and *P. pallida* (19.19%) but only constituted 2.21% of the *P. velutina* volatiles. Recently, 5,6-dihydro-6-propyl-2*H*-pyran-2-one was identified as the major volatile in mesquite flour.[47] Using δ-nonalactone as an internal standard, its concentration was determined to be 59.75 ± 7.07 mg/kg ($n = 3$). This compound, which has only rarely been reported in natural products, possesses a coconut-like odor mixed with a peppermint aroma.

Canadian producers have recently developed an initiative to promote protein isolates and flours from pulses (pea, lentil, bean, chickpea, mustard, sunflower, canary seed, and buckwheat) for use in protein fortification, especially in gluten-free products (http://www.pulsecanada.com/). Due to a less-than-desirable flavor profile in some of these pulse products,[48] *Prosopis* flour is under commercial development for use in improving the flavor profiles of some of these pulse flours (L. Norcini, International Food Products, pers. comm., 2012).

Becker and Grosjean[32] were the first to characterize sugars, minerals, cyanogenic glycosides, and phytic acid in the pods of two North American *Prosopis* species, *P. glandulosa* and *P. velutina*. These authors found no cyanogenic glycosides in the seeds or pericarp of either species. Pak et al.[49] were the first to report trypsin inhibitors and phytohemagglutinins in the seeds of a *Prosopis* from Chile (*P. tamarugo*). Harden and Zolfaghari[50] reported trypsin inhibitors in the seeds of Texas mesquite, although at quite low levels. Oliveira et al.[51] isolated and characterized the trypsin inhibitor from *Prosopis juliflora* in Brazil with the objective of using this protein as a bioinsecticide defense against insects and pathogens for the protection of bean seeds. Aflatoxin contamination of pods of *Prosopis* in native Sonoran desert habitats has been reported.[52] Tests of Argentinean mesocarp flours from 2008 to 2011 using the AOAC (Association of Analytical Communities) 994.08 method measured concentrations of less than 1 ppb for aflatoxin B1, B2, G1, and G2 (Felker, unpubl. observ.). However, whole ground *Prosopis* pods in Kenya had a total aflatoxin concentration of 5.8 $\mu g\ kg^{-1}$ and an ochratoxin A concentration of 38 $\mu g\ kg^{-1}$.[53]

Alkaloids have been reported in *Prosopis* leaves[54–57] or "aerial parts."[58] However, there are no reports of alkaloids in the pods of the species from which commercial "mesquite flour" is made (i.e., *P. alba*, *P. chilensis*, *P. pallida*, and *P. velutina*).

There is a report of toxic effects of feeding *Prosopis* to livestock, leading to degeneration of nerves responsible for mastication when cattle were fed 50% or more of the diet of dried ground *Prosopis juliflora* pods (with the balance of the diet coming from *Cynodon* [Tifton] hay) for more than 45 days.[59] No component of the diet was suggested to be responsible for this symptom. Possibly the pods were contaminated with aflatoxins or possibly some of the seed phytohemagglutinins or trypsin inhibitors might pass through the digestive system to cause this nerve atrophy. It is to be noted that the whole pods were ground for the animal feeding study, whereas the flour for human food is made only from the mesocarp fraction of washed and sorted pods.

In contrast to the negative effects of *Prosopis* pods in the Tabosa et al.(59) study, various theses that employed randomized, replicated feeding trials with balanced diets for Sudanese goats,(60) Brazilian Nelore beef cattle,(61) and Holstein-Zebu milk cows(62) reported no such effects of drooping tongues and difficulty masticating. In a milk production study using 12 Holstein-Zebu milk cows in a switch back design (in which each of four rations described in Table 2 was examined 12 times), Nobre(62) found that the ration with the greatest ground *Prosopis* (60%) had significantly greater total milk production, greater milk production corrected to 4% fat, greater fat content, and greater total solids content than the ration with the corresponding ground wheat content (Table 3). However, it should be pointed out that this ration also contained 30% cottonseed meal, 2% meat and bone meal, and 0.5% bone meal, leading to a well-balanced diet for protein and minerals.

The seeds of many legumes have proteins that are allergenic to humans,(63) with soybeans(64) and peanuts(65) being particularly problematic. However, analyses of the *P. alba* mesocarp flour by the Silliker Laboratory of Modesto, California, for cross-reactivity against these allergens using the Neogen Veratox kit (Neogen Corporation,

Table 2
Ration composition (translated from Portugese(62)) for study of effect of ground *Prosopis* pods on milk quality and production in cattle

	Ration A	Ration B	Ration C	Ration D
Ground wheat (%)	60	40	20	0
Ground *Prosopis* (%)	0	20	40	60
Cottonseed meal (%)	10	16	23	30
Maize grain (%)	15	13	10	5
Peanuts grain (%)	7	5	3	1
Molasses (%)	5	2	1	1
Meat and bone meal (%)	2	3	2	2
NaCl (%)	0.5	0.5	0.5	0.5
Bone meal (%)	0.5	0.5	0.5	0.5

Table 3
Effect of various rations on milk composition and quality of various rations fed dairy cattle in study of Nobre(62)

	Milk production per day—not corrected for fat (kg)	Milk production per day corrected to 4% fat (kg)	Milk fat content (kg)	Total milk solids per day (kg)
Ration A	10.79^{bB}	10.57^{B}	0.41^{bB}	1.24^{B}
Ration B	11.42^{aAB}	11.44^{A}	0.46^{aAB}	1.38^{A}
Ration C	11.54^{aA}	11.58^{A}	0.47^{aA}	1.39^{A}
Ration D	11.65^{aA}	11.79^{A}	0.48^{aA}	1.44^{A}

Note. Values with same letter were not significantly different at 5% level.

Lansing, MI) found concentrations <2.5 ppm for the peanut allergen and of 4.2 ppm for the soy allergen (Felker, unpubl. observ.). A *Prosopis*-specific allergen could still exist. However, since the soy and peanut allergens are found in the seeds and not in the pod mesocarp wall, it seems less likely that a *Prosopis* allergen will be found in mesocarp flours. Analyses for gliadin in *Prosopis pallida* and *Prosopis alba* by the Silliker Laboratory (Modesto, CA) found concentrations <5 ppm using the Neogen text kit (Felker, unpubl. observ.).

There has been considerable effort to promote eating raw foods, which, especially for fruits and leafy vegetables, is a laudable goal. However, there are significant health hazards from consuming raw legume seeds due to trypsin inhibitors and phytohemagglutinins, which are denatured upon heating.[63] Therefore, mesquite flour preparations that are made by grinding the whole pod without heat treatment will have intact anti-nutritional factors. If this flour is incorporated into products that will be baked or cooked, there will be no effect of the anti-nutritional factors. However, if the flour is eaten raw, these anti-nutritional factors could result in nausea and diarrhea.

Cultivation and Production

Issues of sustainability and the ability to reliably amass sufficient quantities of pods from wild trees have limited the development of an industry for *Prosopis* mesocarp flour. Due to the economics of pod harvest (by hand from the wild), it is unlikely that *Prosopis* flour will be commercially produced in the United States. The two major suppliers of *Prosopis* flour, northern Peru for *Prosopis pallida* and the Diocese of Anatuya, Province of Santiago del Estero, Argentina, for *Prosopis alba*, have formed a partnership with a U.S.-based company to certify organic native forests in each country, and to process and distribute the flour in the United States. In Peru, a several-thousand-hectare native forest is being used to produce the pods (Felker, unpubl. observ.). With *Prosopis alba* occurring over most of the surface area of 68,000 km^2 of one of the poorest dioceses in Argentina (http://www.catholic-hierarchy.org/diocese/danat.html) and a network of churches and priests working to improve the economic well-being of their people through economic activities related to *Prosopis* flour production, the resource potential exists for hundreds of tons of *Prosopis* flour per year (Felker, unpubl. observ.). This general area has seen conversion of hundreds of thousands of hectares of native forests of poorly managed luxury quality tropical hardwoods to transgenic soybeans (Felker, unpubl. observ.). Developing markets for products of standing trees will provide an incentive for local people to maintain their native trees. Both *Prosopis* stands in Peru and Argentina have been certified under the USDA organic certification program.

Genetic improvement trials were conducted with *Prosopis alba*[66] in Argentina and with *P. pallida* in Peru.[9] After the easily quantifiable sylvicultural traits (diameter at breast height, form, pod production) were measured and selected for, the last selection criteria involved masticating and ranking the flavor of the pods in the field (by a team) into categories of very bitter, bitter, sweet, or very sweet. In both Argentina and Peru, less than 50% of the trees fell into the class of sweet or very sweet with no bitter taste. The objectionable flavor was not precisely bitter, but somewhat sour and not very palatable. Unfortunately, the thorny, nonerect *Prosopis juliflora*, which has been introduced into the harsh arid tropical zone from Dakar, Senegal, to the deserts of Somalia, Kenya, and Ethiopia and across the Saudi Arabian peninsula to New Delhi, India (and often spread as a weed), has pods that are very bitter/sour. Although a crudely ground mixture of the whole pods was deemed acceptable at the 20% concentration in various products by Kenyan villagers,[53] mesquite flour prepared from the mesocarp of *P. alba* or *P. pallida* after washing and sorting the pods would be much safer and much more palatable. Felker[11] has suggested that erect thornless forms of *P. pallida* with sweet palatable pods be used to replace this thorny, nonerect *Prosopis*. This could provide extensive quantities of human food in this area prone to famine.

In contrast to traditional gluten-free grains such as rice and sorghum and gluten-containing grains such as wheat and barley that are planted and harvested with highly mechanized equipment, *Prosopis* pods are collected by hand from wild trees. This, in combination with the need to hand sort, wash, and heat the pods at 52 °C for several hours (to lower the moisture to the point the pods can be ground), followed by several milling and sieving steps (that eliminates the endocarp with potential bruchid contamination), and the approximate 40% yield of mesocarp flour from the pods, makes mesocarp flour much more costly than traditional cereals. This higher cost dictates that the flour be used for flavor, aroma, and color enhancement in specialty products rather than as a replacement for protein, energy, or fiber.

Food Applications

The pioneering work of Daniel Meyer, who did his Ph.D. degree research using pilot-scale food technology equipment in Saunders' USDA laboratory, appeared in published literature[26] and in his thesis.[25] A summary of Meyer's most important findings that appeared in his thesis but not in the refereed literature follows. Due to the lack of gluten in *Prosopis* mesocarp flour, mixing was compromised but addition of 1% guar gum (but not locust or methyl cellulose gum) greatly improved the farinogram. Meyer successfully extruded drum-dried flakes made with both wheat and corn flour. Surprisingly, he found that after 6 months of storage, hexanal production of flakes with 25% mesquite was 5 times less than the product without mesquite, suggesting the presence of an antioxidant(s) in the mesquite flour.

Meyer et al.[26] examined *Prosopis* mesocarp flour in a variety of products with taste panel tests and found the optimum addition level to be 5% in crackers, 10% in bread, 20% in tortillas, and 50% in chapatti and drum-dried wheat flour. Another group[67] examined nutritional and organoleptic properties of mesquite mesocarp flour combinations with soy milk, yogurt, peanut butter candy, and rolled oats. The two products with the greatest consumer acceptance were mesquite flour in a chocolate beverage base and in peanut butter/mesquite candy. Grados et al.[29] found the optimum concentration to be 5% in bread and up to 25% in biscuits. Our unpublished observations indicate that the optimum concentration is about 15% in dulce de leche granola bars and in gluten-free pancake mixes. The somewhat softer flavor of mesquite than cinnamon is especially well suited to mixtures with cow milk, soy milk, "hot chocolate"-type beverages, and ice creams (Felker, unpubl. observ.). Due the neutral pH of both mesquite flour and dairy products, the high sucrose content of mesquite flour and the lack of antimicrobial treatments of the flour, it would be essential to pasteurize mixtures of mesquite flour and dairy products (Casa de Mesquite has recently experienced a recall due to people mixing mesquite with eggs, milk and then getting diarrhea).

Researchers at the Food Research and Postharvest Centre, Aden, Republic of Yemen (Al-Mussali, pers. comm., 2005) recently found that *Prosopis* flour significantly increases browning of flat and French style loaf breads in the range of concentrations that also optimizes flavor (i.e., 5–20%). As methods to achieve a consumer-desirable brown color with less heating time and temperature would be advantageous, the influence of *Prosopis* flour on browning of a typical "white bread" should be reexamined.

To illustrate the effect of *Prosopis* flour on the color and volume of baked products, *Prosopis alba* mesocarp flour from Argentina was incorporated at concentrations of 0%, 5%, 10%, and 15% of total dry ingredients into commercial gluten-free mix and high-protein wheat flour bread with yeast. The gluten-free mixture was Whole Foods 365 gluten-free all-purpose baking mix (ingredients were white rice flour, potato starch, tapioca starch, guar gum, and salt). The recipe on the box was used that included baking powder and baking soda to increase the volume of the product. The traditional mix used Stone-Buhr white wheat bread flour. After incorporation of yeast, kneading the bread, and allowing it to rise two times, it was baked at 190 °C for 24 min.

The lowest concentration of mesquite flour tested (i.e., 5%) had a noticeable browning effect on the interior and exterior of both the gluten-free and with-gluten mixtures, as illustrated in Figs. 3 and 4 and Table 4. At 15% concentration, both products were probably close to the limit of brown color desirability. The internal color coordinates for the 0% mesquite flour were about 60 for hue (typical of a yellow color), a low saturation of 0.45, and a moderately high lightness of 21 to 17. With increased mesquite flour concentrations, the hue angles dropped to the 40s, closer to an orange color, but with the increase in saturation from 0.45 to 6.47–8.37, the color appeared browner. Although the external brightness values dropped, providing a darker color, the internal brightness values did not change appreciably. Meyer[25] reported a loaf volume of 680 mL for leavened bread without mesquite flour and 675 mL for leavened bread with 10% mesquite mesocarp flour. Although the volumes were not measured, it appeared that the leavened bread with 15% mesquite was not substantially different from the control. Perhaps the high sucrose content of the flour stimulated carbon dioxide production by the yeast. In contrast, it appeared that the volume of gluten-free biscuits with 15% mesquite flour was less than the volume of the control.

Figure 3. Interior and exterior of 120 g of high-gluten wheat flour mixture (sugar, salt, and yeast) with 0%, 5%, 10%, and 15% of *Prosopis alba* flour (left to right) baked at 190 °C for 23 min (color figure available online).

Figure 4. Interior and exterior of Whole Foods 365 gluten-free biscuit mixture with 0%, 5%, 10%, and 15% (left to right) of *Prosopis alba* flour (color figure available online).

Table 4
Color coordinates of gluten-free and whole-wheat bread with varying concentrations of *Prosopis alba* mesocarp flour

	Gluten-free biscuit *Prosopis* flour concentration								Whole-wheat bread *Prosopis* flour concentration							
	0%		5%		10%		15%		0%		5%		10%		15%	
Color coordinates[a]	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int	Ext	Int
L	62.61	60.10	53.7	42.31	45.02	42.73	48.38	41.05	76.24	71.41	66.02	54.02	60.46	46.37	54.83	45.34
a	12.35	0.45	12.52	6.83	15.35	7.50	13.16	8.37	1.92	−0.46	3.99	3.18	5.32	5.26	6.92	6.47
b	33.83	21.44	29.38	17.19	26.60	17.86	25.88	18.69	20.99	16.97	17.25	15.15	17.47	16.12	18.05	16.67

[a]The color coordinates were taken with a Minolta spectrophotometer model CM508d. The values are the means of eight readings.

Studies of food applications of the galactomannan gum in *Prosopis* seeds have been carried out by Figueiredo,[68] Meyer,[25] and Meyer et al.,[26] and Cruz[30] found that the gum in *Prosopis* pods was technically similar to guar gum. However, extraction and utilization of gum from *Prosopis* pods is not economically feasible due to the low price of guar gum and the presence of only about 7% by weight of gum in the whole pod.

Summary

Prosopis mesocarp flour is a versatile ingredient for baked products to provide browning, color, aroma, flavor, and fiber. Due to the absence of these characteristics in traditional gluten-free flours, i.e., sorghum, manioc, rice, potato, etc., and the less-than-desirable flavor profiles of pulse high-protein flours, *Prosopis* flour seems especially promising to enhance flavor/aroma combinations in traditional celiac diets. *Prosopis* flour also appears to be able to reduce lipid oxidation in mixtures of *Prosopis* with other flours. With the advent of organic certification of large forests of *Prosopis* in Latin America, sustainability and supply issues should permit development of a *Prosopis* mesocarp flour industry.

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