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GUAR
In the United States

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Of some 250,000 species of angiosperms which have been identified, about 150 species account for the major proportion of the world's cultivated crops (80, 159).[2] Except for Jerusalem artichoke, pumpkin, squash, and sunflower, the agriculture of the United States is based upon introduced plants that came from the wild or were cultivated in other countries. The procurement of this raw material for potential new crops has been the official policy of the United States government since the administration of President John Quincy Adams (71).

One means of utilizing cropland diverted through allotment programs is to plant it to new crops. If these crops can be grown profitably and can be utilized by industry, they may become successful additions to the nation's agriculture. Research conducted on guar, a crop introduced from the Far East, suggests its possibility for success in the United States. This bulletin represents the authors' attempt to collate the agronomic literature on this new crop.

Pre-World War II History

Guar, *Cyamopsis tetragonoloba* (L.) Taub., is a drought tolerant, summer annual legume that is grown primarily in India and Pakistan. In these countries it is used principally as forage for cattle, as a green manure, and as a vegetable for human consumption. Other minor uses, as noted by Chopra *et al.* (28) and Watt (157), have been as a laxative in biliousness, in treatment for night blindness, and as a shade plant for young shoots of ginger.

Early Guar Introductions

The first published paper on guar in the United States was written by C. V. Piper (119) who wrote that guar was introduced into the country by the Department of Agriculture in 1903. According to the depart-

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[2]Figures in parentheses refer to Literature Cited.

ment's records (74) P. I.[3] 9666, the only unnamed seed for that year was received from the Surat Government Farm, India on May 11, 1903. Hellbusch (69) and Poats (121) have ignored this unnamed plant introduction and have suggested that 1906 or 1913 was the date of the first introduction. However, in a letter dated November 13, 1906 (92), McKee stated to Dr. Piper that seed of P. I. 9666 grown at the Plant Introduction Garden in Chico, California, was used in 1906 in an irrigation and date of planting study. This statement by McKee should eliminate doubt as to the date of first introduction of guar.

The first introductions were sent to the federal and state experiment stations located in the Southwest where it was believed to be adapted to the soils, hot climate, and long growing season of the area. Emphasis was placed on its use as a drought tolerant, soil improving legume, and as an emergency forage for cattle. The list of guar introductions prior to 1940, the year introduced, and place of origin are shown in Table 1 (74).

In 1906, P. I. 9666 was sown on April 9, May 15, and June 20 at the Chico Plant Introduction Garden. The first two plantings received irrigation, while that of June 20 was grown without irrigation. McKee (92) reported that the April 9 and May 15 plantings made practically the same growth as that of June 20 and that the seed of the early plantings were as late in ripening as that of the later planting. This was the first indication that guar has an indeterminate type of growth habit. Furthermore, P. I. numbers 18641 to 18651 were grown at Chico in 1906 and evaluated by McKee. He believed P.I. 18645 (Talabda) and 18646 (Sotia) to be the most promising varieties for forage. The locations and dates where guar introductions were grown in the New World are shown in Table 2.

The following excerpts from correspondence from McKee to Piper (93) in 1908 indicate McKee's findings and opinion of the new crop:

> Eight varieties of guar were sown April 28, 1908, in rows four feet apart. Practically none of the seed germinated .... failure in germination was due to the very dry condition of the soil at the time of planting .... after three seasons tests with guar we are of the opinion that it is of little or no value .... the peculiar taste of the leaves and stems which probably would make them objectionable to stock when fed as fodder.

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[3]P. I. stands for Plant Introduction Number.

Table I. Plant Introductions of Guar Prior to 1940.

Introduction Number	Year	Place of Origin
9666	1903	Surat, India
18641	1906	Surat, India
18642	1906	Surat, India
18643	1906	Surat, India
18644	1906	Surat, India
18645	1906	Surat, India
18646	1906	Surat, India
18647	1906	Surat, India
18648	1906	Surat, India
18649	1906	Surat, India
18650	1906	Surat, India
18651	1906	Surat, India
21003	1907	Bombay, India
21004	1907	Bombay, India
25708	1909	Poona, India
36549	1913	Nagpur, India
37725	1914	Bombay, India
43503	1916	Mandalay, Burma
49864	1920	Mandalay, Burma
49899	1920	Poona, India
49900	1920	Poona, India
49901	1920	Poona, India
49902	1920	Poona, India
49903	1920	Nagpur, India
49904	1920	Nagpur, India
51371	1920	Poona, India
51372	1920	Poona, India
51373	1920	Poona, India
51598	1920	Surat, India
51599	1920	Surat, India
51600	1920	Surat, India
51601	1920	Surat, India
51696	1920	Madras, India
52785	1921	Nagpur, India
52786	1921	Nagpur, India
57833	1923	Poona, India
66654	1926	Batticotte, Ceylon
67265	1926	Jerusalem, Palestine
114932	1936	Teldeniya, Ceylon
114933	1936	Bangalore, India
115462	1936	Poona, India
115463	1936	Poona, India
115464	1936	Poona, India
116034[1]	1936	Jaipur, India
116105	1936	Bikaner, India
124458	1937	Ujjain, India
124562	1937	Hyderabad, India

[1]The only plant introduction in this list whose germ plasm has been preserved.

Table 2. Locations and Dates Where Guar Introductions Were Grown in the United States Prior to World War II.

Location	Year
Chico, California	1905
San Antonio, Texas	1906
Stillwater, Oklahoma	1908
Tucson, Arizona	1909
Chillicothe, Texas	1911
Honolulu, Hawaii	1911
Lubbock, Texas	1912
Pecos, Texas	1912
St. Croix, Virgin Islands	1912
Beeville, Texas	1913
Denton, Texas	1913
Temple, Texas	1913
College Station, Texas	1913
Whittier, California	1913
Angleton, Texas	1914
Nacogdoches, Texas	1914
Spur, Texas	1914
Davis, California	1920
El Centro, California	1921
Iowa Park, Texas	1926
Auburn, Alabama	1929
College Station, Texas	1936
Yuma, Arizona	1939

Exploratory Investigations

There is evidence of conflicting opinion, however, as to the palatability of guar to livestock. The Eighteenth Annual Report of the Oklahoma Experiment Station (106) contained the following statement concerning forages grown by them, "These embrace such well-known crops as the cowpea, soybean . . . Jerusalem artichoke and guar—a foreign leguminous plant." Piper (119) maintains that cattle at the Oklahoma Experiment Station readily ate the straw after the seed had been threshed out. Headley and Hastings (68) planted guar on the San Antonio Experiment Farm in 1906. They reported that guar is very drought tolerant and recommended the plant as a green manure crop or a forage for sheep and goats. The authors further suggested that poor results might be due to a lack of appreciation of the soil fertility and cultural practices necessary to secure the best results.

In 1908, guar was included in an experiment to test forage crops grown under the annual flood conditions of the Colorado River. Thornber (155) reported that guar seed with an initial germination of 98 percent dropped to two percent germination when submerged under water for 38 days. However, forage crops such as sesbania, amber cane, and Johnsongrass germinated 75, 45, and 45 percent, respectively, under similar experimental conditions.

In 1911, Bessey (9) noted in a Bureau of Plant Industry Bulletin that guar seemed to be resistant to root knot nematode. However, no further work on guar was reported by this investigator.

Kelly, Wilcox, and McClelland (86) planted a number of crops at the Hawaii Agricultural Experiment Station in 1911 for the purpose of determining their economic feasibility. Guar was planted in rows five feet apart and two to six inches apart in the row. They reported that the guar plots yielded 1,190 to 2,610 pounds of seed per acre and 2,500 to 5,500 pounds of air dry forage per acre.

Further exploratory investigations were conducted at Angleton, Beeville, Chillicothe, College Station, Denton, Lubbock, Nacogdoches, Pecos, Spur, and Temple, Texas (10, 15, 40, 60, 76, 84, 124, 177, 179). Brooks and Harvey (15) reported that guar was intermittently grown at Balmorhea, Beaumont, Iowa Park, Tyler, Weslaco, and Winter Haven, Texas. In all of the Texas stations, guar was evaluated for its use as a green manure and for forage. In general, the reports were optimistic for its use as a green manure. Opinion as to its value as a forage for livestock ranged from negative to favorable.

Besides Chico, California, guar was grown at Whittier in the garden of R. S. Woglum who collected the seed while on a trip to Nagpur, India (178). The seeds were presented to the Department of Agriculture and assigned the P. I. number 36549. Hellbusch (69) stated that guar was grown on the University of California Experiment Station in the early 1920's and that a few single plant selections were made. Goar (50) wrote that guar was introduced at the Imperial Valley Field Station near El Centro in 1921 and has been grown there since. The results at Davis and El Centro indicated that guar was an excellent green manure crop (72, 73). The 1927-1928 report of the California Experiment Station (100) contained the following statement:

> Experiments with summer legumes covering a period of years have shown that guar, mat bean, and Kearny mung are all well-adapted to Imperial Valley conditions. Guar appears to be the best cover crop for the heavy soils of the valley because it grew 3-6 feet tall and produced from 18-25 tons of green matter per acre. Because of its coarse stemmy character and sparseness of leaves, it is of little value for forage.

Thomas (152) reported than an alkali soil reclamation project was carried out near El Centro, California where alkali had accumulated in consequence of poor drainage. Sesbania and guar were used as sources of green manure. The author stated that guar grew well on areas that supported a good growth of sesbania. Moreover, on areas where sesbania had failed to grow, guar likewise failed.

Smith (136) reported that A. B. Connor of the Texas Agricultural Station sent seed of guar to the St. Croix, Virgin Island Experiment Station and that the crop was grown there in 1912. Since very poor results were obtained, guar was omitted from subsequent plantings.

Taubenhaus and Ezekiel (149) reported that guar was resistant to, or a rather passive carrier of, *Phymatotrichum* root rot. The fungus infected the roots of the plants, but the host developed new roots and produced a seed crop despite the disease. Additional studies with *Phymatotrichum* in Texas were reported by Brooks and Harvey (15).

Piper (120) reported that guar did not "ripen its seed in northern Virginia." Sturkie (143) found that guar could not withstand the climatic conditions and did not appear to be a valuable forage or soil improving crop for the state of Alabama.

A summer legume study to evaluate possible sources for green manure was conducted at the Arizona Agricultural Station in 1933 (17). The report stated that "Guar showed more promise than any of the other kinds of plants and produced a good seed yield. Some difficulty may be experienced in the harvesting of guar seed by machinery but should not be serious."

Guar was grown for green manure at the Yuma station for the first time in 1939 (66). The crop produced a higher average yield than cowpeas and soybeans in the test. Further experiments after 1940 at the Yuma station will be discussed in the second section.

It appears there was little or no attempt to preserve the seed of the early plant introductions. The crop was evaluated for its use as green manure and as forage for cattle and then it remained in virtual oblivion. Discussing the problem of plant introductions, Harlan (59) noted, "The fact that many introductions *look* worthless has led many people to believe that they *are* worthless."

Today, P. I. 116034 is the only germ plasm available from pre-World War II introductions. The introductions from the high rainfall area of Burma and the one obtained by David Fairchild and P. H. Dorsett from Ceylon are lost. With the current unstable political situation and the encroachment of urbanization on agricultural lands in Asia and Africa, it is imperative that all possible genetic variants be collected and maintained.

World War II and the Immediate Post-War Era

Investigations on guar in the early 1940's were mainly concerned with its use as a green manure or cover crop in Arizona and Texas. These experiments were generally similar in kind to those conducted since the crop's initial introduction in 1903.

Guar as a Green Manure Crop

A five-year study at the Mesa Farm in Arizona (19, 20, 22, 67) found guar to be the outstanding green manure crop when compared to sesbania, tepary beans, *Crotalaria juncea,* cowpeas or fallow cropping. The green manures were evaluated by yields of the succeeding barley crop. Moreover, additional studies indicated that guar, when compared to other green manure legumes, would produce the highest yields of air-dry material regardless of time of planting or date of harvest (18). Seed yields of guar showed little variation as affected by the date of planting or the condition of the plants at the time of irrigation (21).

Spacing studies conducted with Mesa variety of guar in 1943 and 1944 (98) indicated that 7-inch and 12-inch row spacings had much better yields than those ranging from 24 to 36 inches. Additional studies on fertilization of soil, planting procedures, harvesting practices and equipment were reported by the investigators in the same bulletin. Briggs (13) briefly reported that guar had been used as a green manure by a few vegetable growers in the Yuma Valley in Arizona.

Pathological studies conducted on guar plots at Mesa, Sacaton, and Tucson, Arizona (22) validated the investigations in Texas by Taubenhaus and Ezekiel (149) on *Phymatotrichum* root rot. The strains of guar in Arizona appeared to be resistant or at least passive carriers of the root-rot fungus. Rogers (127) also confirmed the investigations of the earlier Texas researchers. Matlock, Aepli, and Streets (98) reported additional studies with diseases of guar. In 1947 the Arizona Experiment Station staff conducted agronomic tests with guar at Mesa, Safford, Tucson, and Yuma (23). These were part of a continuing series of investigations (24) of which earlier results have already been reported.

Brooks and Harvey (15) reported that a study was made at Iowa Park, Texas from 1943 through 1947 to determine the adaptation of guar to standard farm machinery. They concluded that a standard grain combine with a slight adaptation should be able to satisfactorily harvest the seed.

Matlock (99) pointed out that in Oklahoma, one preliminary trial of guar was conducted in 1941, but no data were collected. Concerning new crops in Oklahoma, the 1942-1944 Biennial Report of the Oklahoma Agricultural Experiment Station stated, "Work on minor crops is centered on a search for those having value in Oklahoma as cash crops providing oils and other industrial materials, as sources of home grown feed or as green manure." Among the crops under investigation were safflower, sesbania, sunflower, crotalaria, castorbeans and guar (11). However, Ligon (89) reported that the guar tests conducted in 1944 failed. A virus destroyed the crop and the fear of spreading the disease to other legumes caused it to be eliminated from further tests.

Considering the above investigations, the acreage planted to guar logically should have been limited to the barley and flax fields of Arizona and Texas (57) where the crop served as an excellent green manure. However, other factors appeared which transformed guar from its use as a green manure or cover crop to a cash crop, modified its area of adaptation and altered the type and kind of investigations conducted with the species.

Guar as a Carob Seed Substitute

During World War II, the imported stock of carob seed (*Ceratonia siliqua* L.) from the Mediterranean area was depleted. The endosperm of the seed from this perennial legume was the source of carob gum, a galactomannan mucilage which was used mainly as a sizing agent for paper and textiles (128, 161, 162). Carob gum is also known as gum gatto, gum hevo, jandegum, lakoe gum, locust bean gum, lupogum, lopusol, rubigum, tragon, and tragosol. As a food for human consumption it is historically known as St. John's bread or swine's bread (130).

The search for domestic sources of galactomannan gums was initiated by the Institute of Paper Chemistry, Appleton, Wisconsin (94). Analyses of seed from trees and shrubs revealed that potential sources of galactomannan gum were the legumes adapted to the semi-desert environment of the Southwest United States (128). Further inquiries by the Institute found the University of Arizona and the Soil Conservation Service of the United States Department of Agriculture experimenting with various legumes as potential sources of green manures and cover crops.

Upon the recommendation of S. B. Detwiler of the Soil Conservation Service (12), guar seed were analyzed by the Paper Institute for gum content. The future of guar was indicated when the Paper Institute and Anderson (3) reported that the endosperm of guar contained a usable form of galactomannan gum. The Institute of Paper Chemistry, the University of Arizona, and the Soil Conservation Service then combined resources to develop and promote the use of guar seed as a domestic source of this vegetable gum.

Briggs (12) reported that the experimental results with guar at the Paper Institute were so encouraging that, in the summer of 1942, supplies of seed were increased. The green manure experimental plots at Mesa and Tucson were allowed to mature, and together with a supply grown by the H. P. Garin Company at Yuma, they furnished enough seed for planting approximately 700 acres of guar in 1943. Further investigations in Arizona found guar highly adaptable to mechanical planting and harvesting, and it produced, under irrigation, 100-1500 pounds of seed per acre (162).

Rowland (128) pointed out that, in order to provide financial support for the experimental program, 25 paper companies underwrote the adventure. Moreover, in order to induce farmers to grow the experimental crop, they were guaranteed a generous price of eight cents a pound for the seed produced. The General Mills Company supervised the entire program, from the planting operation to the milling of the seed for its mucilage (43).

In 1943, approximately 550 acres of guar were planted at Mesa, 50 acres at Yuma, Arizona, and about 100 acres in the Imperial Valley in California (69). The harvested crop, nearly 100 tons of seed, was shipped to the General Mills plant in Minneapolis for milling. The milled flour was then distributed to various paper organizations for experimental studies on the application of guar mucilage to paper manufacturing. Rowland (128) summarized the verdict of the paper companies in the following statement, "... The beneficial effects of guar mucilage in the paper processing were sufficient to justify the adoption of the product for regular manufacturing formulas." The program continued from 1944 through 1947 when, according to Matlock, Aepli, and Streets (98), General Mills discontinued its processing program with guar seed. In spite of the fact that there were no industrial outlets for the seed crop, the Arizona and Texas experiment stations exhibited foresight and continued their research programs with guar.

Guar Varieties, Inoculation and Scarification

Three varieties of guar were developed in the 1940's, Mesa, Texsel and Groehler (138, 139). Matlock, Aepli, and Streets (98) reported that Mesa variety of guar had been grown on the Mesa Experiment Farm since 1943. The variety came about as a selection from an unknown plant introduction. Brooks and Harvey (15) wrote that Texsel variety of guar was developed by closely roguing Plant Introduction 116034, grown at Iowa Park, Texas. The name "Texsel" was fabricated in 1946 by Mr. John A. Esser of General Mills, Inc. Groehler variety of guar was a single plant selection (S-46-1) made in 1946 from a commercial field of Texsel on the Louis Groehler farm south of Mesa, Arizona.

In 1947, Erdman (42) isolated two strains of *Rhizobium* from *Crotalaria sagittalis* and from *Erythrina indica* which were highly effective in promoting nitrogen fixation in guar plants.

Musil (107) published a note suggesting that a practical means of securing immediate and uniform germination with guar was to scarify the seed with dilute sulfuric acid and to delay planting until the soil was fairly warm.

Other Investigations Prior to 1950

Purdue investigators (161) in 1947 initiated experiments with guar in hopes of establishing the crop in the corn belt. According to Jones (82), C. P. Key attempted to establish guar in South Carolina, and Claasen and Staker (30) reported observational plantings in Lincoln, Nebraska. Other investigations on guar may have been published, but the reports were not seen by the writer.

Meanwhile, the Department of Agriculture revitalized a program for the plant introduction of guar. The plant introductions, the year introduced, and the places of origin are listed in Table 3.

A new dimension was explored when Whistler (162) initiated an intensive program of physio-chemical investigations on guar seed. He analyzed dried seed of guar and found they contain about 7.4 percent moisture, 26.0 percent protein, 1.6 percent fat, 9.9 percent crude fiber, 3.7 percent ash, and 51.4 percent nitrogen free extract. He believed guar could be safely stored at moisture contents of 14 percent or lower. Upon analysis of the milled guar flour, he learned that it consisted mainly of a carbohydrate polysaccharide. Upon hydrolysis, the polysaccharide produced only mannose and galactose in a ratio of 2:1, hence the name galactomannan.

Table 3. Plant Introductions of Guar from 1940 Through 1947.

Introduction Number	Year	Place of Origin
144324	1942	Pusa, India
144325	1942	Chota, Nagpur, India
144326	1942	Sind, Punjaband, India
144327	1942	Cawnpore, India
144328	1942	Cawnpore, India
144989	1942	Orissa, Cuttack, India
144990	1942	Orissa, Cuttack, India
145103	1942	Dacca, Pakistan
149404	1944	Davis, California?
154365	1946	Beltsville, Maryland?
156988	1946	New Delhi, India
157013	1946	Sirsa, India
157014	1946	Sirsa, India
157015	1946	Sirsa, India
157016	1946	Sirsa, India
157017	1946	Sirsa, India
157020	1946	Kavali, India
157876	1947	Bombay, India
158116[1]	1947	New Delhi, India
158117	1947	Bihar, India
158118[1]	1947	Sirsa, India
158119[1]	1947	Sirsa, India
158120[1]	1947	Sirsa, India
158121[1]	1947	Sirsa, India
158122	1947	Sirsa, India
158123[1]	1947	Poona, India
158124[1]	1947	Poona, India
158125[1]	1947	Poona, India
158126[1]	1947	Poona, India
158127	1947	Poona, India
158128	1947	Poona, India
158129[1]	1947	Poona, India
158130	1947	Poona, India
163103[1]	1947	Delhi, India
163104[1]	1947	Jubbulpore, India
164353[1,2]	1947	Jubbulpore, India

[1]Plant introductions maintained at the Oklahoma Experiment Station, the Texas Agricultural Experiment Station, and for the Southern Regional Plant Introduction Station.
[2]Not numbered consecutively according to the date of introduction.

In 1948, the General Mills Company shifted the emphasis of guar production from the irrigated lands of Arizona and California to North Central Texas and Southwestern Oklahoma. The main reason for this shift was the potential use of guar as a rotation crop with flax and cotton and to the lack of response of the crop to irrigation. The company also felt that the support price of guar grown in Arizona and California was inflated and unrealistic in terms of the crop's future growth in the United States. If guar was to succeed, as a permanent crop in American agriculture, it was to do so on its own merits (44).

McKelvey (94) predicted the many industrial uses of guar on the basis of technology known in 1947:

> Aside from the paper industry guar mucilage finds potential uses in textile sizing, in the production of cheese, processing of leather, manufacture of permanent wave sets, and in preparing foods. It may become an ingredient of spaghetti and other pastes, as well as of cereal products. It can be used as a base powder in ice cream and puddings. Pie fillings, jams and marmalades will benefit by the thickening properties of guar mucilage.

Recent Advances in Chemistry, Plant Breeding, Genetics and Cultural Practices

From 1948 to 1952 there were no industrial outlets in the United States for guar seed. Except for the agronomic studies conducted by the Arizona and Texas Experiment Stations and by a few farmers in southern Texas who grew it as a green manure crop, the future of guar in the United States looked bleak. As the supply of imported locust beans from the Mediterranean area increased, the need for a domestic supply of galactomannan gum decreased. Nevertheless, it was during this period that a great number of investigations were conducted on the molecular structure (1, 62, 70, 105, 115, 122, 135, 144, 166, 168, 169), physio-chemical properties (32, 38, 104, 114, 165, 167, 171, 172), and potential industrial uses of guar gum (16, 26, 27, 61, 77, 101, 102, 113, 123, 125, 141, 145, 146, 147, 148, 160, 163). Whistler (164), Whistler and Smart (170), and Goldstein and Alter (55) have presented excellent detailed manuscripts on the chemistry and potential uses of guar.

Molecular Structure and Physio-Chemical Properties

These investigations indicated that the guar gum molecule is a polysaccharide consisting of straight chain pyranose units of D-mannose joined by 1-4 beta glycosidic linkages. On the average, a single D-galactose unit joins every other mannose unit by a 1-6 alpha linkage. The molecular weight of the gum has been estimated at 220,000.

Guar gum exhibits the following properties:

1. Stable over a wide pH range;

2. Forms acid reversible gels with borate ions;

3. Forms viscous colloidal dispersions in hot or cold water;
4. As a non-ionic polysaccharide, it is not inclined to salt out.

From 1948 to 1952, several patents were issued and papers published on the uses of guar, indicating that it:

1. Prevents caving and heaving of formations when used as an additive to water-base drilling mud;
2. Increases bursting strength and folding endurance of paper sheets;
3. Speeds up production of paper manufacturing;
4. Stabilizes ice cream mixes;
5. Assists in the rapid disintegration of pills;
6. Jells lotions, salves and creams; and
7. Maintains turbidity of natural citrus juice in citrus juice concentrates when they are rehydrated.

Industrial Uses of Guar

During the Korean conflict, the supply of locust beans could not keep up with the demand. The price of locust beans increased to the point where guar beans became more competitive. Since locust beans come from a perennial leguminous tree (*Ceratonia siliqua* L.), the supply cannot be increased radically as can be done with guar, an annual plant. When growing conditions damaged the trees during the 1956 season, guar gum had a chance to make inroads into markets dominated by locust bean gum. General Mills, Inc. once again decided to market domestically grown guar gum seed and a plant was built at Kenedy, Texas. The plant has been in operation since 1953. A second company, Stein Hall and Co. Inc., has plants in Long Island City, New York and Charleston, South Carolina. Other known importers or manufacturers of guar gum are the Burtonite Co., Colony Import and Export Corp., T. M. Duche and Sons, Inc. Unigum division, Paul A. Dunkel and Co., Hathaway Allied Products, Meir Corp., Morningstar-Paisley, and Tragacanth Importing Corp.

In spite of competition from other vegetable and synthetic polysaccharides, guar gum usage has increased tremendously in the United States since 1954. According to Goldfrank (52), consumption of guar gum has increased from 2.5 million pounds in 1954 to around 22 million pounds in 1960. This increase is mainly due to industry, which has sought to find new commercial uses for the gum.

Atwood and Bourne (5, 6) reported a use for guar gum in the purification of potash by the flotation process. Christianson and Ramstad (29) developed a method whereby guar gum can be readily dispersed in water without clumping. A patent was issued to Taylor (151) for use of the gum as a water resisting agent jacket around explosives. Moe (103) perfected a technique whereby galactomannans and glucomannans are processed to produce products having unusually high viscosity in aqueous solutions at low temperatures. The addition of guar gum with melamine-HCHO resin to photographic paper to increase the wet strength, folding endurance, dry burst strength, and resistance to liquid penetration was elaborated by Spear (137) in 1954. McCarron (90) reaffirmed previous investigations by reporting that addition of galactomannan gums to paper increases the strength of the paper and speeds up the manufacturing process.

In 1953, Haug (62, 63, 64, 65) published a series of four papers reporting his investigations with guar gum. He found that purified guar gum contained 60.9 percent mannose and 37.1 percent galactose. He also revealed that when purified guar gum is added to a borax solution, an insoluble complex is formed, making it possible to disperse guar gum in water at a concentration of seven to eight percent.

Johnson (78), Jones and Pridham (81), Keen and Opie (85), McNulty (96), Newburger *et al.* (108), and Strange (142), using infrared absorption spectra, colorimetric and/or water extraction techniques, developed procedures for qualitatively and quantitatively measuring guar gum in foods, drugs, paper products, and cosmetics.

From 1955 to 1960, 25 patents which directly or indirectly involved guar gum were issued to individuals or their companies. The patent numbers, authors, and titles of patents are presented in Table 4. In general, the gum found use mainly in increasing the viscosity and stability, and modifying other properties of liquids or solids. For example, Eatherton, Platz, and Cosgrove (39) tested guar gum as a binding and disintegrating agent for tablets of digitalis, lactose, sulfathiozole and thyroid. Goldstein (53) revealed the amounts of guar used, methods of preparation, and points of addition when the gum is used as a wet-end additive in paper manufacturing.

Gruenhut (58) discussed, from a theoretical standpoint, fiber attraction and polysaccharide additives such as guar gum. The writer believed that due to hydrogen bonding, a linear gum aligns itself to the cellulose molecule and is adsorbed on the surface, whereas a branched gum, because of cross linking properties, is moored within the cellulose molecule as well as adsorbed on the surface.

Table 4. Patent Number, Author, Reference Cited, and Title of Patents Issued from 1955 to 1960 Concerning Guar Gum.

Patent Number		Author	Reference Cited	Title of Patent
U.S.	2,708,175	Samfield, *et al.*	129	Tobacco product.
U.S.	2,730,505	Jordan	83	Increasing the viscosity of guar sols by reaction with formaldehyde.
U.S.	2,767,167	Opie and Hamilton	112	Decreasing the viscosity of mannan type gums.
U.S.	2,769,734	Bandel	8	Water-resistant tobacco sheet material.
U.S.	2,774,710	Thompson & Corrente	153	Pharmaceutical preparations for gastric hyperacidity.
U.S.	2,803,558	Fronmuller	48	Treatment of adhesive gums.
U.S.	2,834,774	Anker	3	Improving mannan type gums.
U.S.	2,844,547	Sheldon	134	Textile printing-paste extenders.
U.S.	2,854,407	Mallory	97	Drilling fluid additive.
U.S.	2,856,289	Weinstein	158	Stabilizers for ice cream-type desserts.
U.S.	2,860,448	Carrasso	25	Reclaiming and improving saline and alkaline soils.
U.S.	2,868,664	Goldstein	54	Dry mannogalactan compositions.
U.S.	2,870,059	Williams & Kirchner	176	Stabilization of dithiocarbamate slurries.
U.S.	2,875,185	Wiley	173	Aqueous suspension polymerization of vinylidene compounds.
U.S.	2,891,050	Elverum & Ramstad	41	Treating seeds containing galactomannan polysaccharides.
U.S.	2,899,261	Voorhees & Scott	156	Oxidation-ingrain color emulsions for textile printing.
U.S.	2,919,802	Drake	37	Concentrating ores.
U.S.	2,937,143	Goren	56	Flocculating and settling of slimes in water.
U.S.	2,941,942	Dahlstrom & Emmett	35	Dewatering foundry sand slimes.
Brit.	834,375	Stein Hall & Co.	140	Stabilizers for galactomannan gum solutions.
Ger.	954,233	Diamalt Akt.-Ges.	36	Thickeners for dyes.
Ger.	1,005,272	Wiley	174	Suspension polymerization of vinylidene chloride.
Ind.	61,005	Patel	116	Gum.
Ind.	61,044	Patel	117	Process for obtaining gum.
Span.	234,853	Industries Cemar SA	75	Shelling of guar seeds.

In 1959, Cushing (33) and Cushing and Schuman (34) reported investigations involving combinations of starches and natural gums as interfiber bonders. They found that when cooked starch and guar gum were used in combination, a paper of higher bursting strength was produced than when either ingredient was used alone.

Lewis and Smith (88) found, by use of an electrophoretic technique, that gums from guar, Kentucky coffee bean, tara, and flax were all heterogeneous. Peterson and Opie (118) obtained interesting data on the variables affecting the flocculation of silicon dioxide, ferric oxide, and bentonite slimes by nonionic hydrocolloids.

Today, there are numerous commercial guar gums on the market (131). Each is compounded for a specific use and the potential uses are expanding rapidly.

Agronomic, Botanical and Other Investigations

Agronomic technology concerning guar has not kept pace with its chemical counterpart. Coordinated research and the incentive of the profit motive have aided the investigations on the physio-chemical properties and uses of guar gum. Agronomic technology, that is, plant breeding, genetics, and cultural practices, is largely confined to academic interests. A shortage of money, uncoordinated research, and lack of well-organized interest groups have hindered its development. Furthermore, many university investigations which have been conducted have not been published. The data are hidden in unpublished theses on library shelves. The U.S.D.A., however, has sent plant explorers such as Walter N. Koelz and H. S. Gentry to India and Pakistan to collect genetic variants of the species and to help maintain the collection in the United States. Table 5 shows the introduction number, year of introduction, and place(s) of origin of guar introductions from 1948 through March, 1962.

In 1933, Ayyangar and Krishnaswamy (7) published a short note which stated that the haploid chromosome number of guar was 7. Senn (133), studying chromosome relationships in the Leguminosae, hypothesized that in the tribe Galageae, the genus *Cyamopsis* was derived by means of aneuploidy with subsequent sexual isolation, from the genus *Indigofera* whose haploid chromosome number is 8. Hymowitz (unpublished data) has found that the haploid chromosome number of *C. senegalensis* is 7.

A monograph on the genus *Cyamopsis* was published in 1939 by Chevalier (27). The complete taxonomic history and descriptions were

Table 5. Plant Introductions of Guar from 1948 Through March, 1962.

Introduction Number	Year	Place(s) of Origin
164170	1948	Nagpur, India
164299	1948	Coimbatore, India
164386	1948	Jakhal, India
164420	1948	Loharu, India
164429	1948	Jaipur, India
164446	1948	Chatsu, India
164476	1948	Jaipur, India
164477	1948	Jaipur, India
164485	1948	Jaipur, India
164486	1948	Jaipur, India
164528	1948	Khandar, India
164592	1948	Coimbatore, India
164593	1948	Coimbatore, India
164692	1948	Hubli, India
164765	1948	Belgaum, India
164799	1948	Poona, India
164801	1948	Poona, India
165511	1948	Lucknow, India
165527	1949	Malasa, India
173897	1949	U.P., India
176373	1949	New Delhi, India
176374	1949	New Delhi, India
176375	1949	New Delhi, India
176376	1949	New Delhi, India
176377	1949	New Delhi, India
176378	1949	New Delhi, India
179682	1948	Phulera, Jaipur, India
179683	1948	Pokaran, Jodhpur, India
179684	1948	Marwar, India
179685	1948	Jodhpur, India
179686	1949	Ahmedabad, India
179926	1948	Sakaranpur, India
179927	1949	Jodhpur, India
179928	1949	Barmer, India
179929	1948	Sirohi, India
179930	1948	Pasalia, India
179931	1949	Sihor, India
180285	1948	Manadir, India
180286	1948	Anandra, India
180287	1949	Mount Abu, India
180288	1949	Bhavnagar, India
180431	1949	Abu Road, Sirshi, India
180432	1949	Sidhpur, India
180433	1949	Ahmedabad, India
180434	1949	Rajkot, India
182968	1949	Veraval, India

Continued

Table 5. Continued.

Introduction Number	Year	Place(s) of Origin
182969	1949	Bhuj, India
183129	1949	Junagadh, India
183315	1949	Jamnagar, India
183400	1949	Surat, India
183449	1949	Broach, India
186305	1950	Canberra, Australia
186477	1950	Coimbatore, India
190871	1950	Sao Paulo, Brazil
198296	1951	New Delhi, India
198297	1951	New Delhi, India
200826	1952	Mandalay, Burma
212900	1953	Poona, India
212986	1953	Baroda, India
212987	1954	Baroda, India
212988	1953	Baroda, India
213503	1953	Pharwar, India
214041	1954	Mysore, India
214319	1954	Ferozepur, India
214320	1954	Sirsa, India
215590	1954	Hansi, India
215591	1954	Moga, India
217923	1954	New Delhi, India
217924	1954	New Delhi, India
217925	1954	New Delhi, India
218022	1954	Bombay, India
223685	1955	Anand, India
223686	1955	Anand, India
236478	1957	New Delhi, India
236479	1957	New Delhi, India
250211	1958	Gujrat, Pakistan
250212	1958	Gujrat, Pakistan
250213	1958	Gujrat, Pakistan
250214	1958	Gujrat, Pakistan
250357	1958	Lahore, Pakistan
250358	1958	Lahore, Pakistan
250359	1958	Lahore, Pakistan
250360	1958	Lahore, Pakistan
253182	1958	Glenn Dale, Maryland?
253183	1958	Glenn Dale, Maryland?
253184	1958	Glenn Dale, Maryland?
253185	1958	Glenn Dale, Maryland?
253186	1958	Glenn Dale, Maryland?
253187	1958	Glenn Dale, Maryland?
254367	1958	New Delhi, India
254368	1958	New Delhi, India
255928	1959	New Delhi, India

Continued

Table 5. Continued.

Introduction Number	Year	Place(s) of Origin
262149	1960	Lyallpur, Pakistan
262150	1960	Lyallpur, Pakistan
262151	1960	Lyallpur, Pakistan
262152	1960	Lyallpur, Pakistan
262153	1960	Lyallpur, Pakistan
262154	1960	Lyallpur, Pakistan
262155	1960	Lyallpur, Pakistan
262156	1960	Lyallpur, Pakistan
262157	1960	Lyallpur, Pakistan
262158	1960	Lyallpur, Pakistan
263406	1960	Yangambi, Congo
263525[1]	1960	Bambey, Senegal
263698	1960	Khartoum, Sudan
263874	1960	New Delhi, India
263875	1960	New Delhi, India
263876	1960	New Delhi, India
263877	1960	New Delhi, India
263878	1960	New Delhi, India
263879	1960	New Delhi, India
263880	1960	New Delhi, India
263881	1960	New Delhi, India
263882	1960	New Delhi, India
263883	1960	New Delhi, India
263884	1960	New Delhi, India
263885	1960	New Delhi, India
263886	1960	New Delhi, India
263887	1960	New Delhi, India
263888	1960	New Delhi, India
263889	1960	New Delhi, India
263890	1960	New Delhi, India
263891	1960	New Delhi, India
263892	1960	New Delhi, India
263893	1960	New Delhi, India
263894	1960	New Delhi, India
263895	1960	New Delhi, India
263896	1960	New Delhi, India
263897	1960	New Delhi, India
263898	1960	New Delhi, India
263899	1960	New Delhi, India
263900	1960	New Delhi, India
263901	1960	New Delhi, India
268228	1961	Bahawalpur, Pakistan
268229	1961	Bahawalpur, Pakistan
271025[1]	1961	Bambey, Senegal
279564[2]	1962	Kimberly, South Africa

[1]*Cyamopsis senegalensis* Guill. and Perr.
[2]*Cyamopsis serrata* Schinz.

given for the three species of the genus; *C. tetragonoloba* (L.) Taub, *C. senegalensis* Guill. and Perr., and *C. stenophylla* (Bonnett) Chev. In 1958, Gillett (49) concluded that Chevalier's *C. stenophylla* was an intermediate form of *C. senegalensis* and *C. serrata* Schinz. He preferred to maintain *C. serrata* as the third species and to leave unsettled the status of the intermediate forms.

Except for Sen and Vidyabhushan (132), who used colchicine to obtain tetraploid plants and their triploid and aneuploid progenies, not a single cyto-morphological investigation involving inter- or intraspecific crosses is cited in the literature. All varieties that are grown in India, Pakistan, and the United States today have been developed by introduction or selection. The lack of full time personnel concentrating solely on guar has hindered varietal development.

Since 1947, 156 plant introductions have been brought into the country. Observation nurseries and tests have been conducted at Stillwater, Oklahoma, and Iowa Park, Texas. The establishment of observation nurseries in Indiana, North Carolina, and South Carolina have failed because of disease organisms or other reasons.

When General Mills, Inc. built their guar processing plant at Kenedy, Texas, the center of guar production was in Southeastern Texas. There the crop was planted following the flax harvest. Unfortunately, the rainfall pattern was not conducive to high yields. The rain frequently came before the beans could be combined, and the resulting blackened seed could not be used for manufacturing a usable gum.

Later the center of guar production moved to North Central Texas and Southwestern Oklahoma where it is presently located. Here the crop is largely grown on sandy and sandy loam soils as a cash legume crop in rotation with cotton.

Numerous semi-popular articles have been published by commercial people, Soil Conservation Service personnel, and other interested individuals (45, 46, 47, 51, 52, 109, 110, 111, 126). All described one or more of the following attributes of guar:

1. The crop controls wind and water erosion;
2. Plants of guar are resistant to drought;
3. The crop raises the fertility level of the soil;
4. Guar plants increase the water intake and water holding capacity of the soil;

5. The crop increases the yields of the following crop;
6. The protein in the beans can be used as a feed supplement for cattle; and
7. The beans can be sold as a cash crop .

However, attributes one to five have never been scientifically proven or disproven.

Concerning attribute number six, a number of studies have been conducted with the use of guar for feed purposes. Krantz *et al.* (87), using rats as the experimental animal, found that the nutritional efficiency of guar flour was much less than that of wheat flour but comparable to that of locust bean gum. Brochers and Ackerson (14) reported that jack bean, lentil, velvet bean, horse bean, and blackeye cowpeas were improved as sources of protein by autoclaving, while peanut, partridge pea, guar, lespedeza, mungbean, and common vetch were not improved. McIlvain (91) found rolled guar beans to be an acceptable protein supplement for wintering steer calves on grass. Arrington *et al.* (4) found evidence of poor growth for weaning rats when fed 40 percent guar meal. They further commented that additional research should be undertaken to obtain more information on guar's value for various animal species.

A committee of staff members of Oklahoma State University (31) evaluated selected potential oilseed and industrial crops in Oklahoma. They estimated that under dryland conditions for Southwest Oklahoma, on a per acre basis, the return to land, labor, risk, and management for grain sorghum, sesame, and guar was 8.20, 12.88, and 8.13 dollars, respectively. This report suggests that even attribute number seven may be in doubt.

A review of the variety and cultural studies conducted in Oklahoma from 1950 to 1959 was published by Matlock (99) in 1960. Previously, Brooks and Harvey (15) and Matlock, Aepli, and Streets (98) had published reviews of investigations conducted in Texas and Arizona, respectively. Thompson (154) studied sorghum versus sorghum-guar mixture. He found that the legume did not contribute sufficient additional protein to compensate for the reduction in forage yield which occurred in the mixed stand. Taylor and Gardner (150) surprisingly revealed that root penetration abilities of legumes (guar, hairy vetch, cowpeas, sesbania, and mungbeans) were not significantly greater than of non-legumes (cotton and sesame).

Unpublished theses deposited at the Oklahoma State University library indicated the following; according to Williams's (175) investigation of the cultural practices in guar, the mean yields of seed, forage, and protein were highest at the 20-inch row spacing and lowest at the 40-inch row spacing; Jones's (79) data showed that at a rate of four viable seed per foot, a 42-inch row produced more protein per acre and the protein content of the forage was 2.09 percent higher than the 21-inch rows; and McMurphy (95) concluded that two pounds of 4-(2, 4-dichlorophenoxy) butyric acid per acre could be used satisfactorily as a post-emergence herbicide on fields of guar.

Summary

In summation, the history of guar in the United States can be divided into three periods, during which guar was used (1) as a green manure and forage crop; (2) as a temporary substitute for carob seed; and (3) as an industrial gum, in competition with other natural and synthetic gums. From this history, we find that even though emphasis may be directed toward a single use for a new crop, research must be coordinated among all phases of its development. Although guar has achieved new prominence for its chemurgic properties, there can be only limited progress without further development in the agronomic sciences.

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OKLAHOMA'S WEALTH IN AGRICULTURE

Agriculture is Oklahoma's number one industry. It has more capital invested and employs more people than any other industry in the state. Farms and ranches alone represent a capital investment of four billion dollars—three billion in land and buildings, one-half billion in machinery and one-half billion in livestock.

Farm income currently amounts to more than $700,000,000 annually. The value added by manufacture of farm products adds another $130,000,000 annually.

Some 175,000 Oklahomans manage and operate its nearly 100,000 farms and ranches. Another 14,000 workers are required to keep farmers supplied with production items. Approximately 300,000 full-time employees are engaged by the firms that market and process Oklahoma farm products.