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Growth, varietal development and cultivar diversity in seed production chain of cluster bean (*Cyamopsis tetragonoloba*) in India

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ABSTRACT

India with a contribution of about 90% to the global production ranks first in the world in cluster bean (*Cyamopsis tetragonoloba* [L.] Taub.) production. It is an important feed, fodder, food and industrial crop grown in arid and semi-arid regions of West and North-West India specifically, Rajasthan, accounted for about 87.7% of the production and 91.5% of the acreage during 2020–21. India is also the major exporter of guar gum or derivatives in the international market and during 2022–23, earned valuable foreign exchange worth US $617.14 million by exporting 0.41 million tonnes (mt) of guar gum. During 2020–21 area, production and yield were reduced by 34.6%, 34.0% and 17.1%, respectively, over that of the 2010–11. The compound annual growth rate during the last five years of the decade was -12.4%, -17.5 and -5.7% for acreage, production and yield, respectively. Despite negative CAGR for area during the last twenty years, the production and yield of cluster bean increased with a CAGR of 4.5 and 5.1%. A total of 39 forage or grain type varieties of cluster bean were released and notified during 1976–2023. Varieties HG 2-20 (14.1–45.2%; 8/8) followed by RGC 1038/Guar Karan (1.4–16.7%; 8/8); HG 365 (0.3–10.0%, 8/8) and RGC 1033 (14.9–62.0%; 7/8) were the major contributors with highest frequency of occurrence in the top-most five varieties in the seed chain. Seed requirement for the next five years was assessed. Timely availability of adequate quantity of quality seed at affordable price requires holistic approach involving researchers and developmental personnel responsible for production of seed from both public and private sector.

Keywords: Cluster bean, Crop scenario, Export, Seed production chain

Cluster bean or guar (*Cyamopsis tetragonoloba* [L.] Taub.) is an important crop grown in arid and semi-arid regions of West and North-West India since ages. Besides, livestock feed and fodder, it is also food and an industrial crop providing gum, derived from seeds and is called guar gum. Endosperm of the seed contains about 30–33% gum. Rajasthan, in India, is the principal guar growing state accounting for about 87.7% of the production and 91.5% of the acreage during 2020–21 (Anonymous 2023), because of its hardiness and drought tolerance, making it an ideal legume crop for climatic conditions of Rajasthan. It is also grown in Gujarat, Haryana and Punjab for guar gum and in some parts of Uttar Pradesh and Madhya Pradesh for vegetable purpose and is also gaining importance in Maharashtra, Chhattisgarh and southern states like Karnataka, Tamil Nadu and Andhra Pradesh due to its diversified uses and economic returns. The crop has low input requirement and grows well in sandy soils with moderate and intermittent rainfall both as sole and intercrops with pearl millet/moth bean/sesame. Since, it is a leguminous crop, it improves soil health through symbiotic nitrogen fixation and is also grown as a green manure and cover crop. Being consumed as a vegetable and cattle feed, thus, a valuable source of nutrition to humans and animals. Guar gum has diversified industrial usages such as food (bakery, processed cheese, pastry ices, noodles, meat, dressing and sauces and beverages), textile, oil and well drilling, mining, construction, explosives, paper, cosmetics and pharmaceuticals (Vikaspedia 2022). The present paper reviews the crop scenario, growth, breeding and varietal diversity in seed production chain of cluster bean and also presents future outlook.

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Crop scenario

In India**,** cluster bean acreage showed wide variation and surged from 3.38 million hectares (mha) (2010–11) to 5.96 mha (2013–14) and registered an increase over 2010-11 of about 1.8% during 2011–12 to 76.2% during 2013–14 except during 2019–20 and 2020–21 (Fig 1) when a reduction of 7.1% and 25.1%, respectively, was recorded (Anonymous 2023). This could be due to the fact that the consumption pattern of cluster bean is largely influenced

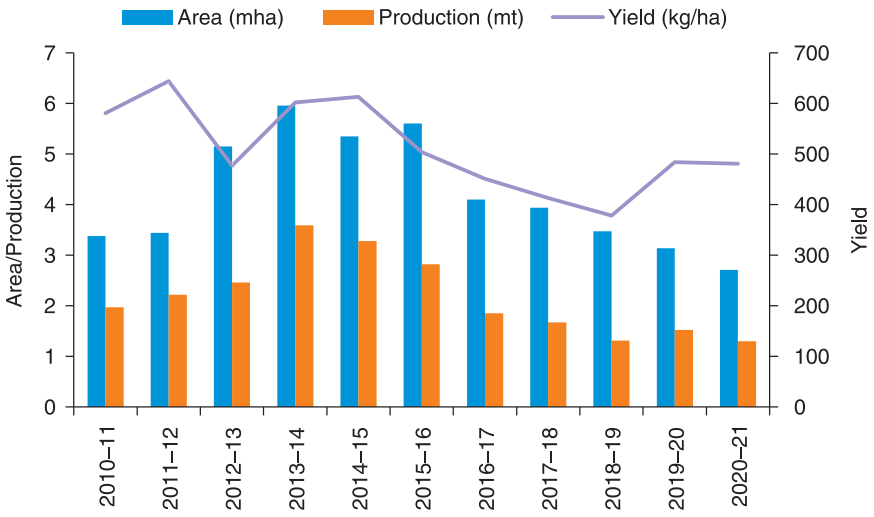

Fig 1 Trends in area, production and yield of cluster bean in India during 2010–11 to 2020–21. *Source*: Anonymous 2023.

by the demands of petroleum industry (APEDA 2023). The acreage (5.96 mha), production (3.59 mt) and yield (644 kg/ha) were the highest during 2013–14, 2013–14 and 2011–12, respectively (Fig 1). Rajasthan is the major cluster bean cultivating state and contributed about 70.0–91.5% to the acreage and 61.4–87.7% to the production of the crop during the last 11 years. Gujarat also has substantial acreage and production contributing from 3.7–7.4% to acreage and 3.3–9.8% to production (Suplementary Table 1). Nevertheless, Haryana also had appreciable area at the turn of the decade accounting for 6.2–7.6% of the acreage and 13.1–16.9% of the production during 2010–11 and 2011–12 with average yield of 1300–1350 kg/ha. Now, the area has reduced appreciably and not even reported separately. Further, yield/ha was, in general, higher in Gujarat varying from 581 kg (2011–12) to 795 kg (2014–15) than in Rajasthan having a range of 334 kg (2018–19) to 616 kg (2011–12). In the country, no definite pattern was evident for acreage, production and yield of cluster bean during the period of analysis and during 2020–21, area, production and yield were reduced by 34.6%, 34.0% and 17.1%, respectively, over that of the 2010–11 and substantially by 54.4%, 63.8% and 25.3%, respectively, in comparison to the highest ever achieved during this period (Fig 1).

The corresponding changes were 72.7%, 59.1% and 12.1% for Gujarat and 49.6%, 58.4% and 25.6% for Rajasthan (Supplementary Table 1). There was further dip in acreage and production of cluster bean during 2020–21 by 12.7% and 10.9%, respectively, but seed yield/ha was marginally higher (1.3%) in Rajasthan as compared to 2019–20. But in Gujarat, acreage, production and yield of cluster bean showed further decline by 14.3%, 18.2% and 4.2%, respectively, during the same year (Supplementary Table 1).

Compound annual growth rate

Growth of cluster bean during the last 20 years was assessed by computing compound annual growth rate (CAGR) during different phases considering five years interval. During 2009–10 to 2014–15, acreage, production and yield recorded the highest CAGR. However, during the last five years of the decade they showed high negative CAGR. Further, the decadal CAGR was negative for area, production and yield during the last decade; negative for area, production but positive for yield during 2000–01 to 2009–10 (Supplementary Table 2). During the last twenty years, despite negative CAGR for acreage, the production and yield of cluster bean increased with a CAGR of 4.5 and 5.1% (Supplementary Table 2).

The acreage had negative while production and yield positive CAGR during 2000–01 to 2004–05 but trend reversed, i.e. positive for acreage and negative for others during 2004–05 to 2009–10. The negative trend is a serious concern and needs to be addressed by researchers, policy planners and development personnel to sustain the cultivation of the crop. Nevertheless, Dhawan and Kashish (2015) reported positive growth rate of 1.86% and 7.40% for acreage and production but negative, -8.38% for yield of cluster bean from 2001–02 to 2011–12 indicating the need for more focused research on breeding varieties to raise the yield ceiling as well as integrated crop management to realize their potential.

Export

Globally, India is the principal exporter of guar gum. The major importing countries are USA, Russia, Germany, Norway and Netherland and together account for 69.4% of the Indian export and 65.3% of the foreign exchange earnings during 2022–23 (APEDA 2022). Of these, Norway was the main importer with a share of 20.1 and USA was the highest contributor (24.2%) to the India's export (quantity) and foreign exchange earnings. Analysis of guar gum export data for the period 2010–11 to 2022–23 revealed that export of guar gum surged since 2010–11 (0.42 mt) during 2011–12, 2013–14, 2014–15, 2017–18 and 2018–19 by 16.7–66.7% and attained the peak (0.70 mt) during 2011–12 (Fig 2). But it was at par (2016–17) or declined during 2012–13, 2015–16, 2019–20 and thereafter and it was the lowest (0.23 mt) during 2020–21 but again increased during 2021–22 and 2022–23 as compared to 2020–21 (Fig 2). The foreign exchange earnings despite reduced export in many years during the period of analysis were always higher than that of the base year except 2020–21 (₹19.49 billion) when a decline of 33.6% was recorded, by 5.7% during 2016–17 to 624.4% during 2012–13 (₹212.90 billion), could be due to increased price of guar gum in the international market (Fig 2). Besides export, India also imported small quantity (90–2150 tonnes) of guar gum valued at ₹2.7–33.6 crores

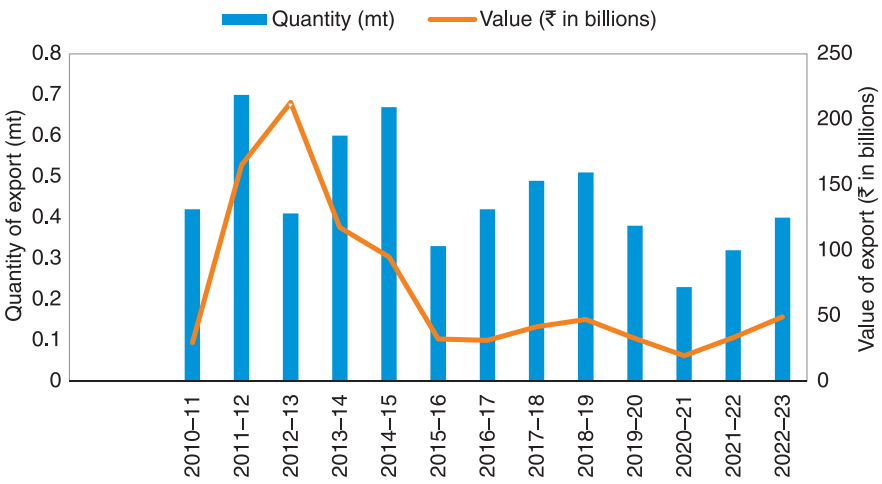

Fig 2 Export of guar gum during 2010–11 to 2022–23. *Source:* APEDA 2022.

during this period. During 2022–23, India exported 0.41 mt of guar gum and earned valuable foreign exchange worth US $617.14 million (₹49.45 billion) and imported only 926 tonnes valued at ₹20.91 crores.

Varietal development

Under National Agricultural Research System (NARS), varietal development and breeder seed production on cluster bean has been carried out under the aegis of All India Coordinated Research Project on Arid Legumes having 8 main and 15 voluntary centres, established in 1993 located at Indian Institute of Pulses Research, Kanpur, Uttar Pradesh (Chauhan *et al.* 2016a). Cluster bean is largely a self-pollinated crop with only about 2% out-crossing, hence breeding methods employed for self-pollinated crops like pure line selection, hybridization followed by pedigree method of selection and mutagenesis have also been followed for developing high yielding varieties insulated against major biotic (bacterial leaf blight, Alternaria leaf spot and powdery mildew) and abiotic stresses (drought and high temperature), that largely affect cluster bean production. Evaluation and screening of cluster bean genetic resources lead to identification of many sources having tolerance to powdery mildew (GAUG 63), bacterial leaf blight resistance (GG1, RGC 1027, GAUG 9406, GAG 75, G 8, G 102 and G 225); Alternaria blight (GC 1, GAUG 9406, GAUG 9003 and GAUG 9005) and root rot such as GAUG 9406, GG 1 and HGS 844 (Kumar 2005). Of these, GAUG 9406 was reported to have resistance/tolerance to multiple diseases and insects. Punia *et al.* (2009) and Pathak *et al.* (2010) used RAPD markers to analyze genetic diversity among varieties/cultivars of cluster bean.

Bhatt *et al.* (2015) reported that germplasm collection from dry region, summer screening to identify tolerant genotypes followed by hybridizing high yielders with tolerant donors and inter-varietal hybridization are the other approaches being followed in development of high yielding cluster bean varieties. Intensive hybridization is very important for recombinant breeding and offers diverse segregating populations for effecting selection and also for gene discovery through genetic and molecular approaches. However, hybridization in this crop is tedious and tiresome due to small flowers, cleistogamy and sensitivity to manipulations acting as deterrents to a strong recombination breeding support in arid legumes, cluster bean and moth bean. Mahla and Sharma (2022) achieved around 28% seed setting and 60% hybrid seeds in cluster bean through direct pollination without emasculation and found this method quite easy and successful compared to earlier techniques of hybridization. Further, this technique would facilitate genetic studies and strong recombination breeding. The major focus in the breeding programme has been on developing vegetable type having high green pod yield, early maturity and improved pod quality such as long green, succulent, tender and low fibre content. Emphasis is also on the development of dwarf varieties with single stem and suitability for growing in summer as well as rainy (*kharif*) season in north-Indian plains. Coordinated research efforts of NARS have led to the release and notification of 39 forage and grain type varieties of cluster bean in India since the first ever variety (FS 277) was notified in 1976 until the latest notification S.O. 1056 (E) dated March 6, 2023 that included Karan Guar 14 and 90th meeting of Central Sub-committee on Crop Standards, notification and release of varieties for agricultural crops held on May 2, 2023 (Seednet 2023). Of these, five varieties were released and notified during 2011–23 (Table 1). Promising varieties for seed and gum purpose are HG 365, HG 563, HG 2-20, RGC 1066 and RGC 1003 whereas; HG 2-20, HFG 119, HFG 156 and Guar Kranti for fodder purpose (Tiwari *et al.* 2020).

Seed production chain

Seed sector, seed systems and supply chain: India has a strong vibrant seed sector comprising several stakeholders from both public and private organizations, farmers and NGOs. Indian seed systems, seed quality assurance framework and supply chain have been elaborately discussed in our earlier publications (Chauhan *et al.* 2016b, 2020a, b).

Varietal scenario: Varietal replacement coupled with indent and production of breeder seed is essential for effective and vibrant seed chain. In the present investigation, the pattern of varietal induction in the seed chain and share of varieties in the breeder seed indent was assessed following Chauhan *et al.* (2020a) from 2014–15 to 2021–22. During the period under investigation number of varieties indented for breeder seed production of cluster bean varied from 11 (2020–21) to 17 (2018–19). Contribution of the five topmost varieties to the seed indent varied from 72.4% (2014–15) to 93.4% (2018–19) and during 2021–22, it was 91.2%.

Table 1 Salient features of cluster bean grain and forage varieties released and notified in India (1976–2023)*

Variety, year of notification and developing organization	Breeding method/source	Recommended state/s for cultivation and salient characteristics
Agaita Guara 111 S.O. 13, December 19, 1978 PAU, Ludhiana, Punjab	Pedigree method of selection from the cross G 325 × FS 277	Punjab Forage type, non- branching type, medium sized grains, suitable for inter-cropping
Ageta Guara 112 S.O. 449(E), July 8, 1983 PAU, Ludhiana, Punjab	Pedigree method of selection from the cross (326 × FS 277) × 315	Entire guar growing areas in the country especially Punjab An early maturing variety, preferred for grain yield, resistant to bacterial and Alternaria blight diseases
Bundel Guar 1 (IGFRI 212-1) S.O. 615(E), August 17, 1993 IGFRI, Jhansi, Uttar Pradesh	Single plant selection from an indigenous material of Rajasthan (Acc. no. B.5/54)	Arid and semi-arid zone of Punjab, Haryana and Rajasthan Dual purpose type, suitable for drier areas with moderate rainfall, moderately resistant to bacterial blight and major pests
Bundel Guar 2 (IGFRI 2395-2) S.O. 408(E), May 4, 1995 IGFRI, Jhansi, Uttar Pradesh	Selection from indigenous material collected from Jodhpur, Rajasthan (Acc. no. 5496-2)	Semi-arid zone of Punjab, Haryana, Rajasthan, Gujarat, Uttar Pradesh and Madhya Pradesh Dual purpose type, suitable for drier areas with moderate rainfall, cultivated for gum and fodder
Bundel Guar 3 (IGFRI 1019-1) S.O. 1050(E), October 26, 1999 IGFRI, Jhansi, Uttar Pradesh	Single plant selection from indigenous material (RGC 19-1) collected from Durgapura, Rajasthan	Entire guar growing areas (suitable for arid and semi-arid zones) in the country Dual purpose type, high protein green foliage, suitable for fodder as well as grain for gum purpose
Durgajay S.O. 470, February 19, 1980 ARS, Durgapura, RAU, Bikaner, Rajasthan	Single plant selection from local germplasm collected from Nagaur, Rajasthan	Entire guar growing areas in the country especially Rajasthan, Gujarat, Maharashtra Dual purpose type, suitable for late sowing, grain rich in gum and protein content
Durgapura Safed S.O. 470, February 19, 1980 ARS, Durgapura, RAU, Bikaner, Rajasthan	Single plant selection from local germplasm of Rajasthan	Entire guar growing areas in the country especially Rajasthan Dual purpose type, preferred for grain production, grain rich in gum and protein content
FS 277 S.O. 786, February 2, 1976 HAU, Hisar, Haryana	Pure line selection from local germplasm	Punjab, Haryana Medium maturity, dual purpose used for fodder, erect and un-branched, moderately resistant to Alternaria leaf spot disease
Guar Kranti (RGC 1031) S.O. 1566(E), November, 2005 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	A derivative of the cross RGC 936 × RGC 986/P 10 through pedigree method of selection	Entire guar growing areas in the country especially Rajasthan Suitable for late sowing, dual purpose, highly nutritive fodder, high quality grain for protein and gum
Guar Kunjal (RGC 1033) S.O. 283(E), February 7, 2011 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	Selection from the cross RGC 1013 × RGC 986/P 6	Rajasthan Medium maturity, branched with medium height, high gum content
Guar Lathi (RGC 1066) S.O. 1703(E), October 5, 2007 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	Selection from the cross RGC 936 × RGC 197	Entire guar growing areas in the country Un-branched type, early maturity, suitable for inter- and mixed cropping

Contd.

Table 1 (*Continued*)

Variety, year of notification and developing organization	Breeding method/source	Recommended state/s for cultivation and salient characteristics
Guar Uday (RGC 1055) S.O. 1703(E), October 5, 2007 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	Selection from the cross RGC 1013 × RGC 986	Entire guar growing areas in the country Medium maturity, synchronous maturity, good yield with high endosperm
Guara 80 S.O. 449(E), July 8, 1983 PAU, Ludhiana, Punjab	Pedigree method of selection, a derivative of the cross FS 277 × strain no. 119	Entire guar growing areas in the country especially Punjab Single cut, dual purpose type, preferred for grain production, resistant to bacterial blight disease
Gujarat Guar 1(GAUG 34) S.O. 793(E), November 22, 1991 GAU, S.K. Nagar, Dantewada, Gujarat	Mutant of Kutch 8	Entire guar growing areas in the country Late maturing, branched, medium bold seeds, moderately resistant to bacterial blight disease
Gujarat Guar 3 (Banas Uday) S.O. 8(E), December 24, 2021 S. D. Agricultural University, S. K. Nagar, Dantewada, Gujarat	Selection from the cross GAUG 0005 × IC 370730	Gujarat Grain type, medium maturity, suitable for arid regions, less infestation against bacterial blight disease, white fly and leaf hoppers, high gum content
Haryana Guar 365 S. O. 401(E), May 15, 1998 HAU, Hisar, Haryana	Selection from the cross Durgajai × Hisar local	Entire guar growing areas in the country Suitable for intensive cropping, early and late sowing, tolerant against bacterial blight disease
HFG 11 S.O. 19(E), January 14, 1982 HAU, Hisar, Haryana	Selection from local germplasm	Entire guar growing areas in the country
HFG 119 S.O. 19(E), January 14, 1982 HAU, Hisar, Haryana	Pure line selection from local germplasm	Entire guar growing area in the country Dual purpose type, high seed production potential, moderately resistant to leaf spot and bacterial blight diseases
HFG 156 S.O. 10(E), January 1, 1988 HAU, Hisar, Haryana	Selection from germplasm	Entire guar growing areas in the country Fodder type, tolerant to bacterial blight disease
HFG 258 S.O. 258(E), January 1, 1988 HAU, Hisar, Haryana	Selection from local germplasm	Entire guar growing areas in the country Suitable for late sowing, moderately resistant to bacterial blight disease
HG 2-20 S.O. 733(E), April 1, 2010 CCS-HAU, Hisar, Haryana	Pedigree selection from the cross HG 365 × FS 277	Entire guar growing areas in the country Grain variety, moderately resistant to bacterial blight disease, resistant to Alternaria blight and root rot diseases
HG 75 S.O. 19(E) , January 14, 1982 HAU, Hisar, Haryana	Pure line selection from local genetic material	Entire guar growing areas in the country Dual purpose type, non-lodging and non-shattering type, preferred for grain production, moderately resistant to Alternaria leaf spot and bacterial blight diseases
HG 182 S.O. 596(E), August 13, 1984 HAU, Hisar, Haryana	Single plant selection from the genetic line, Accession no. HFG 182	Entire guar growing areas in the country especially Haryana Dual purpose type, non-lodging and non-shattering type, preferred for grain, field resistance to most of the diseases and pests

Contd.

Table 1 (*Continued*)

Variety, year of notification and developing organization	Breeding method/source	Recommended state/s for cultivation and salient characteristics
HG 563 S.O. 642(E), May 31, 2004 CCS-HAU, Hisar, Haryana	Selection from the cross Durgajai × Hisar Local	Entire guar growing areas in the country Suitable for both early and late sowing, high viscosity of gum, tolerant against bacterial blight disease
HG 870 S.O. 733(E), April 1, 2010 CCS-HAU, Hisar, Haryana	Selection from the cross HG 75 × HG 296	Entire guar growing areas in the country Early maturity, profuse branching, high viscosity gum, tolerant to bacterial blight and root rot, moderately resistant to Alternaria blight diseases
HG 884 S.O. 733(E), April 1, 2010 CCS-HAU, Hisar, Haryana	Pedigree selection from the cross HG 75 × FS 296	Entire guar growing areas in the country Grain variety, moderately tolerant to bacterial blight disease, resistant to Alternaria blight and root rot diseases
Karan Guar 1 (RGr 12-1) S.O. 1379(E), March 27, 2018 RARI, Durgapura (SKNAU-Jobner), Jaipur, Rajasthan	Selection from the cross RGC 1002 × GAUG 04	Rajasthan Early maturity, drought tolerant, lodging and shattering resistant, moderately resistant to bacterial blight, Alternaria blight and leaf spot and root rot diseases, low incidence of jassids/leaf fly
Karan Guar 14 (RGR 18-1) S.O. 1056(E), March 6, 2023 RARI, Durgapura (SKNAU-Jobner), Jaipur, Rajasthan	Selection from the cross RGC 1038 × RGC 1017	Rajasthan, Gujarat, Haryana and Maharashtra Medium maturity, moderately resistant to bacterial blight and Alternaria leaf spot diseases, good gum content with high viscosity
Maru Guar (2470/12) S.O. 867(E), November 26, 1986 CAZRI, Jodhpur, Rajasthan	Selection from local germplasm received from NBPGR, New Delhi	Entire guar growing areas in the country especially Western parts of Rajasthan Dual purpose type, preferred for grain production, suitable for late sowing, field resistance against Alternaria and bacterial blight diseases
Rajasthan Guar 1 (RGC 471) S.O. 408(E), May 4, 1995 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from local germplasm collected from Barmer, Rajasthan	Entire guar growing areas in the country Dual purpose type, branched, late maturity, highly suitable under low rainfall, late maturity, good gum content
Rajasthan Guar 1038 (RGC 1038) S.O. 449(E), February 11, 2009 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	Selection from the cross RGC 516 × HG 75	Entire guar growing areas in the country Suitable for semi-arid, sandy loam soils, branched with medium height, medium maturity, high fodder and seed yield
RGC 197 S.O. 386(E), May 15, 1990 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from local germplasm collection from Nagaur, Rajasthan	Entire guar growing areas in the country Un-branched, tall, suitable for inter- and mixed cropping, moderately resistant to bacterial blight disease
RGC 936 S.O. 793(E), November 22, 1991 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from the cross EC 248 × RGC 401	Entire guar growing areas in the country Early maturity, branched, photo and thermo insensitive, high gum and seed protein content
RGC 986 S.O. 425(E), June 8, 1999 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from the cross EC 516 × HG 75	Entire guar growing areas in the country Medium height, medium maturity, high seed yield and gum content

Contd.

Table 1 (*Concluded*)

Variety, year of notification and developing organization	Breeding method/source	Recommended state/s for cultivation and salient characteristics
RGC 1002 S.O. 1050 425(E), October 26, 1999 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from the cross NC 4/P 2-1 × RGC 516	Entire guar growing areas in the country Branched, medium height, early maturity, high seed and gum content
RGC 1003 S.O. 425(E), June 8, 1999 ARS, Durgapura, RAU, Bikaner, Rajasthan	Selection from the cross Naveen × HG 75	Entire guar growing areas in the country Branched, medium height, early maturity, suitable for sole crop sequences and gum content
RGC 1017 S.O. 937(E), September 4, 2002 ARS, Durgapura, SKN-RAU, Bikaner, Rajasthan	Selection from the cross Naveen × HG 75	Entire guar growing areas in the country Early maturity, medium tall, suitable for double cropping, high seed yield and gum content
Surya (RGM 112) S.O. 122(E), February 2, 2005	Mutant of Naveen	Entire guar growing areas in the country Early maturity, suitable for dry areas of semi-arid and arid regions, moderately resistant to bacterial leaf blight disease
X 10 S.O. 2986(E), July 20, 2021 Shakti Vardhak Hybrid Seeds Pvt. Ltd, Hisar Haryana	Selection from the cross X 6 × HG 563	Haryana Medium maturity, suitable for rainfed under both high and low fertility conditions, resistant to root rot and bacterial blight diseases

**Source:* Roy *et al.* 2018, Jindal *et al.* 2021, Directorate of Research, SKNAU, Jobner 2023; Seednet 2023.

The varieties released during 2006–10 had the major share in seed indent until 2019–20 but got replaced by those released during 2011–15 in 2020–21 (Table 2). Varieties released during the past 10 years (2011–20) accounted for 17.1% (2016–17) to 73.2% (2021–22) seed indent. Recently released variety contributed 66.4% to the breeder seed indent during 2021–22 (Table 2).

The leading varieties of cluster bean having appreciable contribution and frequency in occurring in the top-most five varieties were HG 2–20 (14.1–45.2%; 8/8) followed by RGC 1038/Guar Karan (1.4–16.7%; 8/8); HG 365 (0.3–10.0%,8/8); RGC 1033 (14.9–62.0%; 7/8); HG 563 (4.3–20.0%, 5/8), Guar Lathi/RGC 1066 (0.3–11.7%; 4/8) and Karan Guar 1 (6.8–66.4%; 2/8). Variety HG 884 and RGC 936 was indented only once with a share of 12.1 and 3.1% during 2015–16 and 2019–20, respectively. In earlier studies, HG 2-20 and HG 563 both of forage cluster bean were observed to contribute appreciably to the breeder seed indent of forages (Chauhan *et al.* 2021). Among the leading varieties, RGC 936 and Karan Guar 1 was the earliest and latest variety released during 1991 and 2018, respectively, and the rest were released during 1998–2011. Of the three varieties released during 2016–21, only one was in the seed chain during 2021–22.

Seed standards: Seed quality as assessed by genetic purity and identity of a variety provided to the end users is ensured as per the Indian Minimum Seed Certification Standards (IMSCS). Foundation and certified seed production is regulated following stringently the IMSCS 2013 (Trivedi and Gunasekaran 2013) through monitoring at various crop developmental stages by duly approved team. Plots to be used for seed production should be free from volunteer plants. A minimum of two crop inspections are mandatory for cluster bean, viz. first before flowering and second at flowering and fruit stage. Seed production plots should be isolated from fields of other varieties and that of the same variety not meeting the varietal purity standards for certification by minimum of 10 m and 5 m for foundation and certified seed, respectively (Trivedi and Gunasekaran 2013). The requisite seed certification standards for cluster bean are presented in Supplementary Table 3.

Breeder seed

Progeny of nucleus seed is termed as breeder seed and produced under the supervision of parent- or designated qualified breeder of the organization sponsoring the variety under reference. The breeder seed has the utmost genetic purity of 100%. Breeder seed production is demand driven and produced in response to indents by the stakeholders. It is monitored by a designated team of scientists and personnel of seed certification agency and National Seed Corporation, but its certification is not mandatory. Concerned breeder provides the golden yellow coloured tag to certify the quality of seed. Breeder seed indent during the period of analysis varied from 76.7 q during 2021–22 to 341.1 q during 2013–14 and 2014–15. Seed indents increased by 2.5–20.1% over the base year up to 2014–15 and decreased consistently thereafter varying from 5.3–73.0% with highest decrease during 2021–22 (Fig 3). Similarly, production was also lower than that of the base year in all the years except

Table 2 Varietal replacement in cluster bean seed chain assessed as contribution of varieties developed during different phases (quinquennial) to the breeder seed indent during 2014–15 to 2021–22*.

Year	Share of topmost five varieties (%)	Varieties indented (no.)	Up to 1995	1996–2000	2001–05	2006–10	2011–15	2016–20
2014–15	72.4	15	3 (10.3)[a]	4 (14.0%)	2 (24.1%)	6 (51.7%)	-	-
2015–16	77.1	14	5 (6.8%)	2 (23.9%)	2 (6.4%)	5 (63.0%)	-	-
2016–17	86.9	15	2 (4.2%)	4 (8.5%)	2 (6.2%)	6 (63.6%)	1 (17.6%)	-
2017–18	92.7	16	3 (3.8%)	3 (8.3%)	2 (5.5%)	6 (62.9%)	1 (19.5%)	-
2018–19	93.4	17	6 (4.6%)	3 (8.1%)	2 (5.7%)	5 (41.2%)	1 (40.4%)	-
2019–20	93.2	17	6 (4.6%)	4 (6.4%)	2 (4.7%)	4 (42.4%)	1 (42.0%)	-
2020–21	92.2	11	3 (0.1%)	1 (0.3%)	1 (0.04%)	3 (36.8%)	3 (62.7%)	-
2021–22	91.2	14	3 (0.6%)	2 (1.8%)	1 (0.3%)	6 (24.0%)	1 (6.8%)	1 (66.4%)

**Source:* Anonymous 2022b, Yadava *et al.* 2023.

2011–12, as expected, as breeder seed production is demand driven. But, production of breeder seed was always higher than the indent by 8.0% (2016–17) to 125.8% (2021–22) during the period of analysis except 2013–14, 2014–15 and 2015–16 where a reduction ranging from 4.3% to 39.8% was recorded (Fig 3).

Foundation seed

Foundation seed is the progeny of breeder seed and is produced by National and States Seed Corporation, registered private seed companies, group of farmers as well as progressive farmers/growers under the supervision of qualified breeders or technical officers. Its production is supervised and approved by the Certification Agency of the region. The crop specific genetic purity of foundation seed should be maintained. The certification agency provides white coloured tags bearing the quality standards and production details. The requirement of foundation seed showed wide annual fluctuations and was the highest during 2014–15 but since then appreciably declined continuously until 2022–23 with highest decrease during 2018–19 (Table 3). Since production of seed is closely linked to requirement, the seed availability followed the similar trend except for the year 2019–20 and 2020–21 when it was more than that of the base year by 15.7% and 28.5%, respectively. However, seed availability was always higher than the requirement during the period of analysis by 17.0–400.9%. Hence, there was no scarcity of foundation seed availability.

Certified seed

Certified seed is the progeny of foundation seed and produced in the similar way as that of foundation seed. Its production is also supervised and approved by the Certification Agency of the region and crop specific genetic purity, which is lower than that of foundation seed. This is the commercial seed made available to the farmers. The certification agency issues azure blue tags as a mark of quality. Analysis of 13 years data revealed that against the

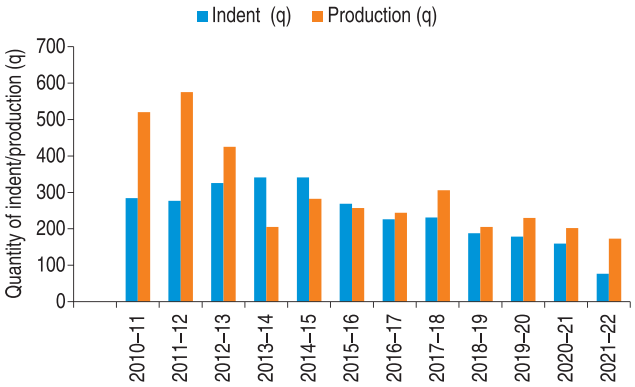

Fig 3 Indent and production of breeder seed of cluster bean during 2010–11 to 2021–22. *Source:* Chauhan *et al.* 2021, Anonymous 2022b, Yadava *et al.* 2023.

requirement ranging from of 0.42 lakh q (2011–12) to 0.81 lakh q (2016–17; 2018–19); the seed availability varied from 0.48 lakh q during 2011–12 to 0.94 lakh q during 2016–17 (Table 3). The seed availability was higher by 2.7–16.0% over the requirement across the years except 2012–13 and 2014–15 where it was lower by 7.4–8.1%, respectively (Table 3).The seed requirement declined since 2010–11 until 2015–16 and 2021–22. In rest of the years, it was higher than that of the base year by 2.6–6.6%. Seed availability followed the trend of requirement as both are linked and demand driven, in comparison to the base year, it was only higher during 2016–17, 2019–20, 2020–21 and 2022–23 registering an increase of 10.6%, 1.2%, 3.5% and 2.4%, respectively.

Way forward

The present study revealed that acreage and consequently production has been continuously declining over the last five years. More than this, there is a disturbing issue of stagnant or reduced seed yield/ha. Besides climatic variables, there is lack of appropriate varieties as evident by low varietal diversity of the seed chain and only five varieties were released during 2011–23. And, old varieties still had large

Table 3 Requirement [R] and availability [A] of certified/quality seed (2010–11 to 2022–23) and foundation seed (2014–15 to 2022–23) of cluster bean[a]

Year	Certified /quality seed (lakh q)/ Foundation seed (q)		Change over the base year [%]		Change in [A] over [R] (%)
	[R]	[A]	[R]	[A]	
2010–11	0.76	0.85	-	-	11.8
2011–12	0.42	0.48	-44.7	-43.5	14.0
2012–13	0.54	0.50	-28.9	-41.2	-7.4
2013–14	0.75	0.69	-1.3	-18.2	8.0
2014–15	0.74 (1152)*	0.68 (1994)*	-2.6	-20.0	-8.1 (71.1)
2015–16	0.75 (652)	0.77 (1201)	-1.3 (-43.4)*	-9.4 (-39.8)*	2.7 (84.2)*
2016–17	0.81 (527)	0.94 (1256)	6.6 (-54.3)	10.6 (-37.0)	16.0 (138.3)
2017–18	0.78 (535)	0.85 (1050)	2.6 (-53.6)	0.0 (-47.3)	9.0 (96.3)
2018–19	0.81 (335)	0.84 (1678)	6.6 (-70.9)	-1.2 (-15.8)	3.7 (400.9)
2019–20	0.79 (614)	0.86 (2308)	3.9 (-46.7)	1.2 (15.7)	8.9 (275.4)
2020–21	0.79 (565)	0.88 (2562)	3.9 (-51.0)	3.5 (28.5)	11.4 (353.5)
2021–22	0.75 (447)	0.83 (523)	-1.3 (-61.2)	-2.4 (-73.8)	10.7 (17.0)
2022–23	0.78 (396)	0.87 (1348)	2.6 (-65.6)	2.4 (-32.4)	11.5 (240.4)

[a]*Source:* Anonymous 2022a; 2023, Seed Division, Department of Agriculture and Farmers Welfare, Government of India, New Delhi. *Within parenthesis is foundation seed data.

share in breeder seed indent. Crop is largely confined to only two states, Rajasthan and Gujarat, greater focus on varietal improvement programme in these states is pivotal. An analysis is required to know the factors responsible for shrinkage of acreage, viz. crop replacement/diversification or less economic returns as it is largely determined by extraneous factors. Value addition to the crop and enhancing indigenous industrial use of the crop should also be focused. Factors responsible for limiting yield such as biotic and abiotic stresses need to be analysed to ameliorate them through appropriate breeding approaches integrating conventional breeding with biotechnological tools like marker assisted selection to hasten the breeding cycle and reduce the time for releasing a variety. Good quality seed and varieties have played significant role in increasing yield of almost all the crops by narrowing down the gap between realized and potential yield and shall continue to be important in years to come. In Rajasthan, an important state for cluster bean, inadequate supply of quality seed was one of the major constraints in cluster bean production (Bhupender *et al.* 2020). Therefore, vibrant and dynamic seed chain of cluster bean needs to be focused upon. Further, analysis of data of breeder seed and foundation seed suggested that there are large indents for breeder seed not at all required as per ideal seed replacement rate for the crop, sheer wastage of resources as breeder seed production is highly specialized and resource intensive. Further, such high production of breeder seed did not match with the availability of foundation seed and requirement indicating its poor conversion to foundation seed. The seed requirement for cluster been for the next five years has been assessed and given in Supplementary Table 4.

It is, therefore, foremost to rationalize the breeder seed indent for appropriate varieties based on region specific/district wise sound planning for at least five years emphasizing on new varieties, acreage expansion, gradually increasing seed replacement rate (SRR) and assessing the seed requirement including for contingencies. Only then, indents of suitable varieties for breeder seed should be placed with the concerned organization and also ensure its conversion to foundation and certified seeds. This requires holistic approach involving researchers and developmental personnel responsible for production of breeder, foundation and certified seed such as ICAR institutes, state agricultural universities, national and state seed corporations, progressive farmers, farmers producing organization as well as private seed companies. Each stakeholder should be assigned a definite role, suitably backed by MoUs, including expected production cost and seed pricing as a legal binding, to energize sustainable quality supply chain at affordable pricing.

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