Guar, *Cyamopsis tetragonoloba* (L.) Taub., is a summer annual legume introduced from India into the United States in 1903. In India and Pakistan, guar is grown as forage for cattle, as a green manure crop, and as a vegetable for human consumption (Hymowitz and Matlock, 1964).

In the United States, initial emphasis was placed on guar as a green manure crop. It was later determined, that in addition to its soil-building properties, guar produces seed that contain a galactomannan gum for which a multitude of food and non-food applications have been developed. Today, the primary importance of guar in the United States lies in the commercial value of its seed. The center of production is in the sandy land areas of north Texas and southwestern Oklahoma, with smaller production areas in south Texas and southern Arizona.

Guar has not been widely used as a basic research tool. Although numerous advances have been made in guar breeding, improvements in yield have been especially hindered by the lack of information on basic physiological processes and inadequate amounts of research on hybridization procedures. Contributions to the literature by the few researchers working with guar are substantial. The reader is referred to a thorough and comprehensive compilation of the literature by Whistler and Hymowitz (1979).

I. PARENTAL MATERIAL

*Cyamopsis* has been variously divided by taxonomists into three or four species. Gillett (1958) divided the genus into three species, *C. tetragonoloba* (L.) Taub., *C. senegalensis* Guill. and Perr. and *C. serrata* Schinz. The status of intermediate forms between *C. serrata* and *C. senegalensis* was left unsettled, although he suggested that intermediate forms may be the result of hybridization between the species. Torre (1960)
Table 1—Chromosome number and geographic distribution of species in the genus *Cyamopsis* †

<table>
<thead>
<tr>
<th>Species</th>
<th>Diploid chromosome number</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. senegalensis</em> Guill. and Perr.</td>
<td>14</td>
<td>Saudi Arabia, Ethiopia, Sudan, Mali, Senegal, Tanzania</td>
</tr>
<tr>
<td><em>C. serrata</em> Schinz</td>
<td>14</td>
<td>S.W. Africa, Botswana, South Africa</td>
</tr>
<tr>
<td><em>C. dentata</em> (N.E. Br.) Torre</td>
<td>?</td>
<td>Rhodesia, Angola, S.W. Africa, South Africa</td>
</tr>
<tr>
<td><em>C. tetragonoloba</em> (L.) Taub.</td>
<td>14</td>
<td>Cultigen</td>
</tr>
</tbody>
</table>

† After Whistler and Hymowitz (1979).

proposed that the intermediate forms be recognized as a distinct species, which he named *C. dentata* (N. E. Br.) Torre. Diploid chromosome number and geographic distribution of the four species are given in Table 1.

From cytological studies, Senn (1938) noted that there was a distinct similarity between the genus *Cyamopsis* and the genus *Indigofera*. He hypothesized that the genus *Cyamopsis* was a derived aneuploid from *Indigofera*. Gillett (1958) preferred to retain *Cyamopsis* as a distinct genus, although it is closely related to *Indigofera*.

The species *C. senegalensis* is a low-growing, annual herb having narrow pentafoliolate leaves and small pods. Seeds are white and average about 1.2 g per 100 seed (Menon, 1973). The species, *C. serrata*, is also a low growing annual, but has narrow trifoliolate leaves. Seed are pink and average about 1.0 g per 100 seed. Both species are reported by Menon to be drought tolerant, disease resistant, and highly dehiscent. Little is known about the annual herb, *C. dentata*. Apparently, it is found in the same semiarid habitats as *C. senegalensis* and *C. serrata*. The chromosome number for *C. dentata* is unknown.

The cultigen *C. tetragonoloba* (formerly *C. psoralioides*) is an erect, annual herb that has never been found growing in the wild (Gillett, 1958). The transdomestication concept has been advanced to explain the origin of the species *C. tetragonoloba* (Hymowitz, 1972). No crossing between species of *Cyamopsis* has been reported in the literature.

In the United States, guar germplasm collections are maintained at the Texas A&M Univ. Agricultural Research and Extension Center, Vernon, Texas; at Oklahoma State Univ., Stillwater, Okla.; and at the Southern Regional Plant Introduction Station, Experiment, Ga. The entire Plant Introduction collection (1050 accessions) and 33 breeding lines and cultivars are stored at the National Seed Storage Laboratory, Fort Collins, Colo.

In India, the most extensive guar germplasm collection is maintained by the National Bureau of Plant Genetic Resources, I.A.R.I. Campus, New Delhi. Other collections are maintained by the Institute of Agriculture, Anand, Gujarat; Millet Breeding Station, Coimbatore, Mysore; Central Arid Zone Research Institute, Jodhpur, Rajasthan; and at the Haryana Agricultural University, Hisar, Haryana. In Pakistan, a guar germplasm collection is maintained by the Agricultural Research Institute, Lyallpur (Whistler and Hymowitz, 1979).
II. PLANT CULTURE

A. Field

Responses of the guar plant to temperature, light, moisture, and mineral nutrition are only partially understood. Research has shown that soil temperatures of 21°C or higher are necessary for guar seed germination (Hymowitz and Matlock, 1964). Guar has an indeterminate growth habit and will remain vegetative and continue to flower and set pods from about 4 to 6 weeks following emergence until terminated by either plant senescence or low temperatures. Mature seed deteriorate rapidly from excessive rainfall and high humidity.

Nutrient requirements for guar have been reported by researchers in India using a sand culture technique. The optimum level of zinc was determined to be 1.0 ppm, boron 0.10 ppm, and copper 0.01 ppm (Nair and Mehta, 1959; Gandhi and Mehta, 1959; Neelakantan and Mehta, 1961). Sastry (1962, 1966) studied the effect of nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur nutrition of guar as it related to local lesion formation by sunn hemp mosaic virus. The optimum nutrient level to avoid the disease was determined to be 420 ppm for nitrogen, phosphorus 31 ppm, potassium 430 ppm, calcium 200 ppm, magnesium 5 ppm, and sulfur 32 ppm.

On fertile soils or where preceding crops have been fertilized, guar usually requires no additional fertilizer. Guar requires high levels of phosphorus. Little critical field research has been conducted to identify optimum fertility levels or soil pH values for guar.

Guar is generally grown under natural rainfall in Texas and Oklahoma. The ability of the guar plant to flower and fruit over an extended period of time partially alleviates yield restrictions caused by droughts of short duration. Prolonged drought stress during the fruiting period is especially yield-limiting. Limited irrigation of breeding nurseries and yield trials has been adopted as a general practice at Chillicothe, Texas.

Guar is generally regarded as a short-day plant. Research in India indicates that guar is photoperiod-sensitive and different light requirements are needed to produce high fodder (vegetable yields) and high seed yields (Paroda et al., 1977). At Vernon, Texas (34°N Lat) guar produces maximum seed yields when planted in June and flowering and pod set occur under 13 to 14 hours of sunlight.

Guar has been successfully grown in winter nurseries at Mayaguez, Puerto Rico. Plant height is reduced, internodes are short with dense clusters of pods on the branches, and fruiting commences near the ground level, indicating sensitivity to short photoperiods. No special requirements appear necessary for advancing breeding lines during the winter season (Stone, 1977).
B. Growth Chamber and Greenhouse

Preliminary data obtained in a greenhouse at Lubbock, Texas, indicated that 13 to 14 hours of light were required to obtain normal plant growth and seed set. Satisfactory flowering and seed set have been obtained in a growth chamber at Vernon, Texas, when plants were grown under 14 hours of light at 27°C and 10 hours darkness at 24°C.

III. FLORAL CHARACTERISTICS

Guar is completely self-fertile and is highly self-pollinated. Floral studies in India indicate that 35 days are required for an initiated bud to develop into a flower (Menon, 1973). Flowers pass through an array of colors from white to deep blue from the bud stage to petal drop, and a mature bud is creamy white in color. Petals develop a pink color just prior to opening. Anthers dehisce about 1.5 to 2 hours before flower opening, and pollen was found to be capable of germination 2 hours before and 11 hours after flower opening. The length of time during which the stigma is receptive has not been reported.

Buds change from a cream color to light pink between 0800 and 1000 hours and petals start opening about 0900 hours (Menon, 1973). Petals continue to open until 1600 hours, with a few flowers opening as late as 0130 hours. The pink petal color changes to deep blue after 1600 hours. Flowers that open early in the morning shed petals the same day, between 1700 and 2000 hours. Late opening flowers shed petals the following morning (Menon, 1973).

The longevity of pollen at room temperature was reported by Menon et al. (1968) to be 11 to 13 hours and maximum pollen germination of 46% was obtained between 0800 and 0900 hours. Each pollen cell normally produced one tube, although two tubes occasionally were observed. The average pollen tube length recorded was 1.6 mm. The viability of pollen stored under refrigeration was not studied.

The inflorescence of guar is a raceme, about 9 to 13 cm long in the branched types and 15 to 20 cm long in the erect or sparsely branched types (Fig. 1). Normally, 40 to 60 flowers are present in an inflorescence of the branched type and 50 to 70 in the erect and sparsely branched types (Menon, 1973). Fruiting pedicels are stiffly erect in the leaf axils (Fig. 1). Flowers are bisexual, about 9 mm long, and almost sessile. The calyx has five sepals and the corolla has five petals (Fig. 2). The standard is circular, the wing petals are oblong, and the keel petals are as long and broad as the wing petals. The keel is blunt and slightly incurved. The pistil consists of one carpel. The ovary is linear, sessile and one-celled containing 6 to 10 ovules. The style is short and incurved with a head-shaped stigma (Menon, 1973; Gillett, 1958; Chandrasekharan and Ramakrishnan, 1928; Jafri, 1966).
Fig. 1—Fruiting raceme of guar at the late bud stage.
There are 10 stamens enclosed in the keel (Fig. 2). The anthers are uniform, and the pollen grains are spherical in shape, averaging 40 to 43 \( \mu \) in diameter (Menon et al., 1968; Menon, 1973).

Fig. 2—Open guar flower showing petals, stigma, style, and stamen.
IV. ARTIFICIAL HYBRIDIZATION AND SELF-POLLINATION

A. Equipment

Artificial hybridization in guar requires only a pair of forceps, short glassine bags, a hand stapler, and label tags. Since guar is normally self-pollinated, no equipment is needed to produce selfed seed.

B. Preparation of the Female

Hand emasculation and crossing techniques were developed and are being used in India (Chaudhary et al., 1974). Mature buds are selected for emasculation in the late afternoon between 1600 and 1800 hours (Fig. 3). Buds are selected whose stigmas will be receptive to pollen for at least 2 days. All self-pollinated flowers below the selected buds are removed, thus, the lowest buds on the raceme are always the emasculated ones. To avoid damage to the raceme, upper buds are not removed until 3 days after emasculation; however, upper buds should be removed if flowers open during this period. No more than two buds usually are emasculated on a raceme at one time.

The bud should be supported by the fingers during emasculation to prevent damage to the stigma or style. The front sepal is removed with a forceps by gently pulling upward. Petals are removed in like manner. Many of the anthers are removed with the petals. Remaining anthers should be removed and visually checked to insure that they are undehisced. The whole inflorescence, including emasculated buds, is bagged with a glassine bag and stapled at the base of the raceme.

C. Pollination

Buds are pollinated the morning following emasculation, preferably between 0800 and 0900 hours (Chaudhary et al., 1974). To obtain better seed set, buds should be pollinated twice, on succeeding mornings. Newly opened flowers are selected for the pollen source (Fig. 2). Pollination is achieved by gently brushing the anthers across the stigma of the emasculated bud. Mature anthers generally dehisce on contact.

Following pollination, the raceme is labeled with a tag and rebagged. The bag should be removed after pod formation takes place, about 3 to 5 days after pollination. Generally, pods resulting from hybridization contain only two to three seeds and are smaller than those resulting from self-pollination. The shape and size of the pod insure easy identification of pods obtained from hybridization. Pods resulting from self-pollination are shown in Fig. 4. Chaudhary et al. (1974) achieved a 6 to 8% effective pod set using the hand emasculation and crossing technique.
Fig. 3—Guar raceme at the late bud stage. Lower buds are suitable for emasculation.
Fig. 4—Early pod formation about 3 to 5 days after self-pollination.
D. Factors Affecting Efficiency

Guar crossing blocks can be arranged in any convenient design which allows sufficient space between rows for emasculation and crossing. Because guar has an indeterminate flowering habit, special techniques for matching flowering dates of different genotypes do not appear necessary.

The pubescent-glabrous marker is used extensively in making controlled natural crosses in the United States and will be discussed in Section V. Glabrous and pubescent plants in guar can be easily distinguished by visual and tactile examination. The glabrous characteristic is conditioned by a single recessive gene (Kinman, 1962).

Prasada Rao and Patel (1973) found that dark green foliage color is completely dominant over light green foliage color and is conditioned by a single gene. Although the authors did not speculate about the utility of this character, it could conceivably be used as a genetic marker. No genetic markers are available for identifying hybrid seed.

V. NATURAL HYBRIDIZATION

Guar breeding in the United States initially involved the evaluation of Plant Introductions (PI). Most guar PI were heterogeneous and a minor amount of outcrossing could easily pass undetected. It was only after a significant portion of the introductions had been evaluated and single plant selections had been made that the degree of natural crossing became apparent.

A reasonably successful method has been developed for using controlled, natural hybridization for generating new material for selection and evaluation. By utilizing the genetic marker glabrous-pubescent leaf type, hybrid plants can be easily identified and utilized for further evaluation. In this procedure, a pubescent breeding line (male parent) and several glabrous breeding lines (female parents) are planted in a block, well isolated from other guar. Isolation requirements equal to or greater than that for Foundation seed production (200 m) are followed. A common design is to plant every third row with the pubescent parent and plant glabrous lines in the remaining rows. Rows in the crossing blocks are generally 5 m long and spaced 1 m apart. Bees or other insect pollinators are needed to achieve maximum crossing between the pubescent and glabrous lines.

No special treatment of plants is required for natural crossing. Natural crossing between early maturity breeding lines and medium to late maturity lines has been found to be only slightly less than crossing within a given maturity class. Altering flowering dates by date of planting does not seem to be necessary in obtaining natural crosses in guar.

Seed is harvested from the glabrous lines on a single row basis. The following season, several rows 100 m in length are planted from seed of each harvested row. Pubescent plants (hybrids) are tagged during the growing season and harvested on a single plant basis. Detectable natural crossing (pubescent × glabrous) using only wild insect pollinators has ranged from
less than 1 to 4.4% at Chillicothe, Texas (Stafford and Lewis, 1975). Other natural crossing (glabrous × glabrous) is less easily detected and has not been utilized.

Genetic male sterility was reported by Mital et al. (1968), but has not been exploited for hybrid seed production. Semisterility caused by reciprocal translocations has been reported in the United States (Kinman et al., 1969) and India (Vig, 1965). It has been of little utility from the standpoint of hybridization techniques.

VI. SEED DEVELOPMENT, HARVEST, AND STORAGE

Successful pollination of hand-emasculated guar flowers can be readily detected after pod formation takes place. Pods are generally small with two to three seed per pod. Guar is commonly harvested either at physiological maturity or shortly after cold temperatures have terminated plant growth. Leaves generally abscline and stems and pods dry to acceptable moisture levels to permit harvest 10 to 14 days following freezing temperatures.

Self-pollinated nursery-row selections are hand-harvested and bagged in burlap sacks. A large sheet-metal funnel, 80 cm across the top and 48 cm at the bottom is used to simplify the bagging process. Bagged samples are air-dried and threshed with a Vogel thresher. Seed is cleaned with a Clipper cleaner. Single-plant selections are cut, bagged in paper bags, air dried, and threshed with a single plant or head thresher. Single-plant selections are commonly cleaned by hand after threshing. Seed is identified by a cross number and a bulk or plant selection number, depending on the selection procedure.

Seed is commonly stored in metal storage trays and boxes at normal room temperatures. Stored grain pests in the United States are generally of little consequence in guar. Naphthalene crystals are routinely placed in the storage boxes as a pest preventive measure. Seed viability can be retained for several years at room temperature.

REFERENCES


Stone, E. G. 1977. Personal communication. Mayaguez, Institute of Tropical Agriculture, Box 70, Mayaguez, Puerto Rico 00708.

