Heliyon 10 (2024) e35735

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Quality seed production scenario of Egyptian clover (*Trifolium alexandrinum*) in India: A 24-year retrospective analysis

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ARTICLE INFO

Keywords:
Berseem
Breeder seed
Varietal replacement rate
Varietal age
Fodder legume

ABSTRACT

Egyptian clover/Berseem (*Trifolium alexandrinum* L.) is the most popular winter leguminous multi-cut fodder crop widely cultivated in the northwest and central parts of India. Quality seed significantly impacts farm productivity, farmers' profitability, and socioeconomic welfare. Foundation and certified seeds enable high-quality seed production, making breeder seed (BS) the most important link in the seed supply chain. In India, berseem BS indent had increased from 1998 - 99 to 2012–13; afterwards, it followed a constant but decreasing trend. Of the 27 notified cultivars, 24 came into the seed supply chain between 1998–1999 and 2021–2022, indicating high varietal availability to stakeholders. The study examines the potential causes of the national decline in BS indent and production and the differences in these figures over time. The highest BS indent was received for the variety JB-1 (276.1 q), followed by BL-10 (205.1 q), Mescavi (165.6 q) and Wardan (153.7 q) from 1998 - 99 to 2021–22. The varietal replacement rate (VRR) is high, 43.30 %, for the varieties that have reached the age of five or less in the recent three years (2019–20 to 2021–22). Additionally, it has been calculated that if the seed chain operates at 100 % efficiency, the BS generated (48.1q) in 2021–22 can cover an area of almost 0.12 million hectares in 2024–25. The study offers an in-depth overview of berseem BS indent and production, an analysis of the difficulties encountered in BS production, and future directions for expanding variety and producing excess BS in the nation.

1. Introduction

Berseem or Egyptian clover (*Trifolium alexandrinum* L.; $2n = 2x = 16$) is an annual leguminous fodder crop cultivated in the tropical and subtropical regions globally under Mediterranean climate having <1700 MSL altitude. The major berseem growing countries are in the Middle East, Mediterranean, Asia Minor regions, and the Indian sub-continent [1,2]. In India, berseem was introduced from Egypt in 1904 and became the most important *Rabi* crop in central and northwest India, and now extends to the foothills of the

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https://doi.org/10.1016/j.heliyon.2024.e35735
Received 13 September 2023; Received in revised form 16 July 2024; Accepted 2 August 2024
Available online 3 August 2024
2405-8440/

Himalayas and eastern India. In India, the winter season is known as *Rabi*, during which crops are planted in mid-October to November and harvested in April to June. It occupies almost two million hectares in India and is mainly cultivated in Punjab, Haryana, Delhi, Uttar Pradesh, and Madhya Pradesh states [3,4]. Among the cultivated leguminous fodder crops, livestock keepers and farmers prefer berseem due to its high green fodder productivity (800–1200 q/ha), multi-cut nature (4–8 cuts) providing green fodder for a long duration (November to May), better nutritional quality (20 % crude protein), high digestibility (up to 65 %) and palatability [5,6]. In India, the berseem breeding program started long back and mainly focused on developing varieties with high biomass, better nutritional quality and resistance to major diseases, i.e., root rot and stem rot [4,7]. Berseem is largely a self-incompatible crop, and a proper seed set requires tripping [3,8,9].

Quality seed plays a vital role in attaining the potential production of crop varieties as the old scripture– "*Manu Smriti,*" says '*Subeejam Sukshetre Jayate Sampadyate',* i.e., quality seed in productive fields yields abundantly. According to estimates, using high-quality seed alone can boost crop yields by 15–20 % and, with appropriate management techniques, by up to 45 % [9–11]. India faces an acute shortage of green and dry fodder, with 11.4 % in green fodder and 23.24 % in dry fodder [12], for many reasons, including the non-availability of quality seeds. Berseem seed production is affected by several factors, such as a narrow genetic base, asynchronous flowering, inherent heterozygosity, self-incompatibility, small floral parts, poor seed set and fertility barriers [4,13]. India imports approximately 100,000 q of berseem seed annually against the total requirement of 500,000 q, meeting 20 % of the demand and resulting in a huge loss to the foreign exchequer [14]. Reliable data on the informal seed chain regarding the quantity of indigenous seed production of berseem is lacking. However, a few surveys and informal queries among the farmers and traders indicate that nearly 70 % of the seed supply is through an informal chain, largely from farmers to farmers and unlabeled seed sales in village markets. Quality assessments of berseem seed traded through an informal seed system failed to meet the minimum seed quality standards required for certification [15]. This highlighted the necessity of implementing targeted policy adjustments and strict quality control measures by seed law enforcement to address the issue of high-quality seed availability in the nation.

Breeder seed (BS) has the highest genetic and physical purity and is the progeny of the nucleus seed. Project Coordinators (PCs) of All India Coordinated Research Projects (AICRPs) in the various crops assist the concerned breeder or sponsored breeder of the Indian Council of Agricultural Research (ICAR) institutes or State Agricultural Universities (SAUs)/agencies in producing it [16]. AICRP on Forage Crop and Utilization (AICRP on FCU) plays a vital and monitoring role in the maintenance and production of the nucleus and breeder seed of berseem, supplying the breeder seed to different stakeholders such as state government/s and national agencies, ensuring meet the BS demand. As a result, it indirectly maintains the seed chain by producing the necessary quantity of certified seed and foundation across the nation. The major indenters of berseem seed are the National Dairy Development Board (NDDB), National Seed Association of India (NSAI), National Seeds Corporation (NSC), Krishi Vikas Sahakari Samiti Limited (KVSSL), and other private seed companies, as well as the state governments that uplift BS and are directly involved in the foundation and certified seed production.

The present study analyzes the BS indent and production trend of berseem varieties in India for the last 24 years (1998–99 to 2021–22), import data, monetary value, and roadmap for self-reliance in seed production. It also provides a holistic view of the factors associated with a varietal mismatch in BS indent and production. In addition, the study also reveals the varietal replacement rate (VRR) in berseem, determines how to produce certified and foundation seeds from the generated BS, and acreage coverage under the berseem crop. Furthermore, it highlights the concurrent challenges affecting the varietal development in the country and discusses a roadmap to reframe our breeding programs in berseem.

2. Materials and methods

2.1. Data mining

The AICRP on FCU annual reports provided information on the BS indent, allocation, and production of several berseem varieties under the Indian seed supply chain [17–40]. The data were collected for 24 years, from 1998 - 99 to 2021–22, covering all the country's production centers.

2.2. Varietal replacement rate (VRR)

It indicates the replacement rate of older varieties with newly released ones. Farm productivity can be enhanced by quickly disseminating new high-yielding varieties instead of old varieties [41]. VRR for the last three years (2019–20 to 2021–22), percent share of old but popular varieties in BS indent, a trend of varieties (<5, 5–15 and > 15 years varietal age) in BS indent for the last five years (2017–18 to 2021–22) were calculated to assess the significant impact of newly released varieties in BS demand. The following formula is used to compute the VRR.

$$VRR = (A/B) \times 100$$

Where A is the computed years' indent of the specified variety (q); B = Total indentation of all crop varieties (q) for the computed years.

2.3. Seed replacement rate (SRR)

It denotes the cropped area covered under quality seeds of improved varieties. High SRR means a robust seed industry and well-established market channels [42]. SRR is calculated using the following formula

SRR = X / Y x 100

Here, X represents the amount of quality seed sown; Y indicates the amount of quality seed (TFL/certified) needed to cover the full production area.

2.4. Seed multiplication ratio (SMR)

It's the ratio of how many seeds are generated from one original seed. Higher SMR tends to reduce the cost of seed production with more yield, thus ensuring cheaper seeds in sufficient quantity. The SMR was calculated for each treatment combination following the equation suggested by Ref. [43].

P = X / Y

Where P is the seed multiplication ratio, X is pure seed yield, and Y is the seed rate. SMR of 1:25 was taken for the berseem crop [44].

2.5. Projected foundation and certified seeds production

The amount of certified and foundation seed generated was determined by converting all breeder seeds at a ratio of 1:25 SMR [44].
Quantity of foundation seeds (q): Quantity of breeder seeds (q) x 25.
Quantity of certified seeds (q): Quantity of foundation seeds (q) x 25.

2.6. Projected area coverage under quality seed

It was calculated based on the cultivable area, which can be sown using the total quantity of quality seeds available at a standard seed rate of 25 kg/ha for fodder purpose cultivation [45].
Area coverage (ha) = Total quality seeds produced (kg)/Seed rate (kg/ha).

2.7. Data interpretation

The collected data were analyzed using Microsoft Excel (2021 version) and interpreted for different parameters to determine the status of BS indent and production, their balance sheet and varieties under the seed chain since 1998–99. Parameters include BS indent and production trend, the contribution of centers in BS allocation and production, and comparison with lucerne BS.

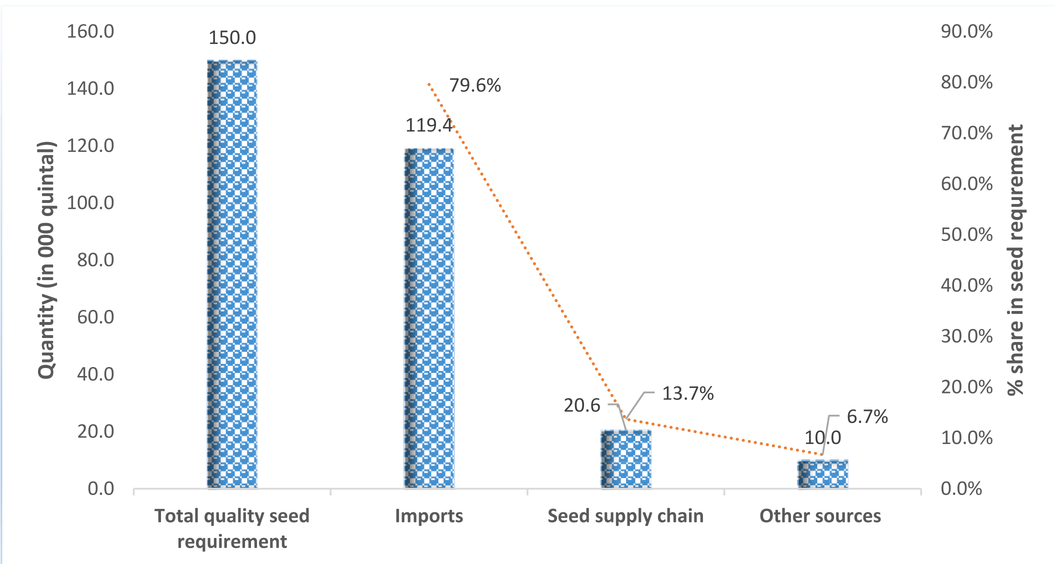


Fig. 1. Berseem quality seed requirement (assuming a 30 % seed replacement rate) and different supply sources in India during 2022–23.

3. Results

3.1. Berseem seed demand, supply chain and seed import status

Authenticated and scientifically proven data on berseem seed demand is unavailable in India. Quality berseem seed demand was estimated to be about 200,000 q based on important criteria such as the expected area under cultivation, seed rate, average seed yield and seed multiplication ratio (SMR) [14]. India needs about 500,000 q berseem seed per annum if a 100 % seed replacement ratio (SRR) is followed. However, most farmers do not purchase seed yearly due to high market prices and lack of awareness about quality seed. Their seed requirement is met either by their savings from the previous year's produce or local markets of unbranded seeds. Being a fodder crop cultivated mainly by poor and marginal farmers, we estimated 30 % SRR to be reliable. It puts the estimate of quality seed requirement at nearly 150,000 q per annum. BS production mainly fulfills the seed requirement through government agricultural institutes, imports and other sources. The BS supply chain has different stages, such as foundation and certified class, where seed multiplication happens with assured seed quality standards. BS production is followed by the production of foundation and certified seeds by national and state-level agencies and progressive farmers. Out of the total seed demand during 2022–23, 20,625 q were fulfilled through the breeder seed supply chain that includes certified seed produced by the central and state government agencies, dairy cooperatives, non-government organizations (NGOs) etc. (Fig. 1). In addition, 119,350 q seed was imported from Egypt and other gulf countries during 2022–23 that had a value of 13.28 million US$ and shared 0.0019 % in total import of India [46]. Berseem seed import from Mediterranean countries started during 2001–02 and is still the major source to meet the domestic demand (Fig. 2). Since 2008–09, India has imported more than 80,000 q berseem seed every year except in 2013–14 when seed import was 51,110 q. The highest quantity was imported in 2012–13 (135,240 q) followed by 2017–18 (122,970 q) and 2022–23 (119,350 q). The remaining seed, i.e., 10,025 q, was supplied by other agencies such as private companies, NGOs, and farmer producer organizations (FPOs) as truthfully labelled (TFL) seed. Nearly 300,000 q seed demand was met by an informal seed system such as farm-saved seed, which was exchanged between farmers and their relatives, compromising seed quality [15].

3.2. Varietal diversification, BS indent and production status

In India, berseem is cultivated as a major green fodder crop in winter, particularly in irrigated areas of Punjab, Haryana, Madhya Pradesh, Chhattisgarh and Uttar Pradesh states. In berseem, DAC F&W (Department of Agriculture, Cooperation and Farmers Welfare), Govt. of India, hereafter known as 'DAC' have indented 24 varieties to the AICRP on FCU for BS production since 1998–99 (Table 1).

In India, berseem genetic improvement program is being carried out at ICAR Institute (IGFRI–Jhansi) and several SAUs such as Punjab Agricultural University (PAU–Ludhiana), Jawaharlal Nehru Krishi Viswavidyalaya (JNKVV–Jabalpur), Chaudhary Charan Singh Haryana Agricultural University, (CCSHAU–Hisar), Govind Ballabh Pant University of Agriculture and Technology (GBPUAT–Pantnagar) etc. Concerted efforts have led to the release of 27 varieties in the crop from 1998 to 2022. Pusa Giant and Mescavi were the first varieties released in 1975 and later came into the seed chain. Besides, PAU–Ludhiana had contributed maximum varieties (8) in the seed chain, followed by IGFRI–Jhansi (6), JNKVV–Jabalpur (5) and CCS HAU–Hisar (3). Most of the varieties were developed through selection breeding methods with high green fodder yield and some specific traits in mind (Table 1). Few old but popular varieties (JB-1, Mescavi, Wardan and BL-10) have covered pan India due to their high seed yield, better adaptability and high green forage yield under different agro-climatic conditions, whereas others were released for particular regions.

In the last 24 years, BS production was surplus in only nine years as compared to the DAC indent, and in other years, BS production could not meet the BS demand (Fig. 3). In the first 16 years (1998–99 to 2013–14), the average number of varieties were less than 10, which increased to more than ten since 2014–15 (Fig. 3). Twenty-four years data were grouped into six blocks of four years each for

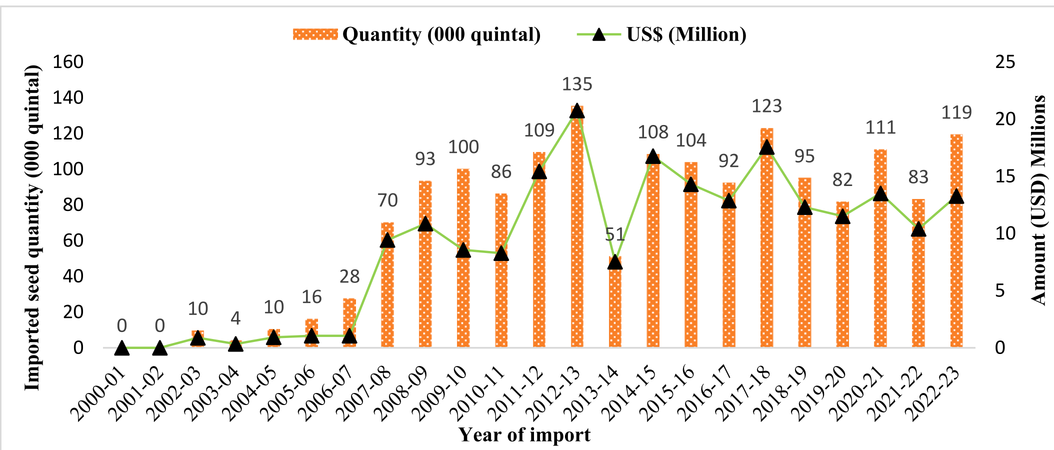


Fig. 2. The significant trend in Berseem seed import (000 quintals) and its value (US$ million) in India since 2001–02 provides a comprehensive and detailed view of the historical and current import scenario [47].

Table 1
A detailed description of the berseem varieties indented during the last 24 years in India (1998–99 to 2021–22) [48].

S. N.	Variety*	Year of release/ notification	Breeding method/source	Parent institute	GFY (q/ ha)[@]	Area of adoption#	Specific features
1.	Pusa Giant	1975	Selection after diploidization of C-10 cultivar (diploid)	IARI, New Delhi	500–600	Pan India	Frost tolerant, tetraploid
2.	Mescavi	1975	Selection from the introduced material from Egypt	CCS HAU, Hisar	580–620	PB, HR, Delhi, UK, UP, and MP	Quick regeneration, wide adaptability
3.	BL-1	1978	Selection from Mescavi cultivar	PAU, Ludhiana	600–650	PB	Early maturity
4.	JB-1	1982	Selection from local material collected from Chhindwara, MP	JNKVV, Jabalpur	700–750	MP, CG, BR and UP	High regeneration potential
5.	Wardan	1982	Selection from accession No. 526	IGFRI, Jhansi	600–650	Pan India	Wider adaptability, tolerance to bacterial wilt
6.	BL-10	1985	Selection from Indigenous material	PAU, Ludhiana	800–900	PB, HR, Delhi, HP and Jammu	Late maturity, resistance to stem rot disease
7.	BL-22	1988	Selection from an irradiated population of Mescavi cultivar	PAU, Ludhiana	480–520	PB, HR, HP, and Jammu	Late maturity
8.	BL-2	1989	Selection from Indigenous material	PAU, Ludhiana	500–550	PB, HR, Delhi, HP, UK and Western UP	Medium maturity
9.	UPB 110	1993	Composite selection from seven berseem lines	GBPUAT, Pantnagar	500–600	North-west, central and south India	Late maturity
10.	BB-2	1997	Selection from the Indigenous material (25776-4-P6)	IGFRI, Jhansi	700–750	PB, HR, UK, part of UP, MP and MH	Superior digestibility, resistance to root rot and stem rot
11.	BB-3	2001	Modified mass selection on tetraploid Indigenous line JHB-89-3	IGFRI, Jhansi	500–550	Eastern UP, BR, JH, WB, Orissa and Assam	Tetraploid, poor in seed setting
12.	JB-2[a]	–	Selection from the irradiated population	JNKVV, Jabalpur	500–600	MP	Multi-cut
13.	JB-3[a]	–	Selection from the irradiated population	JNKVV, Jabalpur	500–600	MP	Multi-cut
14.	JB-5	2005	Recurrent selection from the colchicine-treated material	JNKVV, Jabalpur	550–580	MP, parts of UP, MH, GJ and CG	Late maturity, resistance to stem rot
15.	BL-180	2006	Selection from the irradiated population of BL-10 cultivar	PAU, Ludhiana	500–550	PB, HR, RJ, UK, HP and Jammu	Photo insensitive, late maturity
16.	HB-1	2006	Selection from germplasm no.6 (307011, 11-OP)	CCS HAU, Hisar	600–650	PB, HR, and plain hilly areas of HP and Jammu	Resistance to stem rot and root rot
17.	BL-42	2007	Selection from the irradiated population of BL-2 cultivar	PAU, Ludhiana	600–700	PB, HR and HP	Resistance to stem rot
18.	HB-2	2014	Selection from the irradiated population of Mescavi cultivar	CCS HAU, Hisar	650–700	HR	Late maturity
19.	JBSC-1	2018	Selection from the material (EC 318954) introduced from Germany	IGFRI, Jhansi	150–200	MH, RJ, PB, HR, UP and MP	Single cut, suitable for short-duration conditions
20.	BL- 43	2019	Selection from the poly cross of five varieties	PAU, Ludhiana	550–580	PB	Semi-erect plant-type
21.	JB-05-09	2019	Selection from the irradiated population of JB-1 cultivar	JNKVV, Jabalpur	650–680	PB, HR and UK	Medium duration, tolerance to lodging
22.	BL-44	2021	Selection from a poly cross of nine varieties	PAU, Ludhiana	750–800	Tarai part of UK, PB, HR, RJ, WB, JH, BH, Eastern UP, and Orissa	Resistance to stem rot, late maturity
23.	BB-5	2021	Phenotypic recurrent selection	IGFRI, Jhansi	800–850	Tarai part of UK, PB, HR, RJ, WB, JH, BH, Eastern UP, and Orissa	Late maturity, resistance to *H. armigera,* fast regrowth
24.	BB-6	2021	Phenotypic recurrent selection	IGFRI, Jhansi	750–800	Tarai part of UK, PB, HR, RJ, WB, JH, BH, Eastern UP, and Orissa	Late maturity, resistance to *H. armigera,* fast regrowth

*JB: Jawahar Berseem, BL: Berseem Ludhiana, BB: Bundel Berseem, HB: Hisar Berseem; Wardan is also known as S-99-1, BB-2 as JHB-146, BB-3 as JHTB-96-4, HB-1 as HFB-600, BL-43 as PC-75, BL-44 as PC-91, BB-5 as JHB-17-2, BB-6 as JHB-17-1; GFY[@]: Average green fodder yield (q/ha). [#]PB: Punjab, RJ: Rajasthan, HR: Haryana, UK: Uttarakhand, BR: Bihar, CG: Chhattisgarh, MP: Madhya Pradesh, GJ: Gujarat, UP: Uttar Pradesh, JH: Jharkhand, WB: West Bengal, HP: Himachal Pradesh. [a]Varietal notification year of JB-2 and JB-3 is unknown.

better understanding and comparison, and the first block (1998–99 to 2001–02) was considered as the base year block to ascertain the percent change in subsequent blocks in BS indent and production (Table 2). The study revealed that BS indent decreased staggered in successive blocks. Indent reduced by 15.50 % in the second block (2002–03 to 2005–06), 30.76 % in the fifth (2014–15 to 2017–18) and 26.59 % in the sixth (2018–19 to 2021–22) block. However, indent was increased by 5.47 % and 13.35 % in the third (2006–07 to

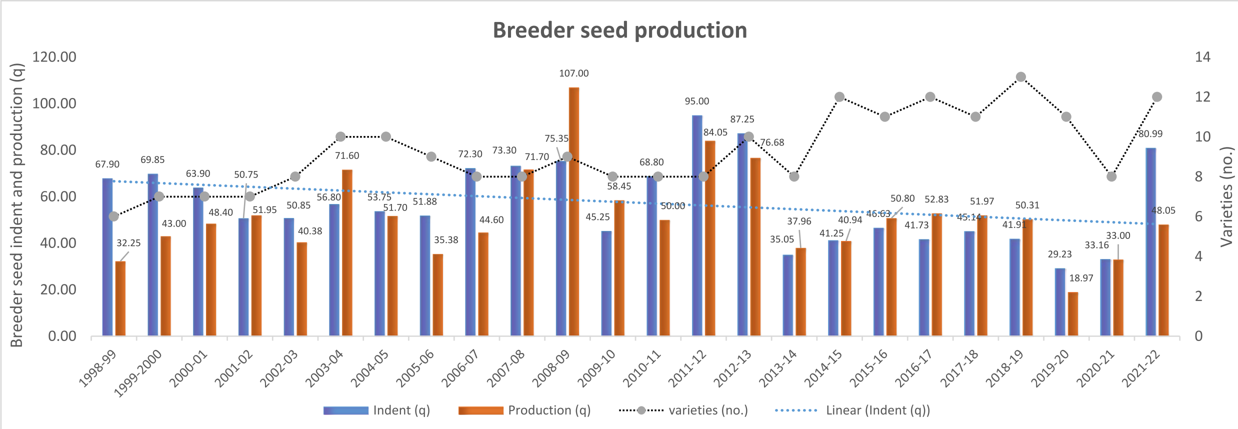


Fig. 3. The pivotal role of berseem BS indent, production, and number of varieties over the last 24 years (1998–99 to 2021–22) in the seed chain in India is crucial and cannot be overstated for understanding the dynamics of seed production.

Table 2
Percent change of berseem BS indent and production at four-year intervals in India during the last 24 years (1998–99 to 2021–22).

Years[a]	Indent		Production		Overall	
	Quantity (q)	% change	Quantity (q)	% change	Surplus/Deficit (q)	Surplus/Deficit (%)
1998–99 to 2001–02 (First block)	252.40	–	175.60	–	−76.80	−30.43 %
2002–03 to 2005–06 (Second block)	213.28	−15.50	199.06	+13.36	−14.22	−06.67 %
2006–07 to 2009–10 (Third block)	266.20	+05.47	281.75	+60.45	+15.55	+05.84 %
2010–11 to 2013–14 (Fourth block)	286.10	+13.35	248.69	+41.62	−37.41	−13.08 %
2014–15 to 2017–18 (Fifth block)	174.75	−30.76	196.54	+11.92	+21.79	+12.47 %
2018–19 to 2021–22 (Sixth block)	185.29	−26.59	150.33	−14.39	−34.96	−18.87 %
Total	1378.02		1251.97		−126.05	−9.15 %

[a] first four years (1998–99 to 2001–02) were considered the base year block, and percent change was calculated over the base year block.

2009–10) and fourth (2010–11 to 2013–14) blocks, respectively, over the base (252.40q) block (Table 2). The BS production is directly associated with the BS indent allocated to different production centers in the country. BS production was increased over the base block (175.60q) except in the sixth block, when production was reduced by 14.39 %. Nonetheless, BS production in the different blocks could not meet the BS indent during the last 24 years except in the third (5.84 % surplus) and fifth (12.47 % surplus) blocks.

3.3. Varietal BS indent and production status

BS production of high-yielding varieties greatly impacts crop productivity, socio-economic footprint and livelihood of end users such as farmers and livestock keepers. Each berseem variety's BS indent and production in the seed supply chain were categorized into the same six blocks (Table 3). The percent share of JB-1 (37.2 %) was the highest, followed by Mescavi (14.5 %) and BL-22 (13.5 %) for BS indent during the first block. Likewise, BS indents of varieties JB-1 and Mescavi were highest during the second and third blocks. However, a significant change was observed during the fourth block, where BL-10 (21 %), followed by Wardan (17.4 %) and BL-42 (14.8 %), shared the maximum stake in the total BS indent (Table 3). In addition, BS indent for BL-10 (60.18 q) was highest, followed by BL-42 (38.97 q) in the fifth block, whereas variety Wardan (34.3 q) followed by BL-43 (22.19 q) had the maximum share in BS indent during the sixth block. Amongst the indented berseem varieties, BS production was in surplus against the indent for 12 varieties only. During 1998–99 to 2021–22, the highest BS indent was received for JB-1 (276.05 q), followed by BL-10 (205.08 q), Mescavi (165.55 q) and Wardan (153.7 q). Likely, BS production was found to be highest for JB-1 (361.18 q), followed by BL-10 (187.25 q), Wardan (147.25 q), and Mescavi (115.72 q) (Table 3). Amongst the ruling varieties, the BS indent of variety JB-1 gradually decreased from 93.9 q (first block) to 1.0 q (sixth block), whereas varieties like Mescavi and BL-1 were inconsistent but decreased over the years (Fig. 4A). However, variety BL-10 BS indent gradually increased up to the fifth block but drastically reduced in the sixth block. Likewise, Wardan BS indent has risen steadily, from 16.3 q during the first block to 34.0 q during the sixth block. Likely, the share of JB-1 in BS indent has reduced significantly inconstant to Wardan and BL-10 over time (Fig. 4B).

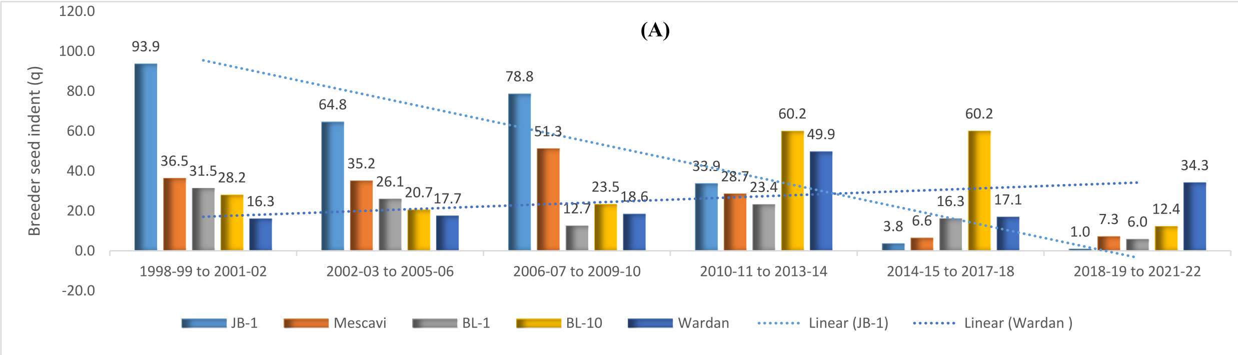
3.4. Center-wise BS allocation and production status

In India, as per the procedure, different agencies give indents for BS after notification of respective varieties. BS indents are allocated preferentially to the institutions that have developed the particular variety. Suppose the institution cannot produce the

Table 3
Varietal BS indent and production of berseem varieties and their contribution every four years interval during the last 24 years (1998–99 to 2021–22) in India [48].

	1998-99 to 2001–02 (First)			2002-03 to 2005–06 (Second)			2006-07 to 2009–10 (Third)			2010-11 to 2013–14 (Fourth)			2014-15 to 2017–18 (Fifth)			2018-19 to 2021–22 (Sixth)			Overall		
	I	P	Net*	I	P	Net*	I	P	Net*	I	P	Net*	I	P	Net*	I	P	Net*	I	P	Net*
Mescavi	36.5 (14.5)	15.5 (8.8)	−21.00	35.2 (16.5)	19.92 (10)	−15.28	51.3 (19.3)	38.2 (13.6)	−13.10	28.7 (10)	30 (12.1)	+1.30	6.55 (3.7)	6.6 (3.4)	+0.05	7.3 (3.9)	5.5 (3.7)	−1.80	165.55 (12)	115.72 (9.2)	−49.83
Pusa Giant				0.5 (0.2)		−0.50							0.1 (0.1)		−0.10				0.6 (0)	0 (0)	−0.60
BL-1	31.5 (12.5)	6.25 (3.6)	−25.25	26.13 (12.3)	26.2 (13.2)	+0.07	12.65 (4.8)	17.2 (6.1)	+4.55	23.35 (8.2)	25.8 (10.4)	+2.45	16.3 (9.3)	17.3 (8.8)	+1.00	6 (3.2)		−6.00	115.93 (8.4)	92.75 (7.4)	−23.18
JB-1	93.85 (37.2)	108.45 (61.8)	+14.60	64.75 (30.4)	73.5 (36.9)	+8.75	78.8 (29.6)	114.6 (40.7)	+35.80	33.9 (11.8)	55.65 (22.4)	+21.75	3.75 (2.1)	7.98 (4.1)	+4.23	1 (0.5)	1 (0.7)		276.05 (20)	361.18 (28.8)	+85.13
Wardan	16.25 (6.4)	18 (10.3)	+1.75	17.65 (8.3)	24.85 (12.5)	+7.20	18.55 (7)	18.9 (6.7)	+0.35	49.85 (17.4)	28.31 (11.4)	−21.54	17.1 (9.8)	18.94 (9.6)	+1.84	34.3 (18.5)	38.25 (25.4)	+3.95	153.7 (11.2)	147.25 (11.8)	−6.45
BL-10	28.15 (11.2)	12.9 (7.3)	−15.25	20.7 (9.7)	23.45 (11.8)	+2.75	23.5 (8.8)	26.1 (9.3)	2.60	60.15 (21)	48.3 (19.4)	−11.85	60.18 (34.4)	63.5 (32.3)	+3.32	12.4 (6.7)	13 (8.6)	+0.60	205.08 (14.9)	187.25 (15)	−17.83
BL-22	34.15 (13.5)	4.5 (2.6)	−29.65	13.15 (6.2)	7.59 (3.8)	−5.56	1 (0.4)	2 (0.7)	1.00	4.1 (1.4)	1.03 (0.4)	−3.07							52.4 (3.8)	15.12 (1.2)	−37.28
BL-2										4 (1.4)		−4.00							4 (0.3)	0 (0)	−4.00
UPB 110													0.1 (0.1)		−0.10	10.8 (5.8)	0.02 (0)	−10.78	10.9 (0.8)	0.02 (0)	−10.88
BB-2	12 (4.8)	10 (5.7)	−2.00	17.7 (8.3)	16 (8)	−1.70	25.9 (9.7)	29.9 (10.6)	+4.00	2.1 (0.7)	5.5 (2.2)	+3.40	1.85 (1.1)	7.62 (3.9)	+5.77	15.2 (8.2)	12.45 (8.3)	−2.75	74.75 (5.4)	81.47 (6.5)	+6.72
BB-3				13.9 (6.5)	0.6 (0.3)	−13.30	45 (16.9)	22 (7.8)	−23.00	37.25 (13)	27.2 (10.9)	−10.05	17 (9.7)	7.8 (4)	−9.20	10 (5.4)	11.5 (7.6)	+1.50	123.15 (8.9)	69.1 (5.5)	−54.05
JB-2				0.6 (0.3)	0.65 (0.3)	+0.05													0.6 (0)	0.65 (0.1)	+0.05
JB-3				0.2 (0.1)	0.3 (0.2)	+0.10													0.2 (0)	0.3 (0)	+0.10
JB-5													2.5 (1.4)	4.72 (2.4)	+2.22	1.1 (0.6)	0.61 (0.4)	−0.49	3.6 (0.3)	5.33 (0.4)	+1.73
BL-180							2.1 (0.8)	3 (1.1)	+0.90	0.5 (0.2)		−0.50	6.7 (3.8)	7.9 (4)	+1.20	1.4 (0.8)	1.8 (1.2)	+0.40	10.7 (0.8)	12.7 (1)	+2.00
HB-1													1.25 (0.7)	3 (1.5)	+1.75				1.25 (0.1)	3 (0.2)	+1.75
BL-42				2.8 (1.3)	6 (3)	+3.20	7.4 (2.8)	9.85 (3.5)	+2.45	42.2 (14.8)	26.9 (10.8)	−15.30	38.97 (22.3)	41.9 (21.3)	+2.93	21.82 (11.8)	16.5 (11)	−5.32	113.19 (8.2)	101.15 (8.1)	−12.04
HB-2													2.4 (1.4)	9.28 (4.7)	+6.88	1.4 (0.8)	1.6 (1.1)	+0.20	3.8 (0.3)	10.88 (0.9)	+7.08
JBSC-1																9.54 (5.1)	11.9 (7.9)	+2.36	9.54 (0.7)	11.9 (1)	+2.36
BL- 43																22.19 (12)	23.05 (15.3)	+0.86	22.19 (1.6)	23.05 (1.8)	+0.86
JB-05-09																20.44 (11)	2.55 (1.7)	−17.89	20.44 (1.5)	2.55 (0.2)	−17.89
BL-44																10.4 (5.6)	10.4 (6.9)		10.4 (0.8)	10.4 (0.8)	
BB-5																	0.1 (0.1)	+0.10	0 (0)	0.1 (0)	+0.10
BB-6																	0.1 (0.1)	+0.10	0 (0)	0.1 (0)	+0.10

I: BS Indent (q), P: BS Production (q); *(±) indicates surplus or deficit BS production (q) compared to allocation (q); values in parentheses represent the percent contribution of each variety to the total BS indent and production; blank cell represents no BS indent or production during a particular phase.



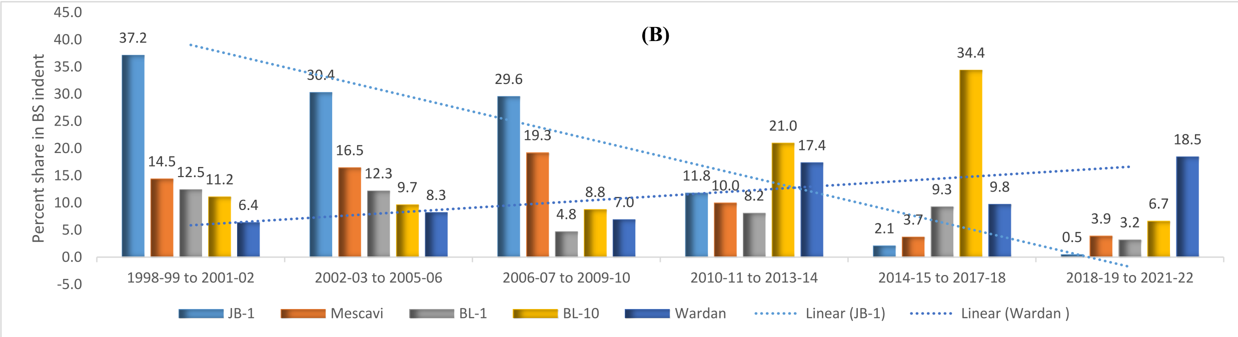


Fig. 4. The BS indent of the foremost five berseem varieties (A) and their percent contribution (B) to the total BS indent over the years in the last 24 years (1998–99 to 2021–22) in India.

indented quantity. In that case, the production target is given to another institution and the nucleus seed is supplied by the institution that has developed the variety (Table 4). The BS indent of 24 varieties was allocated to ten different centers, including government institutions, SAUs, and NGOs. The highest quantity of berseem BS was allocated to PAU–Ludhiana (530.64 q), followed by IGFRI–Jhansi (354.29 q), JNKVV–Jabalpur (307.14 q) and CCS HAU–Hisar (165.60 q) during 1998–99 to 2021–22. BS production was surplus over the allocation by 21.12 % in JNKVV–Jabalpur center only (Fig. 5). Besides, the percent share of PAU–Ludhiana (35.30 %) in BS production was highest followed by JNKVV–Jabalpur (29.71 %), IGFRI–Jhansi (24.13 %), and CCS HAU–Hisar (10.35 %). Three old but popular varieties had more than two production centers; for example, Wardan had five, BL-22 had three, and Mescavi had two centers. However, other varieties were allocated to the single-parent institute. The BS production of the JB-1 variety (85.13 q surplus), produced by JNKVV–Jabalpur, was highest, followed by BB-2 (6.72 q surplus) allocated to IGFRI–Jhansi, whereas the maximum gap between BS indent and production was recorded for BB-3 (−54.05 q) allocated to IGFRI–Jhansi followed by Mescavi (−49.83 q) allotted to CCS HAU–Hisar and ANDUAT–Ayodhya (Table 4). Overall, BS production (1251.97 q) in berseem was 126.05 q deficit against the indent (1378.02 q) from 1998 to 99 to 2021–22.

3.5. *Varietal replacement rate and varietal age*

In the face of unprecedented climate change, the varietal replacement rate, or VRR, is essential for boosting agricultural output and tolerance to biotic and abiotic pressures. In the study, 143.38 q BS indent was recorded during the last three years (2019–20 to 2021–22) in 12 notified berseem varieties and the contribution of <5 years varietal age was found to be 43.30 %. Likewise, varieties having <15 and >15 years of varietal age contributed 53.65 % and 46.35 % in the total BS indent, respectively (Table 5). Since 2017–18, the percent share of newly developed varieties (less than five years)has increased significantly; for example, the contribution of new varieties has increased from 1.15 % (2018–19) to 51.93 % (2021–22). Conversely, the contribution of old varieties (>15 years) has decreased gradually from 75.52 % (2018–19) to 45.99 % (2021–22) in the last five years (Fig. 6).

3.6. *Prediction of certified seed and estimated acreage*

Indian seed supply chain follows a three-tier seed production system, BS to foundation seed to certified seed. This study reported total BS production of 48.08 q in 12 different notified berseem varieties in 2021–22 (Fig. 3). Seed multiplication ratio (SMR) is an important parameter to predict foundation and certified seed. The SMR of berseem varieties is reported to be 25 [44]. Thus, the total foundation seed production would be 1201.25 q in 2022–23 if the seed supply chain operates at 100 % efficiency and other operations are carried out prudently (Table 6). Similarly, certified seed production would be 30,031.25 q in 2023–24 and can cover 0.12 Mha area

Table 4
BS allocation (q) and production (q) of berseem varieties at the institute level and net balance in the last 24 years (1998–99 to 2021–22).

Variety	Allocated center[a]	Allocation (q)	Production (q)	Surplus/Deficit (q)	Surplus/Deficit (%)
Wardan	IGFRI, Jhansi	146.85	139.39	−7.46	−5.08
	JNKVV, Jabalpur	4.00	1.50	−2.50	−62.50
	MPKV, Rahuri	1.85	3.26	+1.41	+76.22
	BAIF, Urulikanchan	1.00	0.50	−0.50	−50.00
	ANDUAT, Ayodhya	0.00	2.60	+2.60	0.00
Mescavi	CCSHAU, Hisar	160.55	115.72	−44.83	−27.92
	ANDUAT, Ayodhya	5.00	0.00	−5.00	−100.00
BL-22	PAU, Ludhiana	49.15	14.62	−34.53	−70.25
	JNKVV, Jabalpur	2.25	0.50	−1.75	−77.78
	SKUAST, Rajouri	1.00	0.00	−1.00	−100.00
BB-2	IGFRI, Jhansi	74.75	81.47	+6.72	+8.99
BB-3	IGFRI, Jhansi	123.15	69.10	−54.05	−43.89
BB-5	IGFRI, Jhansi	0.00	0.10	0.10	0.00
BB-6	IGFRI, Jhansi	0.00	0.10	0.10	0.00
BL-43	PAU, Ludhiana	22.19	23.05	+0.86	+3.88
BL-1	PAU, Ludhiana	115.93	92.75	−23.18	−19.99
BL-10	PAU, Ludhiana	205.08	187.25	−17.83	−8.69
BL-180	PAU, Ludhiana	10.70	12.70	+2.00	+18.69
BL-2	PAU, Ludhiana	4.00	0.00	−4.00	−100.00
BL-42	PAU, Ludhiana	113.19	101.15	−12.04	−10.64
BL-44	PAU, Ludhiana	10.40	10.40	0.00	0.00
HB-1	CCSHAU, Hisar	1.25	3.00	+1.75	+140.00
HB-2	CCSHAU, Hisar	3.80	10.88	+7.08	+186.32
JB-05-09	JNKVV, Jabalpur	20.44	2.55	−17.89	−87.52
JB-1	JNKVV, Jabalpur	276.05	361.18	+85.13	+30.84
JB-2	JNKVV, Jabalpur	0.60	0.65	+0.05	+8.33
JB-3	JNKVV, Jabalpur	0.20	0.30	+0.10	+50.00
JB-5	JNKVV, Jabalpur	3.60	5.33	+1.73	+48.06
JBSC-1	IGFRI, Jhansi	9.54	11.90	+2.36	+24.74
Pusa Giant	IARI, New Delhi	0.60	0.00	−0.60	−100.00
UPB 110	GBPUAT, Pantnagar	10.90	0.02	−10.88	−99.82
	Total	**1378.02**	**1251.97**	**−126.05**	**−9.15**

[a] IGFRI: Indian Grassland and Fodder Research Institute, Jhansi; JNKVV: Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur; MPKV: Mahatma Phule Krishi Vidyapeeth, Rahuri; BAIF: Bharatiya Agro Industries Foundation, Urulikanchan; ANDUAT: Acharya Narendra Dev University of Agriculture and Technology, Ayodhya: CCS HAU: Chaudhary Charan Singh Haryana Agricultural University, Hisar; PAU: Punjab Agricultural University, Ludhiana; SKUAST: Sher-e-Kashmir University of Agricultural Sciences and Technology, Srinagar; IARI: Indian Agricultural Research Institute, New Delhi; GBPUAT: G.B. Pant University of Agriculture and Technology, Pantnagar.

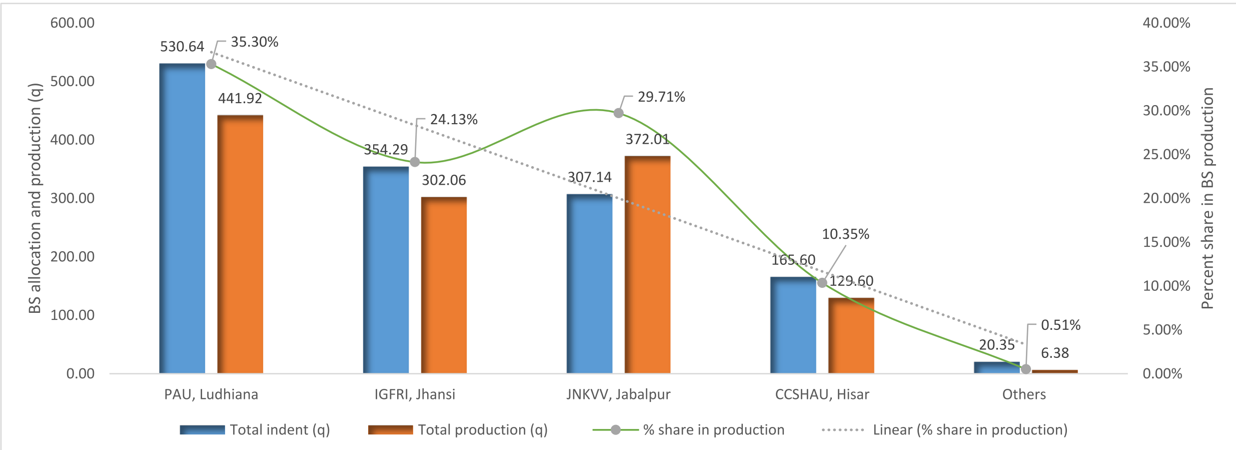


Fig. 5. Representation of total BS production against the allocation at the major centers and their percent contribution to the berseem BS production during 1998–99 to 2021–22 in India.

Table 5
Varietal replacement rate (VRR) in berseem during the last three years (2019–20 to 2021–22).

Number of total notified varieties	No. of varieties in the seed chain	Total BS indent (q)	Varieties <5 years old			Varieties <15 years old			Varieties >15 years old		
			No.	Indent (q)	% share in total indent	No.	Indent (q)	% share in total indent	No.	Indent (q)	% share in total indent
24	12	143.38	4	62.09	43.30	5	76.93	53.65	7	66.45	46.35

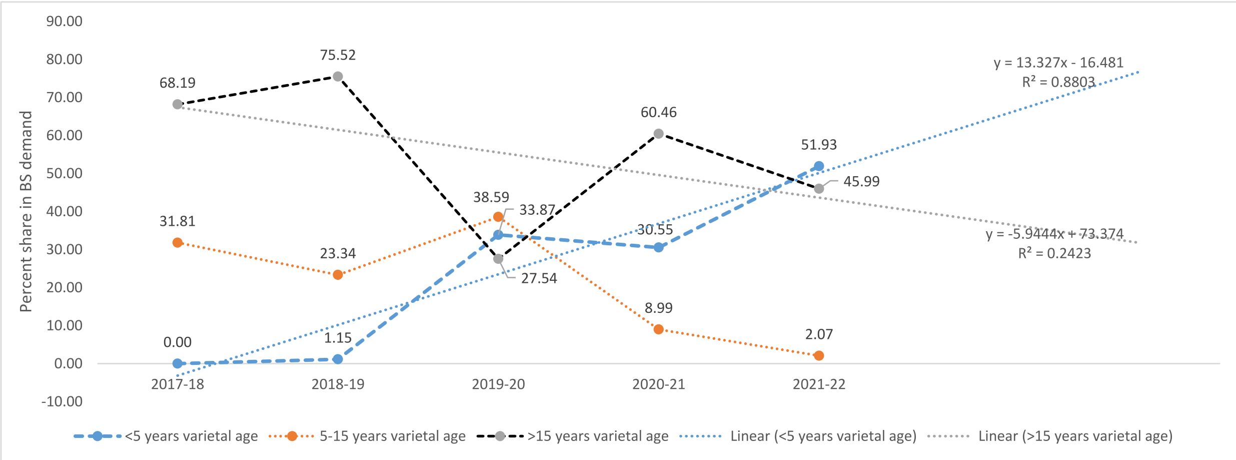


Fig. 6. Percent contribution of berseem varieties (<5 years, 5–15 years and >15 years varietal age) to the total BS indent during the last five years (2017–18 to 2021–22).

across the country for berseem cultivation.

4. Discussion

4.1. BS demand and impact

Forage crops require adequate quality seed production and an efficient seed supply chain to meet the burgeoning livestock population's fodder, feed and nutritional demand, particularly in developing countries [49]. In India, berseem is cultivated as a major fodder crop in the winter season and covers nearly 2M ha under different agro-climatic conditions [44]. It has been estimated that 500, 000 q certified seed is required to cover the projected area under the berseem crop if it follows a 100 % seed replacement rate (SRR). SSR can be increased by improving the seed multiplication rate (SMR), subsidizing the cost of seed, involving public-private partnerships in seed multiplication and distribution, improving the complementary infrastructure (Plant protection and fertilizer sources, irrigation facilities, market accessibility), decentralized seed production system, on-farm forage technology demonstrations (FTDs), etc. Estimated certified seed could be met by producing 20,000 q foundation seed and 800 q BS annually, assuming a 100 % effective seed chain at all stages with 25 SMR [44]. In the last ten years (2011–12 to 2020–21), on an average, 101,062 q (monetary value of approximately 14$ million dollars per year) seed was imported and 31,094.4 q was produced by the formal seed system and estimated to cover 0.54 Mha area under berseem in the country. In addition, BS (48.05 q) produced during 2021–22 could produce only 30, 031.25 q certified seed in 2023–24 and would contribute only 6.0 % and 20.02 % to the total seed requirement (100 % SRR) and actual seed requirement (30 % SRR), respectively. Besides, 'informal and unorganized' (farmer to farmer) and 'organized but informal' (local small-scale seed-producing companies) seed supply systems play key roles and meet almost 70 % of domestic seed demand in the country. For example, it has also been reported that 1,00,000 q of seed is being sold annually in the 'Mandis' of Dabra, Gwalior, Morena and Sabalgarh regions of Madhya Pradesh state (*personal communication*). These systems produce seeds of unknown or mixed varieties with unassured quality control. It highlights the fact that there is a need to increase BS production up to 250 q per annum to curb the seed import without compromising domestic seed demand.

4.2. Varietal diversification and varietal replacement rate

The timely availability of quality seed plays a vital role in the overall production and meeting the ever-increasing fodder demand. In forage crops, varieties have been bred mainly for high vegetative growth, which often reduces the seed yield [50]. Crop and varietal diversifications may improve farm productivity, profitability and food security and increase resilience against climate change [51,52]. Varietal diversification is a practical approach for farmers to minimize farm losses and is also considered a prominent tool to stabilize

Table 6
Prediction of foundation and certified seed production in berseem from the available breeder seed in India.

Crop	Seed rate (kg/ha) for		SMR^	Approx. area^ (Mha)	Seed requirement (q)			Seed production (q)			Estimated area covered (Mha) (2024–25)
	Fodder production	Seed production			BS (2021–22)	FS (2022–23)	CS (2023–24)	BS (2021–22)	FS (2022–23)	CS (2023–24)	
Berseem	25	20	25	2.0	800	20000	500000	48.05	1201.25	30031.25	0.12

^according to **Chauhan et al., 2017**; SMR: Seed multiplication ratio; BS: Breeder seed; FS: Foundation seed; CS: Certified seed.

crop revenue and farm income [53,54]. Of 27 released berseem varieties, 24 are in the seed supply chain until 2021–22. Thus, almost 90 % of the notified varieties are in a seed supply system that provides farmers or seed production companies with baskets of options to grow the best variety per their resource availability, agro-climatic conditions and demand. Berseem varieties were developed mainly for green and dry forage and crude protein content for different agro-climatic conditions of India; however, they have specific features such as tolerance to abiotic (e.g., frost, cold, salinity etc.) and biotic (e.g., stem rot, root rot, fall armyworm etc.) stresses, quick regeneration and wide adaptability, multi-cut and late maturity for prolonged fodder source etc.

Varietal age is an important indicator in determining the technology transfer by the extension workers, adoption efficiency by the farmers and varietal acreage at the farmer's field. Farm productivity and profitability are negatively associated with varietal age as old varieties (>10–15 years in seed chain) are prone to climate change and vulnerable to disease and insect pest outbreaks [55]. In this study, VRR for <5 years varietal age was significantly high (43.30 %) from 2019 to 20 to 2021–22, indicating the effective diffusion and proper technology transfer of the recently released varieties into the farmers' field. Likely, the percent share of <5 years old varieties has increased significantly during the last five years (2017–18 to 2021–22); therefore, farmers are taking advantage of high-yielding varieties. The VRR for fodder lucerne was moderate, or 23.67 %, for the cultivars less than 5 years old from 2019 to 20 to 2021–22 [50]. In other crops, the highest VRR for varieties having <5 years of age was reported for wheat (45.3 %), followed by soybean (41.5 %), chickpea (28.4 %), mung bean (16.9 %), and rice (14.8 %) during 2017–18 to 2019–20 under public sector [55]. Several factors affect the VRR at institutional, technical, environmental and socio-economic levels and play critical roles in adopting new varieties in farmer's fields. Low private investment in high volume-less value crops [56], the gap between varietal notification and its induction in the seed chain [57], non-availability of quality seeds of newly released varieties [58], low per capita income of the farmers [59] and slightest varietal knowledge, input accessibility [60], small land holding [61], subsistence farming [62], etc. affect the VRR in crops.

4.3. BS demand and production discrepancy

Breeder seed has the highest level of genetic and physical purity, and its production decides the availability of quality seed to the farmers through various stages (Breeder, foundation and certified seed) in the seed supply chain [63]. In India, public sector institutions and agencies are solely responsible for producing BS and providing it to the indenters for seed multiplication [64,65]. For instance, ICAR, with the help of its organizations viz., AICRPs, research institutes, SAUs, etc., produces BS in all crops for the county.

In berseem, BS indent was found inconsistent over the years since 1998–99; the average BS indent for the first 15 years (1998–99 to 2012–13) was around 65 q, but indent significantly decreased (<40 q average) for the next eight years (2013–14 to 2020–21). Remarkably, BS indent reached 80.99 q during 2021–22. In contrast, increasing trends of BS over the years were recorded in food crops such as rice [65], wheat [66], barley [64], and pulses [67]**.** Few probable but imperative causes might be associated with reduced BS demand in the country. Firstly, the cultivated berseem area is shifted into fodder crops such as lucerne. Both berseem and lucerne forage crops are leguminous and have nutritional superiority over the other leguminous and grass species cultivated in the regions during winter. Berseem is a winter hardy, short-duration, and higher-water requirement crop than lucerne, and it is predominantly grown in the North-Western Indian states. Mostly, it is scientifically proven that increased BS demand in one crop affects the demand and area in other crops. However, BS indent of lucerne during the last 20 years (2002-03 to 2021–22) indicated that the area under lucerne crop has also declined significantly (Fig. 7). Additionally, the cultivable agro-ecological areas for the two crops differ; for example, berseem is mostly grown in the northwest states, viz., Punjab, Haryana, Uttar Pradesh, and portions of Rajasthan and Madhya Pradesh. Conversely, lucerne is mainly cultivated in the central and southern states such as Maharashtra, Gujarat, Tamil Nadu, and Karnataka [67]. Secondly, the disparity between BS indent and production also affects the demand for BS in subsequent years. BS production could not meet the indent for the first decade (1998–99 to 2007–08), but production was higher than indent in the next decade (2008–09 to 2017–18), whereas a contrary trend was found for the next four years (2018–19 to 2021–22). Less BS production than indent could affect the indenter to search for other crops or options to import to meet their customer/client demand in the long term, leading to reduced BS demand in the future. For example, the production centers could not fulfill BS demand for varieties BL-1 and BL-2; therefore, their seed demand was shifted to other varieties available in the seed chain. The BS production of JB-1 was always higher than its indent; hence, the variety was most popular among all other varieties. JB-1 and Wardan varieties were released in the same year (1982), but JB-1 ruled over other varieties for 12 years (1998–99 to 2009–10) due to its high regeneration potential and broader adaptability. However, later BL-10 was the leading variety both in BS indent and production, followed by Wardan, BL-42, BB-3, JB-1 (fourth block) and BL-2, Wardan, BB-3 and BL-1 (fifth block) (Table 4). BL-10 received a higher indent due to its higher fodder yield ability (800-900q/ha) than other contemporary varieties. In the last four years (2018–19 to 2021–22) period, the Wardan variety got wider popularity among farmers and received the highest indent and production of BS, followed by BL-43, BL-42, JB-05-09 and BB-2 (Fig. 4). The growing demand for Wardan variety was due to its wider adaptability across the different agro-climatic zones and tolerance to bacterial wilt disease. Of 19 varieties released before 2020, BS production was higher than BS indent cumulative during the last 24 years in only eight varieties (Table 4).

Thirdly, private seed businesses have made substantial efforts to produce and directly sell seeds to farmers. This involves a comprehensive process from seed selection to sales, demonstrating their commitment to the industry. Over 500 private companies are actively engaged in seed production, accounting for over 80 % of seed sales in India. Their primary focus is on high-value and low-volume crops [45,68,69]. They have an advantage over government initiatives for transferring their innovations to farmers' fields because of their extensive extension programs, effective marketing techniques, and active farmer participation. Private enterprises engage in large-scale seed production through contracts with farmers. These farmers receive high-quality seeds and additional inputs from the seed firms, underscoring their active role in the industry [45]. These businesses pay fair prices for the farm produce, which

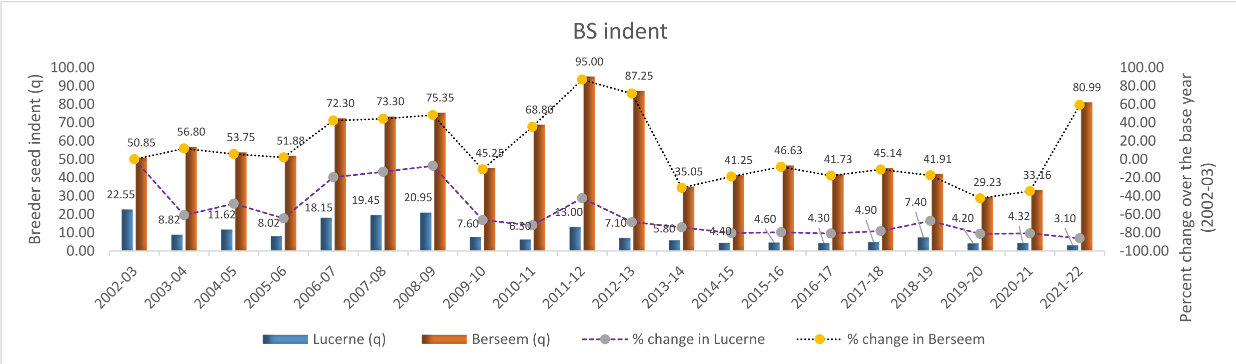


Fig. 7. Comparison of BS indent for lucerne and berseem crops in India during the last 20 years. The Plot series on the secondary axis represents the percent change in BS indent over the base year (2002–03).

they then process or grade and sell at competitive prices to the markets. Fourthly, The unauthorized seed industry, especially farmers who cultivate seed on their properties, shares it with family members and sells it to neighboring farmers [70].

4.4. Breeding constraints and future perspective

As an introduced crop in India, a narrow genetic base is a major handicap in the genetic improvement program. The primary breeding targets besides biomass and nutritive quality were resistance to root rot, stem rot, blight, tolerance to moisture and salinity stress [71]. Breeding target traits remained unchanged over decades, and comparatively small genetic gains have been observed in breeding methods compared to other crops, mainly cereals. Despite being a popular fodder crop in central and northern India, the genetic improvement program was limited to only a few research institutions such as IGFRI–Jhansi, GBPUAT–Pantnagar, PAU–Ludhiana, CCS HAU–Hisar, JNKVV–Jabalpur etc. Low level of genetic gain is due to several factors like a narrow genetic base of the primary gene pool, limited availability of genomic resources, self-incompatibility, heterozygous nature and small flower size [72–76]. Being a fodder crop, the most crucial target trait in berseem is increased biomass. Direct selection for increased seed yield was not found effective [77]; therefore, indirect selection of ancillary traits such as heads/plant, seeds/head, and seed weight could be rewarding for seed yield improvement. Simultaneous selection for biomass yield and seed yield was very effective as they have a weak positive association [78–80]. However, the number of branches/plant positively correlates with seed and biomass yields. Increased biomass is associated with plant height, number of branches, stem thickness, leaf size, number of leaves, re-growth capacity etc. [81–83]. Therefore, indirect selection plays a significant role in enhancing forage biomass and seed yield. Sacrificing one cut also improves seed production. However, farmers prefer buying fresh seeds from the market to increase green fodder.

Besides, the transfer of desirable traits from related species was unsuccessful due to the post-zygotic fertilization barrier. Concerted efforts using embryo rescue techniques led to several successful interspecific hybrids, which enriched the variability [84]. A few successful interspecific hybrids were developed by crossing between *T. alexandrinum* × *T. apertum* [85,86], *T. alexandrinum* × *T. resupinatum* [87], *T. alexandrinum* × *T. constantinopolitanum* [88]. Another line of efforts in developing tetraploids using colchicine led to another variety, Bundel berseem-3, in 2001 [89]. The genetic similarity and potential donors were identified in a systematic study of 134 accessions belonging to 25 species [90]. In addition, mutation breeding has been used extensively to develop varieties in PAU–Ludhiana and JNKVV–Jabalpur. A single-cut variety, JBSC-1, was developed at IGFRI–Jhansi using a different ecotype of berseem and released in 2017 [89].

The future breeding program must be focused on broadening the genetic base through pre-breeding and characterization of germplasm for biotic and abiotic stresses, identification of resource–use efficient genotypes, especially for water and phosphorus, development of genetic and genomic resources, identification of trait-specific donor germplasm, and integration of molecular breeding applications with conventional breeding programs.

5. Conclusions

The current study examined the demand for high-quality seed and the production situation of well-known berseem varieties, India's most significant wintertime legume crop. A twenty-four-year comparative analysis of indent and production data of breeder seeds of different varieties resulted in an idea of varietal seed replacement and the average age of varieties. Further, it highlights the fact that there is a need to increase the quality of the seed production chain, possibly through FPOs, a crucial ingredient to increase farm productivity as well as farmers' income. We also described the breeding challenges in berseem and pertinent options to break the yield plateau. The article will be helpful for policymakers and researchers in increasing forage resources further, especially in terms of seed quality in the country.

Data availability

No, Data will be made available on request.

CRediT authorship contribution statement

Subhash Chand: Writing – review & editing, Writing – original draft, Software, Formal analysis, Data curation, Conceptualization. **Ajoy Kumar Roy:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Investigation, Formal analysis, Conceptualization. **Sanjay Kumar:** Writing – original draft, Formal analysis, Data curation. **Tejveer Singh:** Writing – review & editing, Writing – original draft, Visualization, Supervision. **Vijay Kumar Yadav:** Validation, Resources, Project administration, Investigation, Conceptualization. **Swami Sunil Ramling:** Writing – original draft, Software. **Rajiv Kumar Agrawal:** Supervision, Methodology, Conceptualization. **Devendra Ram Malaviya:** Supervision, Resources. **Awnindra Kumar Singh:** Writing – review & editing, Resources. **Ram Vinod Kumar:** Writing – review & editing, Supervision. **Krishna Kumar Dwivedi:** Writing – review & editing, Validation. **Amaresh Chandra:** Visualization. **Devendra Kumar Yadava:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors acknowledge the Indian Council of Agricultural Research (ICAR), the Indian Grassland and Fodder Research Institute, Jhansi (UP), India, and ICAR-AICRP on Forage Crops and Utilization (FCU) for supplying all the required information. They also express their gratitude to the thoughtful employees of AICRP's FCU centers across the country who produce breeder seeds.

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