Guar Production, Utilization and Marketing

Current Scenario and Future Prospects

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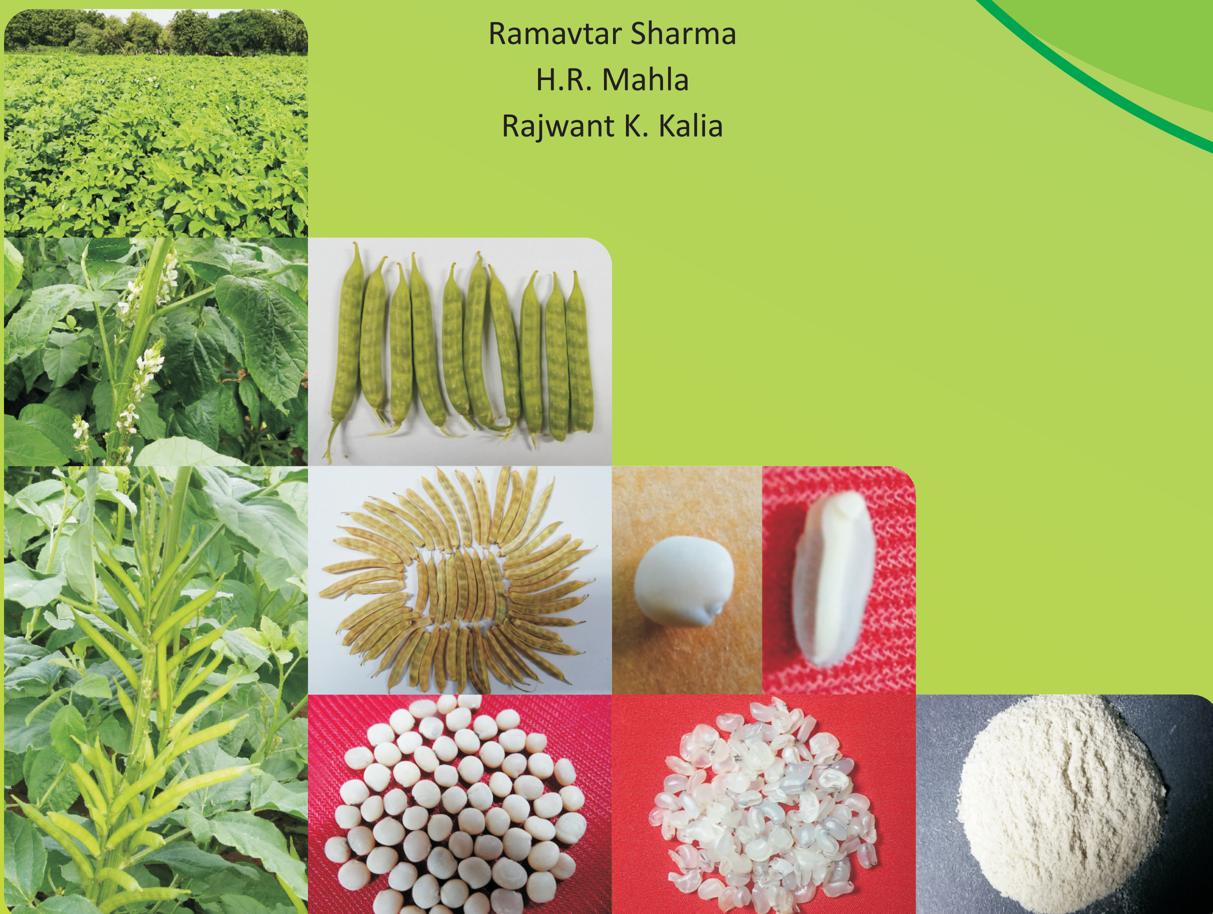

ICAR-Central Arid Zone Research Institute
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Foreword

Cluster bean [*Cyamopsis tetragonoloba* (L.) Taub] commonly known as guar, is a drought tolerant annual legume of hot arid and semi arid regions mostly cultivated on marginal and sub-marginal lands and resource poor soils under rainfed conditions. In recent years it has assumed great industrial importance due to the presence of gum (galactomannan) in the seed endosperm, which constitutes about 30–32% of the whole seed. Other parts of the seed i.e husk or hull and germ are rich in protein and used as guar meal for livestock. Apart from gum extraction, it is also used for feed, fodder, vegetable and green manuring. India is the major producer of guar accounting for about 80% of the total guar produced globally. In India, maximum produce comes from rainfed agriculture of arid and semi arid areas of Rajasthan (~82%) followed by Haryana (10%) and Gujarat (5%).

Guar gum has emerged as an important non toxic, eco-friendly and safe to use agrochemical for human consumption approved by US Food and Drug Administration (FDA). Guar gum has several diversified uses in food processing, pharmaceuticals, cosmetics, mining, explosives, petroleum, well drilling, oil industries, refining, textile, paper industry etc. Guar gum and its derivatives are in great demand in the world market. It is an indispensable commodity in oil and gas industry. Large quantity of its gum is exported to other countries. Foreign exchange earned from its export has increased from Rs. 1.42 crores in 1994 to Rs. 112 billion during 2007 and further to Rs. 323.3 billion in 2015-16. Guar held the position of highest foreign exchange earner of Rs. 212.87 billion in the year 2012-13 among all the agricultural export commodities followed by Basmati rice.

The major challenges in promotion of guar production in the country are fluctuating prices and demand in the international markets. Therefore, focus is required on development of domestic demand for long term survival of guar industry in the country.

In recent past, increasing demand and market rates have helped guar to expand to non-traditional regions and seasons for cultivation. Considering its diversified uses, it will still continue as an important industrial crop under hot arid and semi arid regions. Therefore, there is a need to give due emphasis on development of early maturing, climate resilient varieties with inbuilt plasticity for tolerance to soil moisture stress and resistance towards diseases; development of genotypes with ground clearance and amenability to mechanical harvesting; development of seed chain network from production to marketing to promote direct profit to the farmers. I hope this bulletin will be useful to all stakeholders associated with guar cultivation, processing and marketing.

O.P. Yadav

Preface

Guar or cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] is a self-pollinated leguminous crop usually grown under resource constrained situations mostly in the arid and semi-arid regions. Being a leguminous crop it improves the soil fertility through atmospheric nitrogen fixation. Guar seeds are rich in gum content in the form of galactomannan which is useful for many industrial applications. Guar gum has desirable properties like easy solubility in both hot and cold water, water binding due to hydrogen bonding, resistance to oils, grease and solvents, better thickening action, physiologically inert nature and non-ionic character. Due to these properties and suitability to derivation, new industrial applications of guar gum are increasing day by day. Guar derivatives are being used in food processing, petroleum industry, explosives, mining, pharmaceutical, medicine, printing and textile industries. Due to its multifarious uses, guar has emerged as an important industrial crop with high export value. Guar is cultivated mostly in India, Pakistan, USA, Italy, Morocco, Germany, Spain, Australia, Bangladesh, Myanmar, South Africa and Brazil.

India is the major producer of guar accounting for about 80% of the total guar produced in the world. Major part of India's produce comes from the rainfed agriculture of arid and semi arid areas of Rajasthan followed by Haryana, Gujarat and Punjab. Because of its wider usage and economic value, guar cultivation is also spreading to non-traditional guar growing areas like Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh. The crop is now being cultivated in *kharif* as well as in summer season in traditional areas while expanding to irrigated lands in major guar growing states, Rajasthan, Gujarat and Haryana. The crop has invaded into areas of other *kharif* crops like groundnut, pearl millet, sorghum, cotton, etc. The crop is now grown on black, deep clay type of soils in addition to sandy and red soils covering wide geographical area of the country.

In spite of good monetary value, limited breeding efforts have been made to enhance productivity of guar through genetic improvement. There is an urgent need to develop varieties for important traits like yield, gum content in seeds, and tolerance to biotic and abiotic stresses. In order to apprise various stake holders about the recent developments, we have attempted to compile information on various aspects of guar including high yielding varieties, cultural practices, seed production, and uses, properties and trade of guar gum. This bulletin will be helpful for managing the cultivation, production and marketing of guar.

Authors

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Introduction

Guar commonly known as cluster bean [*Cyamopsis tetragonoloba* (L.) Taub syn. *C. psoralioides* L.], a member of family Fabaceae Lindl. (Leguminosae) and subfamily Faboideae Rudd. (Papilionoideae) is grown as annual crop in hot arid and semi arid regions. This drought tolerant legume with single or branched stem and deep roots is mostly cultivated on marginal and sub-marginal lands and resource poor soils under rainfed conditions. Cluster bean requires warm weather and moderate rainfall for its growth, however it is capable of production even below 250 mm rainfall and temperatures rising above 42°C during growth period. It has been recognized as a cash crop in hot arid regions due to gum content in the seeds. The major cluster bean cultivating countries are India, Pakistan, USA, Italy, Morocco, Germany and Spain (Punia *et al*., 2009). India is the major producer of cluster bean accounting for about 80% of the total guar produced globally (Sharma and Gummagolmath, 2012).

Guar is grown for feed, fodder, vegetable, green manuring and for gum extraction from seeds. Boiled cluster bean seeds are traditionally used as animal feed. However, *C. tetragonoloba* with endospermic gum, was seldom used to feed animals as green fodder except the plants with shattering pod character (arak/wild type) that were uprooted and fed to animals. Dry fodder, usually fed to camel and goat, mainly consists of stem parts (locally called *guna*) and pod coats (locally called *phalgati*) (Mathur *et al*., 2005), as most leafy part drops before or during harvesting. In recent years it has assumed great industrial importance mainly due to the presence of gum (galactomannan) in the seed endosperm, which constitutes about 30-32% of the whole seed. Now it has become a major source of novel food additive, the guar gum, for food stabilization and as source of fibre (Morris, 2010).The other parts of the seed such as husk or hull (14-17%) and germ (43-47%) are rich in protein and used as guar meal for livestock.

Cluster bean gum has emerged as an important agrochemical which is non toxic, ecofriendly and generally recognized as safe (GRAS) by US Food and Drug Administration (FDA). Guar gum has several diversified uses in textile and paper industry, food processing, cosmetics, mining, pharmaceuticals, explosives, petroleum, well drilling, oil industries, refining, etc. Guar gum and its derivatives are in great demand in the world market. Large quantity of its gum is exported to other countries. Foreign exchange earned from its export has increased from Rs. 1.42 crores in 1994 to Rs. 1120 crores during 2007 (Henry and Mathur, 2008) and further to Rs. 3233 crores in 2015-16. During 2012-13 the price of guar seed had increased considerably because of the exponential growth in demand for its use in hydraulic fracturing (Gresta *et al*., 2013). Guar held the position of highest foreign exchange earner of Rs. 212.87 billions in the year 2012-13 among all the agricultural export commodities followed by Basmati rice. Considering its diversified uses, guar is expected to assume still more importance as an industrial crop under hot arid and semi arid conditions. However, due to dwindling market demand as observed during 2012-2014, it is less likely to invade resource rich irrigated regions of the country.

Origin and distribution

Cluster bean has long been recognized as a cash crop for its valuable seed borne polysaccharide (Gillet, 1958). There is lack of general consensus with regard to the origin of this plant. The domesticated species is normally associated with India and Pakistan, where the plant has been grown for centuries as food for both human and animals (Whistler and Hymowitz, 1979). Vavilov (1951) believed that India was the geographic centre of its variability in nature where it does not occur in wild state. Hymowitz (1972) put forth the hypothesis of trans-domestication suggesting that *C. tetragonoloba* had evolved from the drought tolerant wild African species *C. senegalensis* while being carried to South Asian subcontinent by Arab traders as fodder for horses probably sometime between the 9th and 13th centuries AD. Chavalier (1939) described four major species of *Cyamopsis* viz., *C. tetragonoloba*, *C. senegalensis*, *C. serrata* and *C. dentata*, and mentioned that *C. senegalensis* probably extended to Sindh (Pakistan) where after domestication a few of its cultivars became cultivable in India. It also spreaded to other Asian countries including Indonesia, Malaysia and the Philippines, and is now grown in many parts of the drier tropics and subtropics.

Guar is hardy and drought tolerant crop well adapted to arid and semi-arid climates with hot temperatures but can grow in sub-humid conditions, from sea level up to an altitude of 1000 m. It grows well under a wide range of soil types and is tolerant to low fertility and soil salinity to certain extent. It performs best on well drained fertile, medium-textured and sandy loam alluvial soils including black soils but cannot tolerate water logging (Undersander *et al*., 1991; Wong *et al*., 1997). In India it is suited to tropical hot climate, mainly hot arid and semi arid regions of North and North-West India (Haryana and Rajasthan). Most of the India's produce comes from the rainfed agriculture of arid and semi arid areas of Rajasthan (>80%) followed by Haryana, Gujarat and Punjab. Being one of the few crops capable to endure harsh climate, its cultivation in Rajasthan is much higher (82.1%) mostly confining to western drier parts. The contribution of other states to total area is much less, viz. Haryana (8.6%), Gujarat (8.3%) and Punjab (1%). Guar crop is grown in Churu, Nagaur, Barmer, Sikar, Jodhpur, Ganganagar, Bikaner, Jaisalmer, Hanumangarh and Jhunjhunu districts in Rajasthan; Kutch, Banaskantha, parts of Mehsana, Sabarkantha and Pattan districts in Gujarat; Bhiwani, Mahendergarh and Rewari districts in Haryana and Bhatinda, Ferozpur, Muktsar and Mansa districts in Punjab. It is also grown in small pockets in other states of India viz., Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh.

The crop was introduced into the United States from India in 1903 and came into commercial cultivation in the early 1950s being concentrated in northern Texas and south-western Oklahoma. During the same period in 1910 it was introduced into Australia from India and was found suitable for cultivation in the northern region of Australia relatively successfully with potential yield of 2-3 t ha^{-1} (Bryceson and Cover, 2004; Dunne, 2001; Murphy,1998; Doughton and Berthelsen, 1985; Doughton, 1984; Keating, 1984; Jackson and Doughton, 1982). It is also sparsely grown in countries like Australia, Bangladesh, Myanmar, USA, South Africa, Brazil, Congo and Sri Lanka, however, India and Pakistan continue to be the major suppliers in the world (Kuravadi *et al*., 2013). Experiments in Italy have shown the suitability of cluster bean cultivation in Mediterranean region also (Gresta *et al*., 2014). The share of Pakistan is about 15% in the global production, while Sudan, Australia and USA together contribute about 5%. Guar is mainly grown in Punjab and Sindh region in Pakistan mostly (80%) under irrigated conditions (Sharma and Gommagolmath, 2012). Guar is considered a highly viable crop for semi arid zones (Ashraf *et al*., 2005) and an alternative crop for Mediterranean areas (Sortino and Gresta, 2007; Losavio *et al*., 1995), where limited water availability does not allow the cultivation of many summer crops.

Area, production and productivity

The western arid zone of Indian subcontinent (India and Pakistan) is suitable for guar cultivation. In India, maximum produce comes from rainfed agriculture of arid and semi arid areas of Rajasthan (~82%) followed by Haryana (10%) Gujarat (5%), Punjab (1%) and only 1% from other states (Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh). Based on 2011-12 statistics, Rajasthan and Haryana together contributed about 95% of the total cluster bean production in India; Rajasthan alone accounting for three-fourth of the cluster bean production in the country (Bhatt *et al*., 2016). During the year 2012-13, the cluster bean production in India was more than 2.46 million metric tons (MMT) (USDA, 2014). The total area under cluster bean production and its yield during the same period was 5.15 million hectare (M ha) and 478 kg ha^{-1} respectively. The area, production and yield for the year 2013-2014 were 5.6 M ha, 2.7 MMT and 485 kg ha^{-1} respectively. Because of wide industrial applications, its cultivation is now spreading to other states also.

With increasing demand and market rates guar cultivation in Rajasthan has made a shift to high input cultivation with options for irrigation, increasing the productivity comparable to national level in last 5 five years. Recent hike in prices of guar have helped to expand the crop to non-traditional regions and seasons. The crop is now cultivated in *kharif* as well as in summer seasons in traditional areas while expanding to irrigated lands in the major growing states i.e. Rajasthan, Gujarat and Haryana. It has also assumed considerable area in dry tracts of Madhya Pradesh, Chhattisgarh, Andhra Pradesh, Karnataka, Tamil Nadu and other parts in *kharif* as well as in the summer season. The crop has also invaded into the areas of other *kharif* crops like groundnut, pearl millet, sorghum, cotton, etc. The crop is now grown on black, deep clay type of soils along with sandy and red soils covering wide geographical area of the country.

India's guar production fluctuates considerably due to complete dependence of the crop on rainfall. It yielded as low as 2.0 lakh tonnes during 2002-03 and more than 27.0 lakh tonnes in 2013-

14 and 2015-16. In 2002-03 there was a drastic reduction in area sown (0.97 M ha) and productivity (204 kg ha^{-1}) because of poor monsoon rains. However, usually area under cultivation remains unaffected as the crop can be sown with delayed onset of monsoon up to 1st week of August. It is the rainfall pattern during crop growth period that affects productivity and ultimately production. However, since 2007-08 productivity has shown more stability remaining above 450 kg ha^{-1} except during 2009-10 when productivity was much lower (about 198 kg ha^{-1}) while production showed increasing trend with increase in area (Table 1). Factors like prices of guar in the previous season may also affect area and production, however, only drastic escalation in prices and associated speculation can bring more area under the crop, a phenomenon experienced a few years back. Largely, area under crop in the traditional regions remains unchanged due to lack of alternative crops. In spite of certain fluctuations in rainfall and also prices, an increasing trend has been observed in the acreage and production during the last decade in India. The production status from Rajasthan and its contribution at national level are presented in Table 1.

Table 1. Area, production and yield of cluster bean in India and Rajasthan

Years	India			Rajasthan			% area contributed by Rajasthan	% production by Rajasthan
	Area (lakh ha)	Production (lakh t)	Yield (kg ha^{-1})	Area (lakh ha)	Production (lakh t)	Yield (kg ha^{-1})		
1990-91	24.03	11.76	489	20.90	9.46	453	86.97	80.44
1991-92	17.65	3.46	196	15.59	2.04	131	88.32	58.95
1992-93	21.79	7.97	366	18.82	5.83	310	86.36	73.14
1993-94	21.01	4.90	233	18.97	2.87	151	90.29	58.57
1994-95	23.02	9.39	408	19.59	7.08	361	85.09	75.39
1995-96	22.13	9.00	407	17.75	2.74	155	80.20	30.44
1996-97	21.25	8.86	417	18.19	7.40	407	85.60	83.52
1997-98	23.01	9.63	418	19.85	7.34	370	86.26	76.22
1998-99	19.22	4.88	254	16.12	3.20	198	83.87	65.57
1999-00	29.33	3.75	128	26.49	2.32	87	90.31	61.86
2000-01	34.97	6.59	188	30.56	4.81	157	87.38	72.98
2001-02	29.03	10.90	375	24.13	7.63	316	83.12	70.00
2002-03	9.75	1.99	204	5.57	0.28	50	57.12	14.07
2003-04	28.54	15.13	530	22.78	11.63	511	79.81	76.86
2004-05	28.67	9.03	315	23.63	3.66	155	82.42	40.53
2005-06	29.55	10.59	358	24.44	5.93	243	82.70	55.99

Years	India			Rajasthan			% area contributed by Rajasthan	% production by Rajasthan
	Area (lakh ha)	Production (lakh t)	Yield (kg ha^{-1})	Area (lakh ha)	Production (lakh t)	Yield (kg ha^{-1})		
2006-07	33.43	11.69	350	28.07	6.58	234	83.96	56.28
2007-08	34.72	17.88	515	29.09	12.43	427	83.78	69.51
2008-09	38.62	19.35	501	33.15	12.61	380	85.83	65.16
2009-10	29.89	5.93	198	25.81	2.01	78	86.34	33.89
2010-11	33.82	19.65	581	30.00	15.46	515	88.70	78.67
2011-12	34.44	22.17	644	30.94	18.46	597	89.83	83.26
2012-13	51.51	24.60	478	45.33	20.26	447	88.00	82.35
2013-14	53.29*	35.31*	524	50.70	28.62	564	95.14	81.00
2014-15	60.23*	32.72*	585	46.25	27.95	605	77.00	85.42
2015-16	55.81	27.51	493	47.86	22.23	465	85.75	80.80

(*Average of Rajasthan, Gujarat and Haryana; Source: calculated from different sources)

Botanical description

The genus *Cyamopsis* belongs to family Fabaceae (Leguminosae) and sub-family Faboideae (Papilionoideae) with four species *C. dentata*, *C. senegalensis*, *C. serrata* and *C. tetragonoloba* (Dwivedi and Bhatnagar, 2002; Chevalier, 1939). Cluster bean is a self-pollinated crop with 2n=14 (Hymowitz, 1972). Morphologically it is either branched or single stemmed in architecture (Fig. 1). Branches start appearing from the base of the plant and genotypes vary for branching from none to many (>15) primary branches and at times bear secondary branches also (Fig. 2A). It may attain a

Fig. 1. Growth habit of (A) branched and (B) single stem genotypes

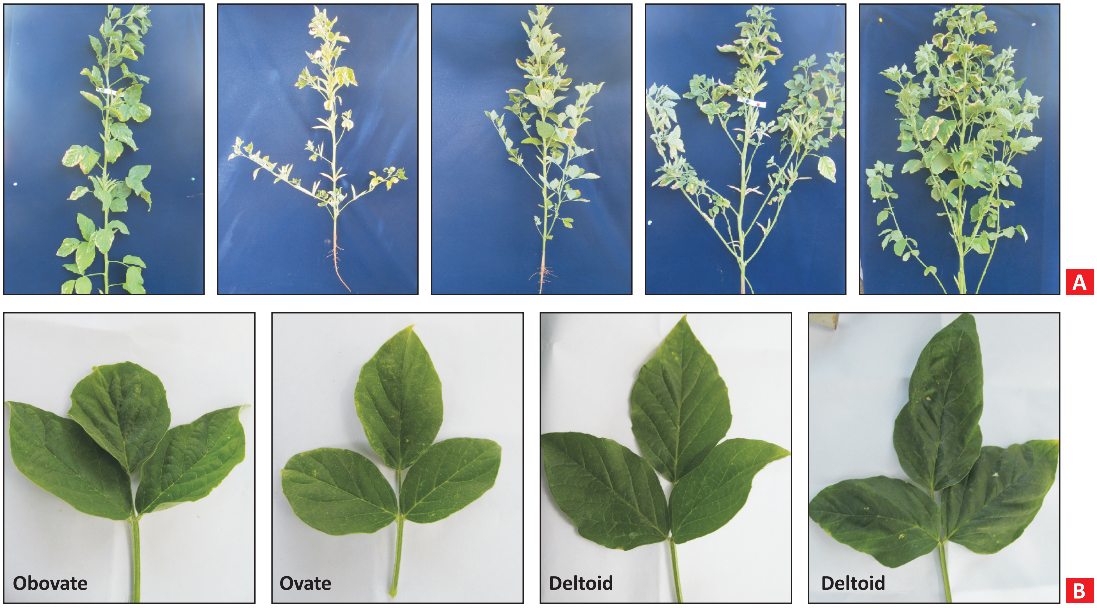

Fig. 2. Variability in (A) branching pattern and (B) leaf shape

height of 50-150 cm while single stem types might grow taller. It has well developed robust tap root system to survive under arid conditions. Being a leguminous crop, its roots bear rhizobial nodules for atmospheric nitrogen fixation. Trifoliate leaves (Fig. 2B) are borne on nodes in alternate fashion. Leaves and other aerial plant parts are pubescent in seed varieties while vegetable types are glabrous. Usually leaves are serrated however the extent of serration varies (Fig. 3). Racemose inflorescence appears in the leaf axils with variability in size and flower orientation (Fig. 4). Flowers are small (5-7 mm), papilionaceous violet, pink or white in colour (Fig. 5). Cluster bean is highly self-pollinated crop but out crossing has also been reported (0.5-7.9%) (Chaudhary and Singh, 1986;

Fig. 3. Variation in leaf margins (smooth and serrated)

Fig. 4. Variation in inflorescence shape and size in different genotypes of cluster bean

Fig. 5. Variation in flower colour (A) white, (B) pink, and (C) purple/violet

Saini *et al*., 1981). Calyx of flower has five unequal sepals, corolla has the orbicular standard, oblong wing and broad keel petals (Kumar and Singh, 2002). Cluster bean flower has diadelphous stamens, short style and head shaped stigma (Sindhu *et al*., 1982; Chandersekharan and Ramakrishnan, 1928). Pods are borne in clusters deriving the name cluster bean (Fig. 6). Pods are flat 5-12 cm long bearing 5-11 seeds of different shape, size and colour. Mature seed is whitish in colour which may turn black due to excess moisture (Fig. 7).

Fig. 6. Variation in (A) cluster length, (B) green and (C) dry pod shape, size and colour

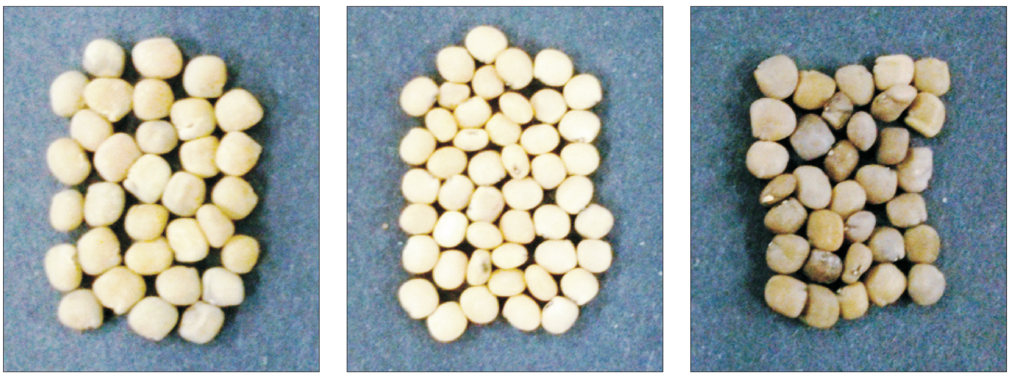

Fig. 7. Variation in seed shape, size and colour

Varietal development

Systematic efforts for cluster bean improvement were initiated in 1961, with the development of genetic resources by Division of Plant Introduction, Indian Agricultural Research Institute (Now National Bureau of Plant Genetic Resources, NBPGR), New Delhi. The diverse germplasm was collected from prime areas (Gujarat, Rajasthan and Punjab) of variability for cluster bean (Thomas and Dabbas, 1982). Subsequently a scheme entitled 'Collection and isolation of superior genotypes for gum purposes' was launched under Public Law 480 (PL 480, 1954) of Agricultural Trade Development and Assistance Act during 1965-70 to give proper support to ongoing programme. Based on initial evaluation of collections, two catalogues were published in succession containing information on 1150 accessions in 1981 (Dabas *et al*., 1981) and 3580 accessions in 1989 (Dabas *et al*., 1989). Presently National Gene Bank at NBPGR, New Delhi, India is maintaining about 5000 accessions of cluster bean along with *C. serrata* and *C. senegalensis*, the two close wild relatives of guar. According to the report of Mishra *et al*. (2009), NBPGR, India is maintaining 4878 indigenously collected accessions in medium term storage while efforts have also been made for long term *ex situ* conservation of 3714 accessions.

Simultaneously, cluster bean improvement work was also initiated at Agricultural Research Station, Durgapura (SKRAU, Bikaner) and CAZRI (Jodhpur) in Rajasthan, and CCSHAU (Hisar) in Haryana with collection and assessment of germplasm. About 40 varieties at central and state level have been released for fodder, seed and dual purposes. Initial varieties (till 1978) came from the evaluation of germplasm and later varieties mainly originated from hybridization and mutation programmes (Mahla *et al*., 2011; Singh *et al*., 1995; Henry *et al*., 1992; Paroda and Saini, 1978). First variety developed through hybridization program was released by Punjab (*Agaita Guara* 111) in the year 1978 while Rajasthan and Haryana continued to contribute varieties derived through selection. Both selection and hybridization programs continued for long time (1978 to 1999). However, recent contributions to varietal development are mainly through hybridization and induced mutagenesis. Morphological variability does exist in cluster bean but is inadequate especially for stress resistance and gum content (Jukanti *et al*., 2015); therefore cluster bean breeding is slower for these traits (Kumar *et al*., 2015).

Induced mutagenesis could be a powerful tool for enriching variation in guar where exploitable and useful genetic variability is meager and artificial crossing is not easy due to small cleistogamous flowers having delicate structures (Arora and Pahuja, 2008). Induced mutation by gamma rays in cluster bean for the first time was carried out by Vig (1965) where ^{60}Co was used as a source of radiation. Obviously useful mutations like male sterility and inflorescence modifications obtained by various workers (Arora and Pahuja, 2008; Vig, 1965) were due to chromosomal aberrations (Chaudhary *et al*., 1973) which is undesirable in crop improvement. Moreover, appearance of male sterile plants in natural population was common (Mittal *et al*., 1968). A high yielding, stable, early flowering mutant of 'Pusa Navbahar' was created by irradiation with ^{60}Co source (10 kR) (Rao and Rao, 1982). Usefulness of chemical and physical mutagens in creating desirable variability has also been reported by various workers (Velu *et al*., 2012, 2007; Bhosle and Kothekar, 2010; Mahla *et al*., 2010, 2005; Babariya *et al*., 2008). However, work on mutation breeding of guar is limited and only three mutants with higher yield and useful attributes have been obtained so far viz. M-83 (vegetable type) is mutant of variety Durgabahar, while two seed type varieties RGM 112 and GG 1 are mutants of variety Naveen and local collection Kutch 8, respectively.

A number of cluster bean varieties developed by various research organizations are suitable for different regions (Table 2). These varieties differ in yield, maturity, branching behavior (single stem/branched), cluster size and pattern, and gum content. Varieties were also developed for disease resistance, drought tolerance, earliness and high seed yield potential. CAZRI, Jodhpur has also collected a large number of germplasm from different sources and currently they are under evaluation for development of high yielding genotypes.

Table 2. Details of released cluster bean varieties

Variety	Year of release	Duration	Yield (kg ha^{-1})	Area	Features
RGC 1033	2011	95-106	1500-2500	Rajasthan	Resistant to major diseases and pests
HG 870	2010	90-95	2000-2200	Haryana	Early type
RGC 1038	2009	95-110	1100-1400	All India	Heavy bearing and photo insensitive
HG 2-20	2008	90-95	1050-1250	North India	Resistant to bacterial leaf blight and root rot
RGC 1055	2007	96-106	1100	Rajasthan	Bold seeded
RGC 1066	2007	95-100	1000-1400	Rajasthan	Unbranched
RGC 1031	2005	110-114	1050-1570	Rajasthan	Resistant to bacterial leaf blight
RGM 112	2005	85-90	1200-1300	Rajasthan	Resistant to bacterial leaf blight
GG 2	2005	80-85	1500	Gujarat	Resistant to bacterial leaf blight, root rot and *Alterneria* leaf spot
HG 563	2004	85-90	1200-1300	Haryana	-
RGC 1017	2001	95-100	1000-1400	All India	-
RGC 1002	1999	100-105	800-1200	Arid zone	Bold seeded
RGC 986	1999	110-115	1000-1200	Rajasthan	-
RGC 1003	1999	90-95	1000-1100	All India	Branched, early
Bundel Guar 3	1999	115-120	1200-1350	All India	Dual purpose
HG 365	1998	90-95	1500-1600	Haryana	-
Bundel Guar 2	1995	115-120	1200-1350	All India	Dual purpose
Bundel Guar 1	1993	115-120	1200-1300	All India	Dual purpose
RGC 936	1991	85-90	900-1000	All India	Suitable for dry region
GG 1	1991	91-122	1000-1300	Gujarat	Resistant to bacterial leaf blight and *Alterneria* leaf spot
RGC 197	1988	110-115	1000-1200	Rajasthan	Unbranched
RGC 471	1987	110-115	1200-1400	Rajasthan	-
Naveen	1987	90-95	1400-1500	All India	-
HG 258	1987	115-120	1400-1500	All India	-
Maru Guar	1986	105-110	1000-1200	Rajasthan	Drought resistant

Variety	Year of release	Duration	Yield (kg ha^{-1})	Area	Features
HG 119	1982	130-135	1600-1900	North India	Dual purpose, drought tolerant
AG 112	1981	90-95	1200-1500	All India	-
HG 75	1981	110-115	1200-1400	All India	Resistant to bacterial leaf blight
HG 182	1981	115-120	1300-1400	Haryana	-
Durgapura Safed	1980	105	1200-1500	Rajasthan	Susceptible to bacterial leaf blight and *Alterneria* leaf spot
Agaita Guara 111	1978	110-111	3000	Punjab, Haryana, UP & Rajasthan	Dwarf, susceptible to bacterial leaf blight and *Alterneria* leaf spot
FS 277	1974	100-105	800-1200	Haryana	Unbranched
Guara 80	1973	125-160	1500	North-western India	Branched and late type

Important varieties in seed production

RGC 936

This dwarf, early maturing (80-90 days), branched, high yielding variety tolerant to bacterial blight was released in 1991 for drought prone areas of the whole country. The pubescent and bushy plants (Fig. 8) bear white flowers and whitish, pubescent leaves with serrated margins. Seeds are pinkish in colour with 100 seed weight of 2.9-3.1 g. Seeds have about 29.2-30.15% gum and 28.05% protein content. This variety is photo-thermo-insensitive and suitable for cultivation in both summer and *kharif* seasons. The seed yield potential ranges between 10-12 q ha^{-1}.

Fig. 8. RGC 936

RGC 1055 (Guar Uday)

This variety notified in 2007 is suitable for cultivation on coarse textured soils of arid and semi arid regions of Rajasthan. Profusely branched (Fig. 9) pubescent plants with deeply serrated leaves attain a height of 60-75cm and bear light pink flowers. This medium duration variety matures in 96-106 days, in synchronized manner. Pods of 5.25-5.95 cm length have deep constriction in between the seeds. Round and medium bold (3.17 g/100 seed) seeds are light grey in colour. Depending upon input management, the yield

Fig. 9. RGC 1055

potential ranges between 10.96-28.81 q ha^{-1}. The endosperm proportion of seed ranges from 35.30-37.23%, with gum proportion between 28.80-30.65% and viscosity profile in the range of 2152-4566 mpas. The carbohydrate and protein content of seed is 36.33- 37.50% and 28.90-29.12% respectively. This photo-thermo-insensitive variety growing well in both *kharif* and summer seasons is also tolerant to bacterial blight and root rot diseases.

RGC 1066 (Guar Lathi)

Released in 2007, this unbranched single stem variety (Fig. 10) is suitable for intercropping and mixed cropping in coarse textured soils of arid and semi-arid Rajasthan. It bears pink flowers about 35-37 days after sowing. Leaves are broad, pubescent with smooth margins. Pods are long (5.50-6.35 cm), pubescent with deep constriction in between the seeds. Seeds are light pink in colour, round and bold (3.38-3.65 g/100 seeds). It matures synchronously in 97 days. This variety has seed yield potential ranging from 10.32-14.51 q ha^{-1}. Seeds have high gum (31.32%) and protein (30%) content while carbohydrate content (33.70%) is less. This variety has medium viscosity profile of 3660 mpas. This photo-thermo-insensitive variety resistant to bacterial blight, root rot and aphid infestation is cultivated in both *kharif* and summer seasons.

Fig. 10. RGC 1066

RGC 1038 (Rajasthan Guar)

High in fodder and seed yield, this variety was released in 2009. Plants bearing pink flowers are pubescent, branched (Fig. 11), medium tall (60-75 cm) having leaves with serrated margins. Seeds are dark gray in colour, round with seed index ranging between 2.95-3.6 g. Depending upon climate this variety flowers in 30-42 days and takes 95-105 days to mature. The variety has grain yield potential ranging from 10.71-29.85 q ha^{-1}. Seeds have high gum (30.79-32.60%), protein (29.64-30.87%) and carbohydrate (36.30-37.40%) content.

Fig. 11. RGC 1038

RGC 1033

This branched (Fig. 12), pubescent variety notified in 2011 for rainfed conditions of Rajasthan bearing pink flowers has medium maturity (95-106 days). Pubescent leaves are dark and shiny with smooth margins. The round seeds are white in colour having 3.07 g/100 seed weight. The yield potential ranges from 15.0-25.0 q ha^{-1} while the gum content varies from 29.9-31.5%. This variety has high degree of resistance to major diseases and insect pests.

Fig. 12. RGC 1033

HG 2-20

Released in 2010 this variety is recommended for cultivation in the states of Uttar Pradesh, Haryana, Gujarat and Rajasthan under timely sowning, normal fertility and rainfed conditions. Branched (Fig. 13), pubescent 70 cm tall plants bear leaves with serrated margins. Early flowering plants take about 100 days for maturity. Average yield is about 10.61 q ha^{-1}.

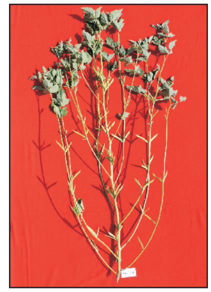

Fig. 13. HG 2-20

HG 884

This variety released in 2010 is recommended for cultivation in Uttar Pradesh, Madhya Pradesh, Haryana, Gujarat and Rajasthan under timely sowing, normal fertility and rainfed conditions. Plants ranging in height from 70-80 cm bear pubescent leaves with serrated margins and pink flowers. Medium duration, branched (Fig. 14) variety taking about 110 days to mature has a yield potential of approximately 10.45 q ha^{-1}.

Fig. 14. HG 884

HG 365

This pubescent, branched (Fig. 15) and short stature, lodging resistant variety was released in 1998 for early as well as late sown conditions. It bears pink flowers and serrated leaves. Medium bold and grey seeds have high gum content. With an average yield 10 q ha^{-1} it matures in 90-95 days.

Fig. 15. HG 365

HG 563

This variety released in 2004 for Haryana and Rajasthan, maturing in 85-100 days has an average seed yield of 12-13 q ha^{-1}. The pubescent plants having brisk podding behavior are 60-100 cm tall. The flowers are light pink in colour and leaf margins are smooth. The length of the pod is 5-7 cm. Gum content in seed is approximately 33%.

Fig. 16. HG 563

Production technology

Areas of cultivation

Guar is cultivated during warmer seasons covering many soil types ranging from heavy to light textured sandy soils in hot arid and semi-arid regions. However, well-drained, fertile, medium-textured, sandy loam soils with good structure are most suitable. Heavy continuous rains and water logged conditions cause damage to the crop. Stagnant water or high moisture renders the crop vulnerable to various microbes and pathogens causing rotting. Guar may tolerate and remain productive under soil salinity to some extent. Being a deep rooted leguminous crop it has added advantage for its survival and improves health of marginal lands. The root nodules directly make available the atmospheric nitrogen and also help in solubilization of other minerals with the help of associated rhizospheric bacteria. Earlier guar used to be grown on marginal lands only and got least priority but now farmers are growing it in their fields regularly (Fig. 17). Land preparation and fertilizer use is minimal. However, production technology to enhance its productivity is well worked out (Table 3) and is followed frequently in view of enhanced interest in this crop. The suitable areas of cultivation are Rajasthan, Haryana, Gujarat, Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Maharashtra, Karnataka and Andhra Pradesh.

Fig. 17. Guar crop at farmer's field

Sowing time

Guar germinates and grows well at temperatures above 25°C but lower night temperatures tend to delay germination. Good germination and stand is expected when temperatures are around 30°C. Summer sowing is appropriate during February last week to March first week in north India with assured irrigation. *Kharif* sowing is done during June last week to second week of August depending on receiving of sufficient rains and temperatures falling below 35°C so as to increase seedling survival. In the southern states of Karnataka, Andhra Pradesh and coastal areas of Gujarat where winter temperatures are not low, summer crop gives excellent results in terms of yield and quality as weather associated risks are very low and irrigation is under control. Dry and sunny weather during summer is good for growth as disease and insect pests remain under control. However, frequency of irrigation increases after 15th May with increased heat waves in northern India.

Land preparation

Field should be well prepared for good germination. It should be fine textured, free from weeds and without too many clods. There is no need of preparing an extremely fine field. The first ploughing should be done with soil turning plough or disc harrow so that at least 20-25 cm deep soil may become loose. It should be followed by one or two cross harrowing or ploughings. The ploughing should be followed by planking so that soil is well pulverized and leveled. Properly leveled field is required for good drainage.

Seed treatment

Seeds should be treated with either Trichoderma (4 g kg^{-1} of seed) or Bavistin (2 g kg^{-1} of seed) followed by Chloropyriphos (2 ml kg^{-1} of seed) before sowing. The seed should be first treated with fungicide, followed by insecticide and *Rhizobium* culture. In order to increase nitrogen fixation and solubilization of phosphorus, seed treatment with *Rhizobium* + Phosphorus solublizing bacteria (PSB) culture is desirable to increase the yield. Seed should be inoculated with suitable *Rhizobium* culture (600 g/15 kg of seed). *Rhizobium* culture should be mixed with a solution of jaggery, prepared by mixing 250 g jaggery in one liter of water. After having uniform coating of slurry over the seeds, it should be dried for 30 minutes in the shade. Dried seeds should be sown within 24 hours of inoculation.

Sowing method and seed rate

Majority of farmers follow the broadcast method of sowing. But to ensure uniform germination, to maintain optimum plant population and easy inter-cultivation operations, sowing should be done in rows. Cluster bean should be sown with 45-50 cm row to row and 15-20 cm plant to plant spacing. However, reduced row to row distance (30 cm) is recommended for single stem varieties like RGC 1066. To achieve optimum plant density 12-15 kg ha^{-1} seed is required for sowing. Sowing can be done with the help of seed drill or cultivator.

Manure and fertilizers

Cluster bean being a leguminous crop, needs a small quantity of nitrogen as a starter dose during early growth period. Application of nitrogen (20 kg ha^{-1}), phosphorus (40 kg ha^{-1}) and gypsum (150 kg ha^{-1}) is recommended for traditional guar growing areas. Well decomposed farm yard manure (FYM, 2.5 t ha^{-1}) can fulfil the 50% nutrient requirement of guar and would improve soil structure. Guar is prone to termite attack and raw dung in undecomposed FYM may increase the incidence of termite attack. The zinc deficient soils usually require soil application of zinc sulphate (20 kg ha^{-1}). Full dose of nitrogen and phosphorus should be applied at the time of sowing and fertilizer should be placed at least 5 cm below the seed.

Irrigation

Usually cluster bean is grown as rainfed crop in arid and semi-arid conditions. The irrigation should, however, be provided whenever the crop suffers from moisture stress. If irrigation facilities are available then life saving irrigation can be given particularly at the time of flowering and seed filling. Since crop usually suffers from moisture stress in arid region, it is recommended to use water management practices like bunding of the field and mulching with plant residues (3-5 t ha^{-1}) for avoiding moisture loss due to evaporation and conserving moisture in the soil. Spray of 0.1% Thiourea solution at 25 and 45 days after sowing (DAS) also improves the yield of cluster bean during conditions of moisture stress.

For summer cultivation, adequate moisture is required for good crop growth. Crop should be sown after applying pre-sowing irrigation. If crop does not germinate properly, a light irrigation can be given 6-7 DAS. At least 5 irrigations should be given after germination of the crop at regular intervals of 15 days each. Water should not be allowed to stand in the field at any stage of growth. Irrigation at seed setting time improves the seed yield. Water requirement in southern states could be much lesser depending on the temperatures and sun shine; 3-5 irrigations may give good produce in these regions.

Weed control

Cluster bean grown during summer or *kharif* season suffers severely due to grassy, broad leaved and sedge weeds. Severe competition between the crop and weeds for moisture, nutrients and space drastically reduce the yield. Therefore, the crop should be weed free at least for initial 30-35 DAS. Generally manual weeding is very effective for controlling all type of weeds. Two manual weedings given at 25 and 45 DAS are sufficient to keep the crop weed free. However, sometimes due to non-availability of labour, herbicides like Pendimethalin (2.5-3.30 l ha^{-1}) can be applied by mixing with 500 litres of water as pre-emergence application within 2 days of sowing. After that one manual weeding at 30 DAS or post emergence application of Imazythypro (400 g ha^{-1} mixed with 500 liter water) can be applied 20-25 days after sowing.

Insect pests and their management

Cluster bean is infested with more than 40 species of insect pests in the field, of which jassids, white flies, aphids and termites are the major ones in traditional guar producing areas. These pests cause damage from sowing to maturity.

Termite: Termite is a polyphagous widely distributed soil borne insect that damage the crop in light textured soils of western Rajasthan. They feed on roots and stem of growing plants, and even on dead tissues of plants. As a result of termite attack, wilting (Fig. 18A) and drying can occur at all stages of crop growth and ultimately plants may succumb. Some important control measures for termite are:

Fig. 18A. Termite attack

- Locating the termitorium, digging out the queen and destroying it is the only permanent remedy.
- Seed treatment with Chlorpyriphos 20 EC (4.0 ml kg^{-1} seed) or Imidacloprid 600 FS (5.0 ml kg^{-1} seed).
- Destruction of crop residues which form sources of infestation.
- Soil application of Chlorpyriphos 20 EC (4.0 l ha^{-1}) with irrigation in termite infested crops.

Jassids, aphids and whiteflies: Sucking pests viz., jassids, aphids and whiteflies are found on the underside of tender leaves causing leaves to crinkle and curl. Both nymphs and adults suck sap from tender leaves and shoots (Fig. 18B) causing leaf curling and stunted growth. Flowers and pods are also affected. Excretion of honey dew leads to sooty mould which interferes with the photosynthetic activity of plants.

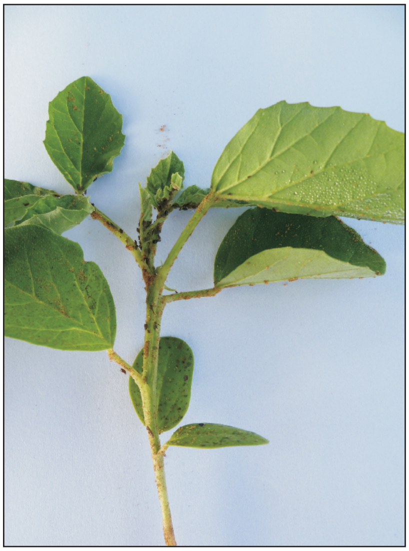

Fig. 18B. Aphid infested plant

These pests can be managed by adopting the following practices-

- Keeping the fields weed free.
- Seed treatment with Imidacloprid 600 FS (5.0 ml kg^{-1} seed) .
- Application of Imidachlorprid, Rogor, Monocrotophos or Melathion (1.5 to 2 ml l^{-1} of water).
- Foliar application of Thiamethoxam 25 WG (0.3 g l^{-1} of water) for aphids, Triazophos 40 EC (1.0 ml l^{-1} of water) for whiteflies and Monocrotophos 36 SL (1.0 ml l^{-1} of water; not used for vegetable guar) is effective to manage these pests.
- Keeping yellow empty tins smeared with grease as trap in white fly endemic areas. Trapped whiteflies should be wiped out every day and grease must be applied again.

Gall fly: Although not a major pest, but gall fly (Fig. 19) is showing its presence for the last 2-3 years in Jodhpur region and control measures are required to contain its spread.

Fig. 19. Gall fly infested pods of cluster bean

Disease Management

A number of fungal and bacterial diseases are known to affect guar. However, conscious selection against diseases has brought down the incidence of most diseases and incorporated disease resistance subsequently.

Bacterial blight: Bacterial blight is caused by *Xanthomonas cyamopsidis*. The disease infestation mostly occurs during *kharif* season on leaf surface. The spots of the disease are intraveinal, round and well defined on the dorsal surface of the leaf. The pathogen invades vascular tissues and cause flaccidity of the affected portion. The flaccid spots become necrotic and turn brown. The infection advances to petiole and stem, resulting in blackening and cracking of stem (Fig. 20). Resistant varieties and certified seed should be used for sowing purpose. Seed treatment with Streptocycline (250 ppm solution) for 90 minutes and spraying the crop with a mixture of zinc sulphate (0.25%) + Azadiractin (1.5 ml l^{-1} water) twice starting from onset of disease at an interval of 15 days can effectively control the disease. Spray of Streptocycline (0.1-0.25 g l^{-1}; 500-700 litre water for one hectare) can be done on the appearance of bacterial disease during standing crop.

Fig. 20. Bacterial blight infested plant

Fig. 21. *Alternaria* leaf spot

***Alternaria* leaf spot:** This fungal disease is caused by *Alternaria cyamopsidis*. The symptoms of the disease appear mainly on the leaf blade as dark brown, round to irregular spots varying from 2-10 mm in diameter (Fig. 21). The water soaked spots turn grayish to dark brown with light brown lines inside the spots. Spray of Dithane Z 78 (0.2%) should be done at least twice at an interval of 15 days.

Anthracnose: This fungal disease is caused by *Colletotrichum capsici* f. *cyamopsicola*. The symptoms of the disease appear on the leaves, petiole and stem in the shape of black spots. Spray of Diathane Z-78 (0.2%) can be used for controlling this disease.

Powdery mildew: This disease is caused by the fungus *Erysiphe polygoni*. The symptoms of the disease start with white powdery growth over the leaf surface. This white growth consists of the fungus mycelia and its spores. The disease can be controlled by spray of wettable sulphur like Suffex (2-3 kg ha^{-1}) or dusting of sulphur powder (20-25 kg ha^{-1}) or with spray of Kerathane (1.5 ml $litre^{-1}$ water). Spraying Carbendazim (Bavistin, 0.1%, 300 g ha^{-1}) or Thiophanate methyl (0.1%) twice at 10 days interval soon after noticing the disease will control it. Fungicides like Mencozeb (Dithane M-45, 35 g/15 litre water), Dinocap (Kerathane, 0.05-0.1%), Benomyl (0.2%), Tridemorph (Calixin, 0.05-0.1%) and streptocycline (3 g/15 litre water) can also be used.

Fig. 22. Root rot infested cluster bean plants

Wilt/Root rot: Seed treatment with Moncern (3 ml kg^{-1}) + Carbandazim (Bavistin, 2 g kg^{-1}) + soil application of *Trichoderma harzianum* (1.5 kg ha^{-1}) will help reduce the incidence of this fungal disease (Fig. 22). In case of continued problem during crop growth, spray of any of these fungicides can be undertaken - Blitox/Blue copper (20 g $litre^{-1}$ water), Mancozeb (Dithane M-45, 1.5-2.0 kg ha^{-1}, 0.15-0.2% spray) or Bavistin (0.1%). About 500-700 litre water is required to spray the recommended dose of fungicides in one hectare area.

Harvesting

Crop is harvested by cutting the crop at ground level when 80% pods turn straw coloured. Harvesting is difficult in guar since all the released varieties have pubescence on stem, leaves and pods which cause irritable itching while manual harvesting. Suitable genotypes for mechanical harvesting are not yet available. Single stem tall varieties viz., RGC 1066, FS 277 and *Ageta Guara* 112 may also suffer considerable losses due to mechanical harvesting as bearing in these varieties start from the base of the main stem. Hence, traditional method of uprooting or cutting by sickle is still followed in guar.

Threshing

Threshing can be done either by bullocks or thresher after thorough drying. Weather forecast must be carefully followed during harvesting because crop maturity should not coincide with continuous or cyclonic rains which will affect the seed quality and hence fetch lower prices.

Post-harvest technology

Dried seed should be stored properly in nylon or polythene bags or compactly knitted gunny bags. Moisture content should not be more than 8-10% at the time of packing and storing the seeds.

Table 3. Improved production techniques for maximization of yield in cluster bean

S.No	Requirements	Description
1.	Climate	Arid and semi-arid tropical climate. Temperature during sowing to be about 30-35°C. It can tolerate up to 45°C; rainfed crop.
2.	Soil type	Well drained, medium to light soils (pH 7.0-8.5)
3.	Sowing time	15th June - 1st week of August (*kharif*); last week of February to 1st week of March (summer)
4.	Field preparation	2-3 ploughings
5.	Fertilizer	15-20 kg N and 30-40 kg P_2O_5 per ha; 2 t ha^{-1} farm yard manure (FYM) if available + 50% RDF. In Zn deficient soils apply 20 kg $ZnSo_4$ ha^{-1}
6.	Seed source	Breeder seed – authorized seed producing institutions/centres Foundation/certified seed – National Seed Corporation, State Seed Corporation, SAUs, ICAR Institutions (CAZRI), seed companies and seed grower/farmers.
7.	Popular varieties	RGC 936, RGC 986, RGC 1002, RGC 1003, RGC 1017, RGC 1033, RGC 1038, RGC 1055, RGC 1066, RGM 112, HG 365, HGS 563, HG 870, HG 884, HG 2-20, GG 1, GG 2
8.	Isolation	3-5 meter for large scale cultivation
9.	Seed rate	12-15 kg ha^{-1}
10.	Seed treatment	With *Rhizobium* and phosphorus solublizing bacteria (PSB); Bavistin (2 g kg^{-1} seed), Thiram (3.0 g kg^{-1} seed), or Captan (2.5 g kg^{-1} seed)
11.	Spacing	45-50 x 15-20 cm (branched); 30 x 15-20 cm (unbranched)
12.	Sowing	By seed drill to maintain plant population and easy inter-cultural operations
13.	Irrigation	*Kharif* - rainfed or 1-2 supplemental irrigations at pod filling stage during drought conditions (if required). Summer - 5-8 irrigations in addition to pre-sowing irrigation During drought conditions wider row spacing, spray of 0.05% Thiourea solution at flowering

S.No	Requirements	Description
14.	Weed management	1^{st} weeding at 20-25 days after sowing (DAS) and II^{nd} at 20 days after the 1^{st} weeding, or pre-emergence application of Pendimethalin (0.75-1.0 kg ha^{-1}) with hand weeding at 35-40 DAS
15.	Pest management	Spray of Malathion 50 EC (0.05%) or Monochrotophos WSC (0.15- 0.2%) to control aphids, pod borer, leaf hopper and other sucking pests
16.	Disease management	Spray Mancozeb or Captafol (1.5 kg ha^{-1}) at 45-50 DAS to control *Alternaria* leaf spot. Seed treatment with Vitavax (2 g kg^{-1}), Bavistin (2 g kg^{-1}) and *Trichoderma* (4 g kg^{-1}) to control root rot complex
17.	Rouging	Remove off types, diseased and other crop/variety plants at vegetative and flowering stage to maintain purity
18.	Harvesting	At proper maturity stage
19.	Threshing	Thresher or manual
20.	Seed yield	7-8 q ha^{-1} (*kharif*) and 10-12 q ha^{-1} (summer)

Cost of cultivation

Guar seed production fluctuates with rainfall as the crop is grown under rainfed conditions in hot arid regions. As the price increased during 2011-12 and 2012-13 it was also grown in summer under irrigation. Guar is an economical crop with low cost of cultivation as it require minimum fertilizers, insecticides and irrigation. The cost of cultivation comes to around Rs. 15,000-20,000 per ha and production is 5-6 q ha^{-1}. The market price fluctuates between Rs 5,000-6,000 per quintal in a normal year, therefore, the net return from guar cultivation comes to around Rs. 10,000-16000 per ha under rainfed conditions.

Quality seed production

Cluster bean is a composite crop therefore farmers can produce quality seeds easily at their own field by following the proper package of practices. Selection of the field for seed production is very important. It should be ensured that cluster bean cultivation was not undertaken during the previous year in the field selected for seed production during the current year. The field should be leveled, clean, clod free with fine soil. There should not be any cluster bean field up to 10 meters surrounding the field selected for seed production. Quality of seed taken for sowing is equally important to get genetically pure seeds. Therefore, seed (breeder/foundation /certified) should be sourced from authorized agencies. Seed should be sown at proper time following the standard practices. Proper roughing of the field should be ensured so that there are no off types, weeds and disease infested plants in the field. Harvesting of the crop should be done at proper maturity stage leaving 5-10 meter area surrounding the field. After harvesting, crop should be dried properly, threshed separately and the seed should be properly cleaned, graded and dried. Moisture percentage in the seed should not be more than 8-10%. After treatment with some fungicide like Bavistin, seed should be stored in the seed bins. Farmers can use this seed for sowing purpose during the next year.

Seed requirement in India

The seed demand of different varieties of cluster bean has increased many fold over the years. There are more than 15 varieties in the seed production chain in different states. Some of the old varieties are still in the seed production chain because of their demand at farmer's level and also low variety replacement rate (VRR). New varieties are bred by the researchers for increased production, tolerance to diseases, erect and single stem types, but due to non-availability of quality seed and poor extension mechanisms, these varieties are not reaching to the farmer's field. The availability of the certified seed is only 15-20% of the total requirement as per the area under cultivation. Most of the seed demand is met from the seeds saved by farmers. In the seed production chain, breeder seed of a particular variety is produced by the concerned ICAR Institutes/SAUs who have released/developed the variety. If there is shortfall of the breeder seed then the responsibility is given to other institutions also. Foundation and certified seeds are mainly produced by the National Seed Corporation (NSC), State Seed Corporations, SAUs, seed companies and registered seed growers. Breeder seed is produced in requisite quantity for multiplication as per indent from different seed growing agencies. If all the breeder seed produced and allotted to different seed growing public and private sectors are multiplied with 1:30 multiplication ratio, the seed replacement rate (SRR) can be achieved up to 50% in guar. But on the basis of previous production data of breeder, foundation and certified seed only 8-10% seed is converted into other categories. Therefore, SRR remains very low and seed demand is mainly met from the seeds saved by farmers in addition to the quality seeds produced by the seed growers, SAUs, ICAR-CAZRI and some private seed companies.

The area under cultivation has increased from 3.4 m ha (2000-01) to 5.6 m ha (2013-14) and it is expected that it will increase further as the demand for cluster bean gum is increasing in the international market. The projected requirement of different category seeds with 10, 25 and 100% SRR was estimated with 10% increment in cultivation area every year (Table 4). Therefore, there is an urgent need to give more emphasis on seed production, quality control, distribution, VRR, SRR and HRD so that the benefit of research may go to the farmers and other clients in the guar industry. Each seed producing agency should be linked to national seed network.

The rolling plan of seed production from breeder seed to certified seed is presented in Table 5. As per DAC report, total breeder seed production was 257 q during kharif 2015. If all the breeder seed is multiplied with 1:30 multiplication ratio, 231300 quintal certified seed will be produced

Table 4. Requirement of different category of seeds in India (in million tons)

Year	Area (m ha)	10% SRR			25% SRR			100% SRR		
		CS	FS	BS	CS	FS	BS	CS	FS	BS
2014-15	4.368	6.55	0.22	0.0072	16.38	0.54	0.018	65.52	2.18	0.073
2015-16	4.805	7.21	0.24	0.0080	18.02	0.60	0.020	72.07	2.40	0.080
2016-17	5.285	7.92	0.26	0.0088	19.80	0.66	0.022	79.27	2.64	0.088
2017-18	5.814	8.72	0.29	0.0096	21.80	0.73	0.024	87.21	2.91	0.097
2018-19	6.395	9.59	0.32	0.0110	23.98	0.80	0.027	95.92	3.19	0.106
2019-20	7.035	10.55	0.35	0.0120	26.38	0.88	0.029	105.52	3.52	0.117

CS - Certified seed; FS - Foundation seed and BS - Breeder seed
(Seed rate 15 kg ha^{-1}; multiplication ratio 1:30)

which will be covering only 1.54 m ha, and 30% seed replacement rate (SRR) will be achieved. Similarly, during 2016 breeder seed indent is 268.89 q and after multiplication 242001 q certified seed will be produced covering 1.61 m ha with SRR of 30%. SRR more than 50% can be achieved by multiplying the F1 foundation to F2 foundation category and/or C1 certified to C2 certified category.

Table 5. Seed multiplication programme during the years 2015 and 2016

Year	Breeder seed (q)	Foundation seed (q)	Certified seed (q)	Area (M ha)
2015	257.00	7710.00	231300.00	1.54
2016	268.89	8066.70	242001.00	1.61

(Seed rate 15 kg ha^{-1}, multiplication ratio 1:30)

Crop rotation and intercropping

In the rainfed conditions of Rajasthan, cluster bean is traditionally grown as a mixed crop with pearl millet, mung bean, moth bean and sesame. But with the increase in its demand it is also grown as sole crop. It fits well in different cropping systems and crop rotations involving cereals. It is mainly mix cropped and rotated with bajra in its major growing area. In the rain fed areas it is successfully intercropped with pearl millet in 2:1 row ratio (Fig. 23). This system is quite profitable as compared to sole cropping of pearl millet. Cluster bean is mostly used as a rotational crop with pearl millet under rainfed conditions to improve the soil health and nutrient status of the soil which is useful for the next growing cereal crop. Following crop rotations are recommended:

Cluster bean- pearl millet (two year rotation in rainfed condition)

Cluster bean-wheat (one year rotation)

Cluster bean-cumin (one year rotation)

Cluster bean-wheat- cluster bean-cumin (two year rotation)

Cluster bean-wheat-mung bean-mustard (two year rotation)

Cluster bean-cumin-pearl millet-mustard (two year rotation)

Cluster bean-wheat-pearl millet-cumin (two year rotation)

Fig. 23. Cluster bean-pearl millet (2:1 ratio) inter cropping system

Contingency plan

In traditional areas guar is grown on marginal lands as rainfed crop without substantial inputs of fertilizers and irrigation. Its production would largely depend on amount and distribution of precipitation received during the growing period. In hot arid regions it is very likely that frequent drought spells would be experienced by the crop. In order to minimize the damage and yield loss following management strategies have been devised:

- Early varieties should be grown.
- Wider row spacing (50 cm) will be more beneficial for better utilization of available moisture and nutrients.
- If water scarcity is experienced during crop growth every third row can be removed to reduce competition for water improving survival of left over plants.
- Spray of 0.05% Thiourea solution on standing crop to improve survival of plants.

Nutritional composition of guar seeds

Chemical composition of cluster bean seed is quite variable viz., crude protein (28.3-35.0%), ash (3.5-6.0%), fat (1.8-5.2%), carbohydrate (38.8-59.1%), crude fibre (4.1-8.0) and gum (23.9-34.2%), as reported by Pathak *et a*l. (2011). Ahmed *et al*. (2006) observed lower values for carbohydrate (23.7%) and higher values for crude fibre (9.3%) and also estimated certain anti-nutrient factors including polyphenols (25 mg/100 g), tannins (1750 mg/100g) and phytic acid (540 mg/100g) in cluster bean seed. Kaushal and Bhatia (1982) reported the presence of several toxic compounds in cluster bean seeds including gallotannins, gallic acid and its derivatives, myricetin-7-glucoside-3-glycoside, kaempferol-7-glucoside-3-glycoside, kaempferol-3-rutinoside, kaempferol-3-glucoside, chlorogenic acid, caffeic acid and ellagic acid. Mehta and Ramakrishnan (1957) reported 4.2% oil, whereas Shinde and Bhargava (1968) reported higher value of oil content (9.8%) in cluster bean. Variability in oil content (3.06-7.5%) was also reported by Joshi *et al.* (1990). Linoleic acid (38.85%), palmitic acid (24.97%) and oleic acid (23.59) were the major fatty acids reported in guar seed (Arora *et al*., 1985). Joshi *et al*. (1981) observed higher linoleic acid content (55.1%) in cluster bean seed oil. The percentage of unsaturated and saturated fatty acids was 69.38% and 30.52% respectively (Arora *et al*., 1985). Fatty acid composition of cluster bean seed oil is reported to be similar to common edible oils (Singh and Mishra, 1981).

Guar seed consists of hull (14-17%), endosperm (25-42%) and germ (43-47%) (Fig. 24). Its seed is rich in lipids, protein and minerals. Germ portion of cluster bean seed is highly proteinaceous in nature (55.3%) with good fibre content (18%), and D-glucose which is the major carbohydrate in the germ. Crude fiber content is highest (35%) in hull. A considerable amount of carbohydrates (78-82%) is present in the endosperm in the form of galactomannan (Das and Arora, 1978). D-galactose

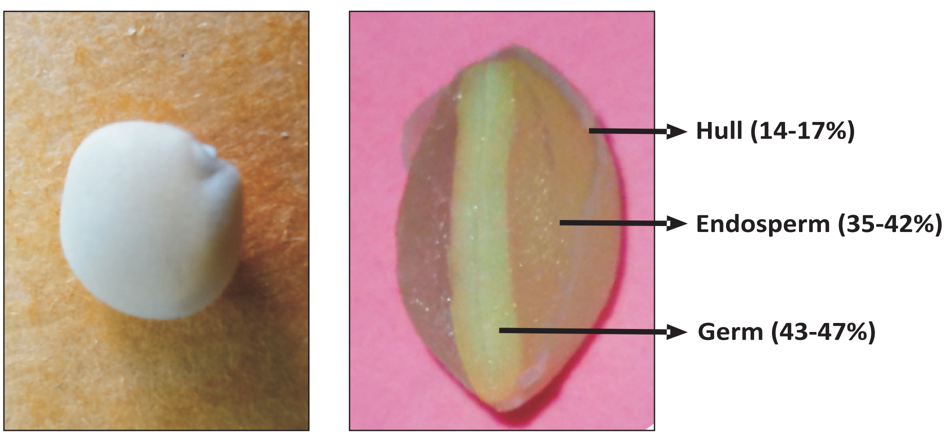

Fig. 24. Guar seed and its Components

anhydride (36.6%) and mannose anhydride (63.1%) make up a unit of galactomannan (Das *et al*., 2000). But, Sabahelkheir *et al*. (2012) reported higher mannose (67-73%) and lower galactose content (28-33%) with a total carbohydrate content of 83.3-87.5%. Joshi and Arora (1993) reported that the gum possesses considerable fractions of Zn (5.6 ppm) and Cu (2.5 ppm) along with protein (5.0%). The cluster bean gum lacks uronic acid that is usually present in gums of other plant species, differentiating itself from other crops (Tripathy and Das, 2013).

Guar gum

Guar gum extracted from the endosperm of guar seed has variable industrial applications ranging from food industry to shale owing to its viscous gummy nature. This gummy nature is imparted by long chains of mannose and galactose capable of absorbing water up to 20 times its own weight. Guar gum consists of long, straight chains of α-D-mannopyranosyl units linked together by β-D (1→4) glycosidic linkage. α-D-galactopyranose, is a hexose which forms the side groups by α (1→6) glycosidic bonds, appearing on both sides of approximately every alternate mannose on the main chain (Stephen, 1983). The ratio of mannose to galactose in galactomannan of cluster bean gum is approximately 2:1 (Englyst and Cummings, 1988; Robinson *et al*., 1982) (Fig. 25). Determination of its molecular weight is difficult and its range is estimated to be between 200-300 kilodaltons (Glicksman, 1969). Galactomannan acts as a good water absorber due to binding of water molecules in the active sites of D-galactopyranose and D-mannopyranose. Ability to form viscous dispersions or solutions in water is the most important characteristic of cluster bean gum powder. Viscosity of the guar gum powder varies with its particle size. Fine powder produces a solution of higher viscosity. For example, if particle size is 200 mesh then viscosity is 4000-6000 cps

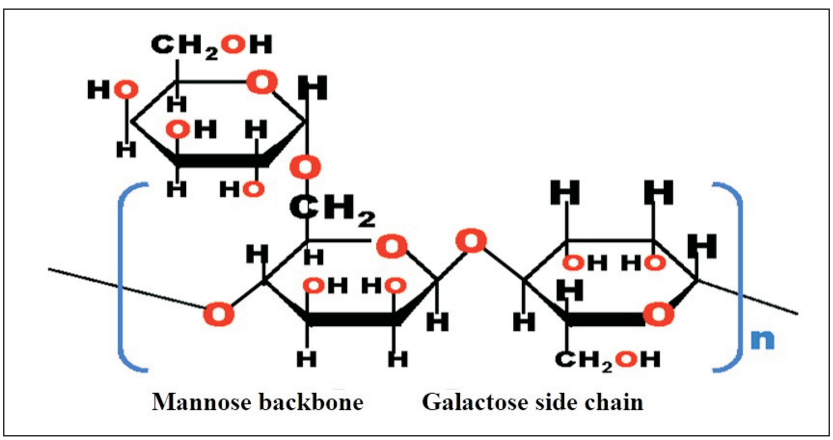

Fig. 25. Structure of guar gum (galactomannan)

and if size is more (80 mesh) then viscosity is less than 3000 cps. Viscosity varies with moisture content of the guar gum at the time of grinding while it is not much affected by pH. Peak viscocity is observed in the pH range of 7.0-9.0 while its stability range is between pH 4.0-10.5 (Chudzikowski, 1971). It has also been reported that cluster bean gum solutions are resistant to electrolytes. Guar gum solutions are not affected by hard water and have the ability to tolerate huge quantities of electrolytes that would “salt-out” most other gums (Chudzikowski, 1971). Guar gum lacks self gelling property in water as it needs addition of a small amount of sodium borate solution for the formation of a gel.

Industrial processing

In industrial process, cleaned guar seeds are graded into two to three sizes using cylindrical grader and then milled to split them into two halves. The splits are then passed through a germ separator, where germ is removed from the splits. The splits are then heated in a kiln where change in surface colour of splits occurs due to conduction. After heating, the hot splits are dehulled to separate split and germ. The cooled splits are separated using air screen cleaner after dehulling where broken germ and hull are separated and cleaned guar gum splits are collected and packaged. During dehulling process, around 18-25% endosperms are converted into powder or broken and get mixed with hull. The broken endosperm and powdered hull is used as cattle feed.

The splits are eventually ground to fine powder of different particle sizes depending upon their uses. Attrition mills, hammer mills or ultra-fine grinders are used in the industry for this purpose. The moisture content of guar gum splits is usually adjusted to 10% (wet basis) after grinding. Wet grinding of the splits is also done to get specialized products. The final product is dried and reground to produce desired particle size. Precipitation and recovery of water dissolved guar gum with ethanol or isopropanol may produce further purified and clarified gum containing higher levels of galactomannans. The gum powder is a white to yellowish white, odour and tasteless (Fig. 26) powder. The gum is soluble in cold water and form a highly viscous solution but is insoluble in organic solvents.

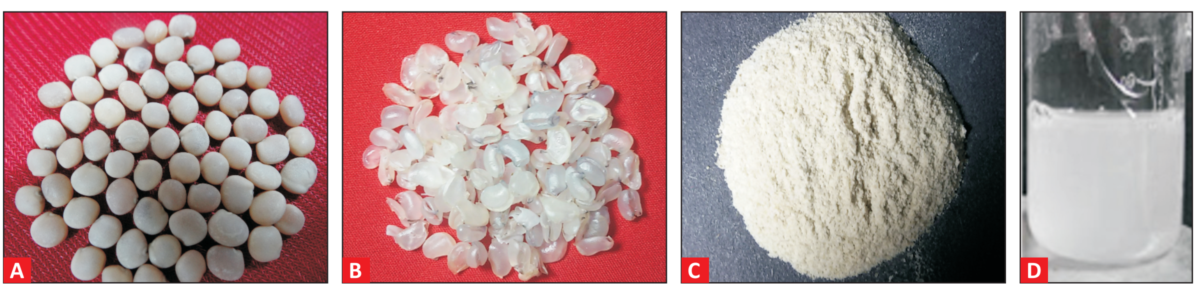

Fig. 26. Guar (A) seeds, (B) guar gum splits, (C) guar gum powder and (D) gel

Guar meal

After extraction of guar gum from endosperm, the remaining part termed as guar meal consists of churi (powder) and korma (granular) which are germ and hull accounting for 29 and 37% respectively (Sharma and Gummagolmath, 2012). It is a relatively inexpensive high protein meal produced as a by-product of guar gum industry. The protein content of guar meal ranges between 33-45% depending on processing, contamination and impurities (Srivastava, 2011; Conner, 2002; Nagpal *et a*l., 1971). The presence of anti-nutritional factors, toxic, bitter and foul smelling compounds in the meal affects the palatability and makes it unsuitable for direct animal feeding. Although guar meal is the cheapest source of protein, but it should not exceed 25% of the cattle ration (Gohl, 1982). Guar meal is comparable to soybean meal in terms of nutritional content (Mathur and Mathur, 1989). Guar meal has 50% protein, 6.8% fiber and 5% fat compared to soy meal having 48% protein, 3% fiber and 1% fat. Owing to higher solubility (89%) compared to soybean meal (78%) and balanced amino acid content viz. 3.22% lysine, 0.79% cystine, 1.94% threonine, 3.62% arginine, 3.7% leucine, 0.73% methionine, 0.68% tryptophan, 2.31% isoleucine and 2.35% valine, guar protein is considered to be of better quality (Heo *et al*., 2009).

Commercial applications

The ability of gum to suspend solids, bind water by hydrogen bonding, form viscous aqueous solutions, and form strong tough films are the major reasons which makes it suitable for various industrial applications. Various forms of natural guar gum are manufactured that include, guar splits, guar refined splits, clarified guar gum, gum powder, and treated and pulverized guar gum (textile, printing and thickener). Guar gum powder available in different particle sizes, is further processed to produce various derivatives according to the requirements of end user industries such as textile, petroleum, paper, food and pharmaceuticals. Some of the derivatives of guar gum are: Carboxymethyl guar gum, Hydroxymethyl guar gum, Hydroxypropyl guar gum, O-carboxymethyl-O-hydroxypropyl guar gum (CMHPG), O-2-hydroxy-3-(trimethylammonia propyl) guar gum (HTPG), O-carboyxymethyl-O-2 hydroxy-3-(trimethylammonia propyl) guar gum (CMHTPG), Ammonium hydroxyl propyl trimethyl chloride guar gum, Acryloyloxy guar gum, Methacryloyl guar gum, Methylated guar gum, Sulfated guar gum, guar gum esters and cross linked guar polymer chains (Gupta and Verma, 2014).

Guar gum and its derivatives are used in oil drilling, mining, pharmaceuticals, paper industry, water treatment, cosmetics, medicines and textile industry (Table 6). Guar gum being a naturally derived gum from guar seed has been used for edible purposes in various forms. It is frequently used as natural thickener, emulsifier, stabilizer and bonding /firming agent in various food items and in pharmaceuticals. It is frequently used in food processing industries as a thickener and as a means of preventing ice crystal formation in frozen desserts. Food quality guar gum is sold in the market with certain specifications and are added to bread, cake, bakery and confectionary products, breakfast cereals, jams and jellies, milk products (cheese, ice cream), processed vegetables, frozen foods and vegetable juices, soup and soup mixes, sweet sauces, toppings and syrups, puddings and meat products. As per various reports its global consumption is 5-10% in pharmacy (cosmetics and medicines), 25-30% in food industry (bakery, beverages, dairy, dressing, deserts, ice creams, cheese, sauces, ketchups and pet foods) and 70-75% in other industries (oil drilling, mining, refining, explosives, textile and paper printing, photography, etc). Guar gum and its derivatives are in great demand in the world market. Increased demand for gum has led to escalation in its prices in the international market. However, prices are mainly governed by demand from the oil/gas extraction industry for hydraulic fracturing of subsurface shale. Details of various commercial applications are as follows:

Table 6. Industrial uses of guar gum

S.No	Industry	Uses	Functions
Food processing			
1	Bakery	Bread, cakes, pastries	Better moisture retention, increased shelf life and dough improvement
2	Dairy products	Yoghurts, desserts	Texture retention after sterilization
3	Canned foods	Pet foods, meat, baby foods	Acid resistant thickening and suspending agent
4	Animal feed	Calf milk replacer, veterinary foods and pet foods	Suspending and granulating agent
5	Frozen food	Ice creams, frozen cakes	Water retention, stabilizer, and ice crystal inhibition
6	Instant mixes	Sauces, desserts, beverages	Dispersible, thickening and texturizing agent
7	Meat	Meat products, canned meat products	Lubricant and excellent binder
Pharmacy			
1	Pharmaceuticals	Laxative, slimming aids	Bulking agent and appetite depressant
2		Gastric acidity	Synergistic activity with bismuth salt
3		Diabetic treatment	Reduces glucose loss through urine
4		Cholesterol treatment	Cholesterol reducing aid
5		Vitamin formation preparation	Water soluble suspension

S.No	Industry	Uses	Functions
Cosmetics			
1	Cosmetics	Shampoos and conditioners	Detergent compatible thickener and protective colloid film forming agent
2		Tablets	Disintegrating and granulating agent
3		Ointments	Thickening agent
4		Lotions	Lubricating and suspending agent
Others			
1	Textile printing	Cotton, silk, wool sizing and carpet printing	Reduces wrap breakage and dusting film forming; thickening for dyes
2	Paper	Photographic/wrapping/craft/filter paper	Increases strength, decreases porosity and pulp hydration
3	Mining	Ore concentration and filtration	Flocculating and settling agent
4	Explosives	Stick explosives and blasting slurries	Water proofing and gelling agent
5	Oil well drilling	Drying fluids and hydraulic fracturing	Water loss control, viscosity/ suspension/turbulence and friction reduction
6	Water treatment	Industrial and drinking water	Coagulant aid
7	Photography	Emulsions and gelatine solutions	Gelling and hardening agent
8	Ceramic	Enamels and electroceramics	Fixing, binding and thickening agent
9	Synthetic resins	Polymerization, suspension, and collagen dispersion	Thickening and binding agent

(Adapted from USDA 2014 report)

Status of Indian industry

All the guar seeds produced by farmers go to the industries directly or indirectly through traders. Before 2011, there were only 55-60 units engaged in guar processing in Rajasthan alone but increased demand of guar gum in the international market and higher prices have resulted in establishment of more processing units. In 2012 the price of guar seeds increased to Rs. 3600 per quintal in the market which increased further during 2013-2015 to around Rs. 4000-7500 per quintal. There are a number of guar processing industries mainly in guar growing regions of

Rajasthan (Jodhpur, Bikaner, Ganganagar, Alwar and Jaipur), Haryana (Bhiwani and Sirsa) and Gujarat (Deesa and Ahmedabad). These industries are mainly involved in guar split and guar gum powder manufacture. With more than 600 guar processing units in India, guar gum products (split and powder) dominate the export (Rai, 2015). The processing capacity of India is about 7.0-8.0 lakh MT annually, of which only 4.5-5.0 lakh MT is realized (NIAM, 2013).

Following the demand shift, Indian industries started producing and marketing more of the pulverized gum powder however, about 20% of the exports are still in the form of refined splits (Rai, 2015). Processing of guar seed had a further boost due to ban on export of whole guar seed encouraging industrial development in India. However, a number of factors determine the viability of guar gum industry, for example, area and production (dependent on rains), demand from food industry and associated food safety concerns, demand from petroleum and other industries. Falling natural oil and gas prices adversely affects shale gas and oil production and consequently the guar gum demand and prices. All these factors interact to swing the prices of guar seed and guar gum products destabilizing the gum industry. It has amply been demonstrated in recent years that prices are mainly governed by demand in oil and gas industry where guar gum is an indispensable commodity and will continue to be so till some alternative is worked out.

Guar gum processors procure guar seeds either from village traders or from the farmers in the market (*Mandi*) through commission agents. Stockiest also play an important role in the supply chain because of greater shelf life of guar seed, while at times processors play the role of stockiest. However, lower supply chain remains the same involving direct procurement from farmers or through commission agents or traders. The gum powder manufacturers usually procure guar splits from split manufacturers. However, certain units procure guar seed from the available chain in the market and produce both split and powder. The end product of processing of guar seed, the split or industry specific guar gum powder is mostly exported and part of it is made available to the domestic market.

Area and production of guar fluctuates considerably depending on rainfall pattern and amount during crop growth period. The time of onset of monsoon also affects the area of sowing and further disturbances can hamper the production potential equally. Hence, production figures are more drastically influenced compared to area. This is more so because of little choice of crops available for sowing in the traditional arid region of guar cultivation. The market price of guar, mainly governed by demand and availability of stocked product, also influence the area under the crop. However, market usually has small effect on guar area and production as it is a major crop for cultivation on marginal lands. Nevertheless, highly fluctuating market demand and prices have stopped fast spread of the crop in the non-traditional resource rich regions, despite terrific price rise in the recent years.

To facilitate price risk management and price discovery, future trade on NCDEX platform for guar seed was initiated in April 2004. Subsequently, future contracts have been extended to NCDEX, MCX, NMCE and Bikaner Commodity Exchange platforms for trading. The future contracts of guar seed and guar gum are liquid enough and provide sufficient opportunities to minimize the price risk.

International trade of guar gum and its derivatives

India is the major exporter of guar gum, its derivatives and products, to a large number of countries. Demand of guar gum in the international market has increased because of the growth of shale gas and oil drilling industry world over. It is used as a thickening agent and emulsifier in oil and gas extraction for hydraulic fracturing ("fracking") of subsurface shale. Therefore, the volume and trade of guar gum and its derivatives has increased significantly over the years. Before 2005, guar gum consumption in food industry was around 50% while in oil drilling industry it was only 30% of the total consumption. But with increasing use in shale and oil drilling, the demand from food industry has reduced to around 20% (Rai, 2015). Total export of guar gum and its value in the international market gradually increased from Rs. 1.42 billion in 1994 to Rs. 11.20 billion during 2007 (Henry and Mathur, 2008) which further increased many fold during 2011-12 (Rs. 165.24 billions) and 2012-13 (Rs. 212.87 billions) escalating to the position of highest foreign exchange earner (exported 406.30 thousand MT) among all the agricultural export commodities. The country exported 665.18 thousand MT of guar gum to the world for the worth of Rs. 94.80 billion during the year 2014-15 which was reduced to half in quantity (325250.7 MT) earning only one third of exchequer (Rs. 32.338 billion) during the year 2015-16 (APEDA, Fig. 27).

The gum is mainly exported as (i) gum treated and pulverized, constituting ~83% of the total guar gum trade (ii) gum refined split (~16%) and (iii) guar meal (~1%) (Singh, 2014). The export value of treated/pulverized gum, refined split and meal during 2012-13 was Rs. 177.6, 33.9 and Rs. 1.4 billion respectively. The quantity of these cluster bean derivatives exported during 2012-13 was ~263.2 thousand metric tons (MT), ~70.5 thousand MT and ~74.8 thousand MT respectively. India is the major exporter of refined split with an increase of ~76%, 23% and 20% growth in 2012-13 (compared to 2011-12) in the export value of refined split, treated gum and meal respectively (Bhatt *et al*., 2016).

USA has been the largest importer of guar products for a long time and increased its share further in recent years. In the international market, trade of guar gum is categorized under 'Mucilages and Thickeners' group. India accounts for ~73% of global mucilages and thickeners trade followed by USA (5.5%), Spain (4.4%) and Pakistan (4.3%). Major importing countries of mucilages and thickeners are USA (~63%), Germany (~6%), Canada (~4%) and China (~3%) (USDA, 2014). In

2014, USA accounted for 65.5% of world imports by quantity and 67% by value. However, export to USA was 40% of total exported quantity from India to about 112 countries in 2015-16. Other major importers of guar products include China, Germany, Canada, Japan, Australia, Russian Federation, UK, Denmark and the Netherlands.

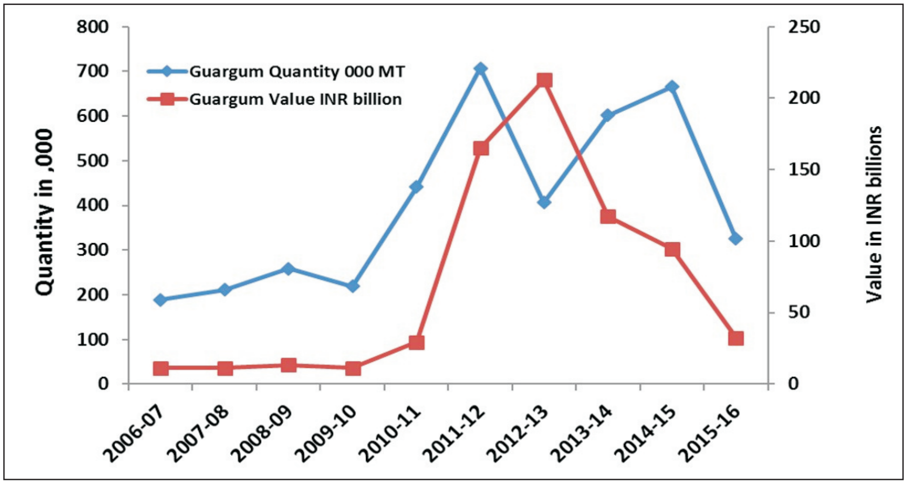

Fig. 27. Export of guar gum in last ten years (APEDA)

Future thrust

Cluster bean is an important industrial crop of India due to the presence of gum (galactomannan) in seeds. It can bring potentially very high economic returns not only for the farmers but for the country also in the form of foreign exchange. There is need to give due emphasis on:

1. Development of early maturing, climate resilient varieties with inbuilt plasticity and resistance potential towards diseases, with high gum content and high viscosity for better export potential and industrial applications.

2. Development of genotypes with ground clearance for amenability to mechanical harvesting and intercultural operations.

3. Development of seed chain network from production to marketing with farmer participation.

4. Research and development to eliminate anti-nutritional factors and toxic compounds present in the germ, which contain more than 50% protein. This will help to tap this rich source of protein for human consumption.

5. Improved process and machinery is still required to reduce the losses during processing of seed to separate endosperm, germ and hull.
6. There is a good potential for marketing of value added products, guar based health foods and medicines as dietary fiber, slimming-aid, fat replacers, etc, at international level.
7. Development of small scale guar seed processing units at cooperative level to give maximum benefit to the farmers for direct export.
8. Focus on development of domestic demand for long-term survival of guar industry in the country through the use of guar products as food ingredients in Indian food processing industry.
9. Human resource development at various clientele levels engaged in guar cultivation, marketing and processing industry, and develop skilled manpower for the industry.
10. Farmer-industry linkages to promote direct marketing at farmer level.

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