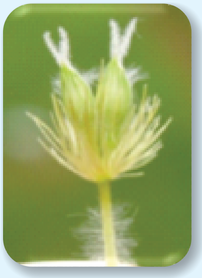
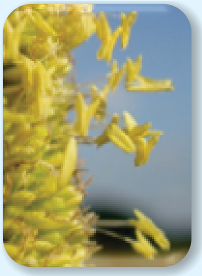
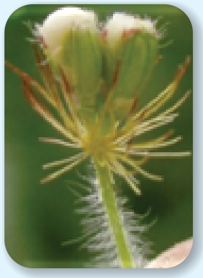
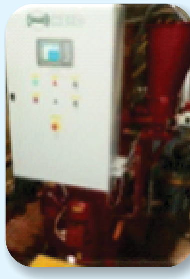
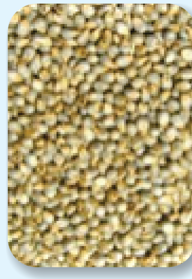
Pearl Millet Seed Production and Processing

OP Yadav, RS Mahala, KN Rai, SK Gupta, BS Rajpurohit and HP Yadav

भाकृअनुप
ICAR

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Foreword

Use of improved seed has made a tremendous impact on productivity of field crops including pearl millet, which is a very important dual-purpose crop providing both grain and stover. Pearl millet is now widely recognized as health food and its stover is an important fodder resource in the arid and semi-arid tropical regions of Asia, Africa and Latin America. Commercial cultivar types available in pearl millet include hybrids and open-pollinated varieties (OPVs). India is the largest grower and producer among more than 30 pearl millet growing countries, and have a distinction of being the first country in the world to produce grain hybrids in 1960s using cytoplasmic-nuclear male-sterility (CMS) system. Since then extensive advances have been made in cultivar development, seed production and seed processing of pearl millet.

During the last 30 years, 125 high-yielding hybrids and 29 OPVs with in-built resistance to downy mildew and tolerance to various abiotic stresses have been developed for various production ecologies, and several of them have been widely adopted by farmers. The area under improved cultivars has increased considerably over the years and currently >70% of pearl millet area is under improved cultivars, mostly hybrids. The crop productivity has gone up from 288 kg/ha in 1950 to 1164 kg/ha during 2013-14, registering four-fold increase in productivity. This is a tremendous achievement, given that most of the pearl millet crop is grown under risky and hostile agro-ecologies of north-western India by poor farmers.

Seed production programme of improved pearl millet cultivars has evolved rapidly and very extensively in India. The 'seed village' concept involving multiplication of specific cultivars in particular villages has been effectively used to undertake seed production programme in non-traditional area for pearl millet, largely in southern India. Seed production by small farmers under contractual arrangement with seed corporations and private seed companies is a unique example of willingness of Indian farmer to embrace new and intricate technology to produce genetically pure seed with high seed vigour and quality. During last two decades, yield levels in seed production plots of hybrids have doubled, mainly due to development of high-yielding parental lines and improved crop management skills of farmers. Seed processing process has also been shortened considerably, reducing the time period from harvesting to delivery of seed in target regions within a month. This circumvents the need of storage of seed over season, resulting in reduced overhead cost. At present, the National Seeds Corporation, State Seeds Corporations and several private sector seed companies produce and market seed of over 120 hybrids and a few OPVs in different parts of pearl millet growing regions.

The present book 'Pearl Millet Seed Production and Processing' authored by scientists with fairly long experience in pearl millet research-for-development provides a brief overview of strategies followed in cultivar development with elaborate treatment of seed production and processing technologies in pearl millet and would be of immense values to seed producing and other developmental agencies. It is hoped that the experience and success story of pearl millet in India may be useful for those dealing with this crop in other countries, as well for those dealing with hybrid seed production of other crops.

10/3/15

(J.S. Sandhu)

10 March 2015

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1. Introduction

Seed is the vital input and driver in crop production, as seed quality determines the return on investment made on other inputs like fertilizer, irrigation, pesticide, labour etc. A poor seed quality will result in poor return despite best investment on other farm inputs, which, implies that utmost attention must be given to the use of quality seed in crop production. Therefore, every country needs a robust seed production and supply chain system as one of the key components of sustainable growth in agricultural production. A robust seed production programme is central to providing high quality seeds of improved hybrids, pure-line cultivars and open-pollinated varieties (OPVs) for agricultural development, and food security. High quality in case of seed refers to high genetic purity (true to type), high physical purity (freedom from objectionable weeds, other crops' seeds, inert matter etc.) and high seed vigour and germination in addition to freedom from seed-borne diseases.

Use of improved seed has made a tremendous impact on productivity of all crops including pearl millet (*Pennisetum glaucum* (L.) R. Br.), which is one of the most important cereals in the arid and semi-arid ecosystems in India and Sub-Saharan Africa. It is annually grown on more than 30 m ha in the arid and semi-arid tropical regions of Asia, Africa and Latin America (Yadav and Rai, 2013). India is the largest grower (9.3 m ha) and producer (9.0 m ton) among pearl millet growing countries. Pearl millet holds significant economic importance in India as it is an important source of food and fodder for resource-poor farmers in the arid and semi-arid regions of the country.

Fig. 1: Pearl millet panicles showing full stigma emergence (left) and initiation of pollen shedding (right). The time gap between two stages is referred to as protogyny period.

The major pearl millet growing states in India are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana, which together account for more than 90% of pearl millet acreage in the country. Most of pearl millet in India is grown in rainy (kharif) season (June – September). It is also being increasingly cultivated during the summer season (February – May) in parts of Gujarat, Rajasthan and Uttar Pradesh; and during the post-rainy (rabi) season (November - February) at a small scale in Maharashtra and Gujarat.

Pearl millet is a highly cross-pollinated crop due to its protogyny (Fig. 1) wherein female part of the flower emerges out of the spikelets earlier than the male part. This nature of flowering facilitates the breeding of hybrids and open-pollinated varieties (OPVs) as the two broad cultivar types. Significant progress has been made during the last five decades in cultivar development; and in developing seed production, seed processing, and marketing strategies of improved seed of pearl millet. This document attempts to provide a brief overview of strategies followed in cultivar development with elaborate treatment of seed production and processing technologies in pearl millet.

2. Cultivar development in pearl millet

Two cultivar types are available in pearl millet, which include OPVs and hybrids. OPVs differ from hybrids primarily in their ability to self-perpetuate and are genetically and phenotypically heterogeneous populations. Seed harvested from an isolated plot of an OPV should have essentially the same yield potential and uniformity level as the crop from which it was harvested, at least for 2-3 crop cycles. In case of hybrids, it is necessary to reconstitute the cultivar by crossing its parents so as to retain uniformity and yield potential of the cultivar.

Hybrid cultivars have several advantages compared to OPVs. They include higher yield potential at comparable maturity, ability to combine desirable characters from different parents into a single cultivar, and greater uniformity facilitating harvest operations and farmers' appeal. Further, closed pedigree and the necessity of reconstituting hybrids from their parents allow private seed sector to protect their intellectual property owing to their investment in research and development.

Developing new cultivars in India started in 1930s at a modest scale, and it largely concentrated on improving the yield by mass selection and progeny testing, which led to development of some OPVs (Joshi et al., 1961; Ahluwalia, 1964; Krishnaswamy, 1962; Rachie and Majumdar, 1980). Since these OPVs were developed from landraces with narrow genetic base and restricted field testing, they provided limited improvement in actual yields. Also, these were not backed with adequate seed production, and hence could not make much impact.

Impetus for the development of OPVs as a part of population improvement programme started in 1970s with the availability of diverse germplasm, mostly from the African sources through the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Exploiting a diverse range of germplasm, several diverse and trait-specific composites were developed and improved by recurrent selection (Singh et al., 1988), resulting in the development and dissemination of a large number and diverse range of breeding materials and OPVs (Govil et al., 1986; Zaveri et al., 1989; Gill, 1991; Khairwal and Singh, 1999; Witcombe, 1999).

Since pearl millet is a highly cross-pollinated crop with outcrossing rates being more than 85% (Burton, 1983) and it displays a high degree of heterosis for grain and stover yields, attempts were made in the 1950s to breed hybrids for greater exploitation of heterosis by utilizing the protogynous nature of flowering. The usual method at that time for production of hybrid seed was growing the parental lines in mixture and allowing them to cross-pollinate (Gill, 1991). The resultant seed contained approximately 40% hybrid seed when the two parental lines had synchronous flowering. These so-called chance hybrids outyielded local varieties by 10-15%. However, they could not become popular due to their limited yield advantage over OPVs, narrow range of adaptation, and lack of reliable and adequate seed production programmes.

The above-mentioned limitations in the exploitation of heterosis were circumvented with the discovery of cytoplasmic-nuclear male-sterility and release of male-sterile lines Tift 23A and Tift 18A in early 1960s at Tifton Georgia, USA. These lines were made available to Indian breeding programmes (Athwal, 1961, 1966). The male-sterile line Tift 23A was extensively utilized, both at the Punjab Agricultural University and the Indian Agricultural Research Institute, because of its short stature, profuse tillering, uniform flowering and good combining ability (Dave, 1987). This laid the foundation of pearl millet grain hybrid breeding in India.

The major approach in hybrid breeding has been to strategically utilize germplasm from African and Indian subcontinent (Yadav and Rai, 2013) with the result that a large number of genetically diverse hybrids have been developed with different combination of phenotypic traits that are important for adaptation to different ecological regions (Yadav et al., 2012).

Pearl millet hybrid development programme in India has been very dynamic and responsive in order to deal with challenges related to diseases and other production constraints, and to cater to variable needs of different regions and sectors. As soon as cytoplasmic nuclear male-sterility was discovered, it was immediately utilized in hybrid development programmes. When cultivation of individual hybrids like HB 1, HB 3, BJ

104 and BK 560 on large scales between 1965 and 1980 created a situation of genetic uniformity, congenial for downy mildew (*Sclerospora graminicola* (Sacc.) Schroet) pathogen to proliferate and overcome host plant resistance of individual hybrids, they were withdrawn from cultivation, and were replaced with new resistant hybrids viz., MH 179, Pusa 23, MLBH 104, MBH 110 and Eknath 301 (Dave, 1987). Upon succumbing to downy mildew (DM), these were replaced by another series of hybrids like ICMH 356, Shradha, Saburi, JKBH 26, 7686 and 7688. Some of most important current hybrids are HHB 67 Improved, HHB 94, GHB 538, GK 1004, Proagro 9444, Proagro 9555, 86M64, MPMH 17, 86M88, 86M86, 86M11, RHB 173, RHB 177, B 70, Nandi 5, Nandi 52, Nandi 60, 7792, Kaveri Super Boss, HHB 197, HHB 223 and HHB 226. This rapid replacement process could become possible due to strong genetic diversification programme, especially at ICRISAT, leading to strong hybrid development efforts in the National Agricultural Research System (NARS) and private sectors that continuously have been producing DM resistant hybrids with higher yield potential.

In order to diversify the genetic base of hybrids, efforts were made to breed a diverse range and large number of male-sterile lines (A-lines) using various cytoplasmic-nuclear male sterility (CMS) systems. During the last 15 years, 143 A-lines have been developed and disseminated by ICRISAT to the public and private sector breeding programmes. Out of these, 49 are based on A_1 CMS system, 73 on A_4 CMS system and 21 on A_5 CMS system. At a recent consultation meeting with hybrid parents users at ICRISAT, it was recognized that greater use should be made of the A_4 and A_5 CMS systems for A-lines breeding (Rai et al., 2012). In view of the lack of restorers of the A_4 and A_5 CMS system A-lines, an efficient breeding strategy for converting A_1 system restorers into their A_4 and A_5 restorer versions, otherwise maintainers of the A_4 and A_5 systems has been developed (Rai et al., 2006). Moreover, it is revealed that the genetic background of male-sterile lines in A_4 and A_5 cytoplasm has no affect on the fertility restoration of hybrids, whereas the genetic background of A_1 cytoplasm has significant effect on the fertility restoration (Gupta et al., 2010).

Cultivar development programmes successfully addressed the need of diverse ecologies under which pearl millet is cultivated by breeding cultivars with a wide range of maturity (65-90 days) and adaptation to the target regions. Hybrids have been developed and deployed as per trait preferences in various regions that include high tillering, small panicles and medium-sized grain for north-western India; and low-tillering, bold-seeded and large panicles for central and southern India. Due to the growing importance of pearl millet stover for fodder purposes, there has been considerable emphasis in recent times on breeding for high stover yield in combination with high grain yield (Yadav and Khairwal, 2007).

Hybrids have occupied most of areas of A- and B-zones (receiving >400 mm of annual rainfall), which are two separate pearl millet growing agro-ecologies/mega-environments (Gupta et al., 2013). While considering the specific need of the drier region of north-western India, which has yet to harness the full benefits of hybrid technology, a special zone (A_1-zone) that includes drought-prone areas receiving <400 mm of annual rainfall in the adjoining states of Rajasthan, Gujarat and Haryana was carved out of the A-zone representing northern India by the All India Coordinated Pearl Millet Improvement Project (AICPMIP). This has strengthened, to some extent, the cultivar development programme for the A_1-zone (Yadav et al., 2011). Also, pearl millet cultivation is now expanding in "summer" season in north-western India, especially in northern and central Gujarat, southern Rajasthan, and western Uttar Pradesh. Pearl millet, being a heat tolerant crop can set seed under air temperatures of >42^{0}C during flowering (Gupta et al., 2015), and several high-yielding and heat-tolerant hybrids are available for this new ecology.

In view of the serious problem of micronutrient malnutrition, efforts are underway to develop cultivars that have higher contents of micro-nutrient like iron and zinc. A high-iron OPV (Dhanashakti) with high iron content has been recently released (Rai et al., 2014) and available commercial cultivars have been evaluated to identify those with relatively higher iron content (Rai et al., 2013). Further efforts are under way to develop high-iron hybrid parents and hybrids with good prospects in sight.

During the last 30 years, 125 high-yielding hybrids (Annexure I) and 31 OPVs (Annexure II) have been developed for various production ecologies and several of them have been widely adopted by farmers. Currently >70% of pearl millet area is under improved cultivars, mostly hybrids. Several factors have contributed to large-scale adoption of hybrids in India: 1) availability of hybrids in the broad maturity duration (60-90 days) with in-built resistance to diseases and abiotic stresses, 2) recovery of seed cost by farmers with even as low as 10% grain yield advantage over local cultivars, and 3) a highly effective and profitable contractual hybrid seed production system that has evolved in India. The area under improved cultivars has increased considerably over the years. The adoption scale of high-yielding cultivars, however, has been different in various states. The highest levels of adoption are in the states of Haryana and Gujarat while it is lowest in Rajasthan.

Following the adoption of improved cultivars backed with effective seed production technology, pearl millet productivity has been consistently increasing since 1950 (Fig. 2). The crop productivity has gone up from 288 kg/ha in 1950 to 1164 kg/ha during 2013-14 registering four-folds increase. During the last three decades, pearl millet registered 112% increase in productivity, which is highest among all the food crops (Table 1).

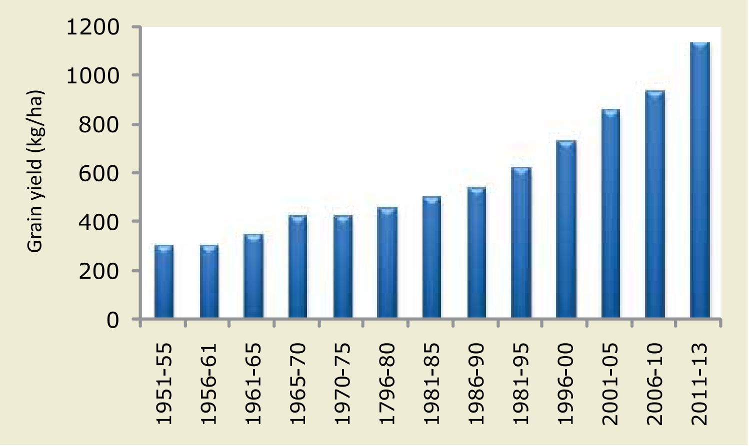

Fig. 2: Grain yield productivity of pearl millet in India since 1951

Period	Grain yield (kg/ha)					Improvement (%) in yield during the period over that of 1986-90				
	Wheat	Rice	Sorghum	Maize	Pearl millet	Wheat	Rice	Sorghum	Maize	Pearl millet
1986-1990	2066	1584	744	1297	539	-	-	-	-	-
1991-1995	2388	1807	827	1548	620	16	14	11	19	15
1996-2000	2603	1897	825	1723	733	26	20	10	33	36
2001-2005	2679	1957	784	1890	856	30	24	5	46	59
2006-2010	2775	2148	962	2125	932	34	36	29	64	71
2011-2013	3094	2365	912	2524	1140	50	49	23	95	112

(Source: DAC, Government of India http://www.agricoop.nic.in)

3. Indian national seed system

Agriculture provides the principal means of livelihood for over 50% of India's population. Availability of high quality seed is a critical and basic input for enhancing agricultural production and productivity. Seed industry in India has been making great strides since independence, and the government, through policy initiatives, helped the development and growth of the seed industry. Seed production of improved varieties of pearl millet is approximately 25,000 tons.

3.1 Legislative framework and policy

Several policy initiatives, given below, have been taken by the Government of India in seed sector.

- Enactment of the Seeds Act (1966)
- Seed Review Team (1968)
- National Commission on Agriculture Seed Group (1972)
- Launching of the World Bank aided National Seeds Programme (1975-85) in three phases leading to the creation of State Seeds Corporations, State Seed Certification Agencies, State Seed Testing Laboratories, Breeder Seed Programmes etc.
- Seed Control Order (1983)
- Creation of the Technology Mission on Oilseeds & Pulses (TMOP) in 1986, now called the Integrated Scheme of Oilseeds, Pulses, Oil Palm and Maize (ISOPOM)
- Production and Distribution Subsidy
- Distribution of Seed Mini-kits
- Seed Transport Subsidy Scheme (1987)
- New Policy on Seed Development (1988)
- Seed Bank Scheme (2000)
- National Seeds Policy (2002)
- Formulation of National Seed Plan (2005)
- National Food Security Mission (2007)
- Rashtriya Krishi Vikas Yojna (2007)

The most important amongst them is “The Seeds Act, 1966” which provides the legislative framework for regulation of quality of seed sold in the country. The Central Seed Committee (CSC) and the Central Seed Certification Board (CSCB) are the two apex agencies set up under the Act to deal with all matters relating to the administration of the Act and quality control of seeds. The proposed Seeds Bill, 2004 to replace the Seeds Act, 1966 is currently under discussion by the government of India.

The major thrust areas of National Seeds Policy (2002) include variety development, plant variety protection, seed production, seed quality assurance, seed distribution and marketing, infrastructure facilities, import of seeds and planting materials, seed exports, promotion of domestic private sector seed industry, and strengthening of the monitoring system.

3.2 Schemes of seed division

A central sector scheme viz., ‘Development and strengthening of infrastructure facilities for production and distribution of quality seeds’ was launched during the Tenth Plan. The main components of the scheme were quality control arrangements of seeds, transport subsidy on movement of seeds to North-East and other hilly areas, establishment and maintenance of Seed Bank, Seed Village Scheme (SVS), assistance for creation of infrastructure facilities, assistance for boosting seed production in private sector, human resources development (HRD), assistance for seed export, propagation of application of biotechnology in agriculture and promotion of use of hybrid seeds of rice.

3.3 Protection of plant varieties

In order to fulfill the obligations under TRIPs (Trade-Related Aspects of Intellectual Property Rights) agreement, Indian government has ratified and the Department of Agriculture and Cooperation has enacted legislation for Protection of Plant Varieties and Farmers’ Rights. In order to provide necessary back-up support for enactment of the above Legislation, a Central Scheme is also under implementation. The required rules and regulations under the Protection of Plant Varieties and Farmers’ Rights Act were notified in 2003. The Protection of Plant Varieties and Farmers’ Rights Authority (PPV & FRA) envisaged under the Act has become operational since 11 November, 2005. PPV& FRA maintains a National Register of Plant Varieties. Any pearl millet variety proposed for registration should be distinct from the other varieties for at least one essential trait among the 26 notified traits (Annexure III) described under distinctness, uniformity and stability (DUS) guidelines (PPVFRA, 2007). The certificate of registration of varieties shall be valid for six years in field crops including pearl millet and it can be further extended. For extant varieties (varieties about which there is common knowledge or other varieties which are already in the public domain) notified under section 5 of the Seeds Act, 1966 Act, the total period of variety protection shall not exceed 15 years.

3.4 Public and private sector institutions

National seed system in India includes the participation of public sector viz. Central and State governments, Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) as well as co-operative sector and private sector institutions. Commercial seed production in public sector is undertaken by the National Seeds Corporation (NSC), and 13 State Seeds Corporations (SSCs). In private sector, it is done by about 50 major seed companies of which 45 seed companies are involved in pearl millet research and hybrids production. For quality control and certification, there are 22 State Seed Certification Agencies (SSCAs) and 101 State Seed Testing Laboratories (SSTLs). The generalized diagram (Fig. 3) depicts various steps of seed production and distribution in the national seed system, most of which are relevant to other countries as well. Since changes in India's seed regulations during 1990s, private sector has started to play a major role in the production and distribution of pearl millet hybrid seed.

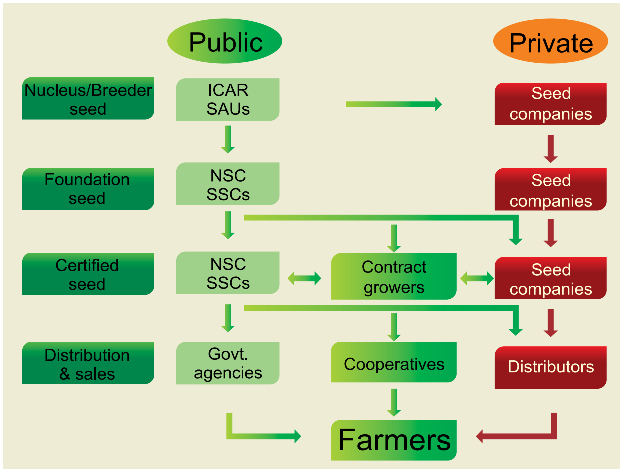

Fig. 3: Generalized diagram showing seed production and distribution by public and private sector in India

4. Seed classification

Indian seed programme largely adheres to the limited generation system for seed multiplication. The system recognizes basically four generations, viz., nucleus, breeder, foundation and certified seed. The system provides for adequate safeguards to ensure quality assurance in the seed multiplication chain to maintain the purity of hybrids and parental lines, and identity of OPVs which flows from breeders to the farmers. Seed classification is, therefore, a description of four stages in the seed multiplication process. The guidelines for this are designed to meet genetic and physical purity standards and adequate seed stock for each seed class.

4.1 Nucleus seed

It is the first stage of seed to produce breeder seed as well as its own stock. Therefore, nucleus seed should have highest genetic purity in case of hybrid parents, and highest degree of varietal identity in case of OPVs. Nucleus seed of OPVs and parental lines [male-sterile (A) line, maintainer (B) line and restorer (R) line] of hybrids is maintained by the originating breeder/institution.

4.2 Breeder seed

Breeder seed is the progeny of nucleus seed and is produced by the originating breeder or by a sponsored breeder of any other institution. Breeder seed production is the mandate of ICAR and is being undertaken with the help of ICAR Research Institutions, SAUs and the All India Coordinated Research Project Centres of different crops. Private seed companies produce their own breeder seed. Breeder seed production of pearl millet OPVs and parental lines of hybrids is supervised jointly by a monitoring team including breeders and personnel from seed certification agency.

4.3 Foundation seed

Foundation seed is produced either from breeder seed or from foundation seed which can be clearly traced to breeder seed. Foundation seed produced directly from breeder seed is designated as foundation seed stage I (FS I). Foundation seed produced from FS I is designated as FS II. The seed of A- and R- lines of hybrids used for producing certified seed is termed as foundation seed. Foundation seed is produced and maintained by a seed production agency in public sector and parent seed department in private sector. The responsibility for production of foundation seed has been entrusted to the NSC, State Seeds Corporation, State Departments of Agriculture and private seed producers, who have the necessary infrastructure facilities. Foundation seed is required to meet the standards of seed certification prescribed in the Indian Minimum Seeds Certification Standards, 1988 (Tunwar and Singh, 1988), at the level of both field and laboratory testing.

4.4 Certified seed

Certified seed is the progeny of foundation seed and must meet the standards of seed certification prescribed in the Indian Minimum Seeds Certification Standards, 1988. Certified seed production is organized through State Seeds Corporations, Departmental Agricultural Farms, Cooperatives etc. The efforts of the State Governments are also supplemented by NSC which produces seed of varieties of national importance. The production of certified seed by NSC and State Seed Corporations is mainly organized through contractual growing arrangements with progressive farmers. The production and distribution of certified quality seeds is primarily the responsibility of the State Governments. The private sector also plays a very important role in the supply of quality seeds (mostly hybrids) of pearl millet.

5. Pearl millet seed production – process and technology

5.1 Floral biology

Pearl millet is a highly cross-pollinated crop. The flowers are protogynous that facilitates cross pollination through wind-mediated pollen movement.

Pearl millet inflorescence is a false spike, with the panicle size in commercial cultivars ranging generally from 20 to 40 cm in length and 3 to 5 cm in diameter. The panicle is terminal, varying in shape from cylindrical to candle-shaped. The spike consists of a central rachis which is closely packed with fascicles. Each fascicle consists of one or more spikelets. An inflorescence contains, on an average, 1600 spikelets (Khairwal et al., 1990).

The spikelets are small, lanceolate, and acute. Each spikelet consists of two glumes, one outer and one inner. The outer glume is broad, short, membranous, and truncate. The inner glume is half the size of the spikelet. Between the two glumes, there are two florets. The lower floret is staminate and the upper floret is hermaphrodite. Spikelets are generally bifloret (Maiti and Bisen, 1979). The staminate flower has one lemma and one palea, and enclosed between them is the androecium with three stamens. The upper hermaphrodite floret has a broad, pointed lemma and a thin, oval palea, and the androecium and gynoecium are enclosed between them.

The pearl millet androecium consists of three anthers, each attached to a long filament. There is a two-layered epidermis, a tapetum, and pollen grains. The anthers are yellow or purple with a tuft of fine hairs at the apex. The gynoecium consists of a monocarpellary and superior ovary with two styles and a feathery stigma. The pistil in its young stage shows two carpels, one larger than the other. The larger one contains the primordium of the ovule. The growth of the two carpels is unequal. The thicker one, bearing the primordium, grows in girth, while the thinner one grows in length and soon overtakes the other to form the style and stigma at the top (Rachie and Majumdar, 1980).

The emergence of the panicle from the sheath takes about 4-6 days. Flowering starts after the emergence of the panicle out of the boot, but in some genotypes style exertion commences before completion of panicle emergence. Stylar exertion begins first in the florets in the central upper portion of the panicle and then progresses upward as well as downward. The maximum exertion of styles is on the third day of flowering. The stigma remains receptive for 18-24 h after full emergence.

Anther emergence begins one day after the emergence of the stigmas is completed on the panicle. It first starts in the hermaphrodite florets followed by the staminate florets. Anther emergence is facilitated by the protogynous styles and the tufts of hair on the tips of the anthers. Anthesis continues throughout the day (Sundararaj and Thulasidas, 1980). Protogyny is expressed in varying degrees in pearl millet, depending on the genotype and the environment (Rachie and Majumdar, 1980).

Anther emergence starts in the upper portion (at about the two-thirds point) of the panicle and proceeds in both directions. The first flush of anthesis is completed in a week's time on population basis under irrigated conditions. Panicles emerging from the tillers start flowering later and the process may continue up to three weeks. Under rainfed conditions, first-flush anthesis of a plant may take place over 12 days, and it may continue on the tillers till seed formation.

After pollination, the stigmas dry up in 24 h. Seed-set can be seen in the panicle about a week after fertilization. There is a gradual increase in the dry mass of grains from the milk to dough stage, reaching maximum at physiological maturity. Physiological maturity of the grain is indicated by the appearance of a black layer just above the hylar region on the abgerminal side of the grain opposite the embryo (Fussel and Pearson, 1978). At physiological maturity, the seed contains 30% moisture. There are large variations in seed shape, size and color. The grain mass in commercial cultivars generally varies from 8 to 12 mg. Time course of different stages from anther emergence to seed formation are shown in Fig. 4.

Fig. 4: Different stages from initiation of stigma emergence to seed formation in pearl millet

Photoperiod and temperature affect flowering in pearl millet. A combination of high temperature and drought adversely affects pollen viability, stigma receptivity, and seed-setting.

5.2 Method of seed production

The CMS system provides a genetic mechanism to produce pure single-cross hybrid seed on a commercial scale from cross between A-line and R-line under open pollination in isolation (Fig. 5). The counterparts of A-lines with same nuclear gene constitution but fertile cytoplasm are maintainer lines, commonly referred to as B-lines.

OPVs are random mating populations. These are maintained and multiplied by random mating their representative bulk in isolation.

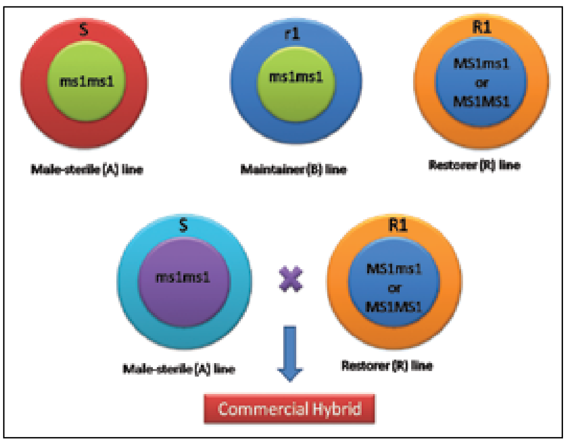

Fig. 5: Nuclear (inner circle) and cytoplasmic (outer circle) constitution of male-sterile (A), maintainer (B) and restorer (R) lines. Commercial hybrid is produced by crossing A-line and R-line in isolation.

5.3 Seed multiplication process

Seed production involves multiplication of various classes of seeds at different stages (Fig. 6), and linkages among different departments and agencies (Fig. 3).

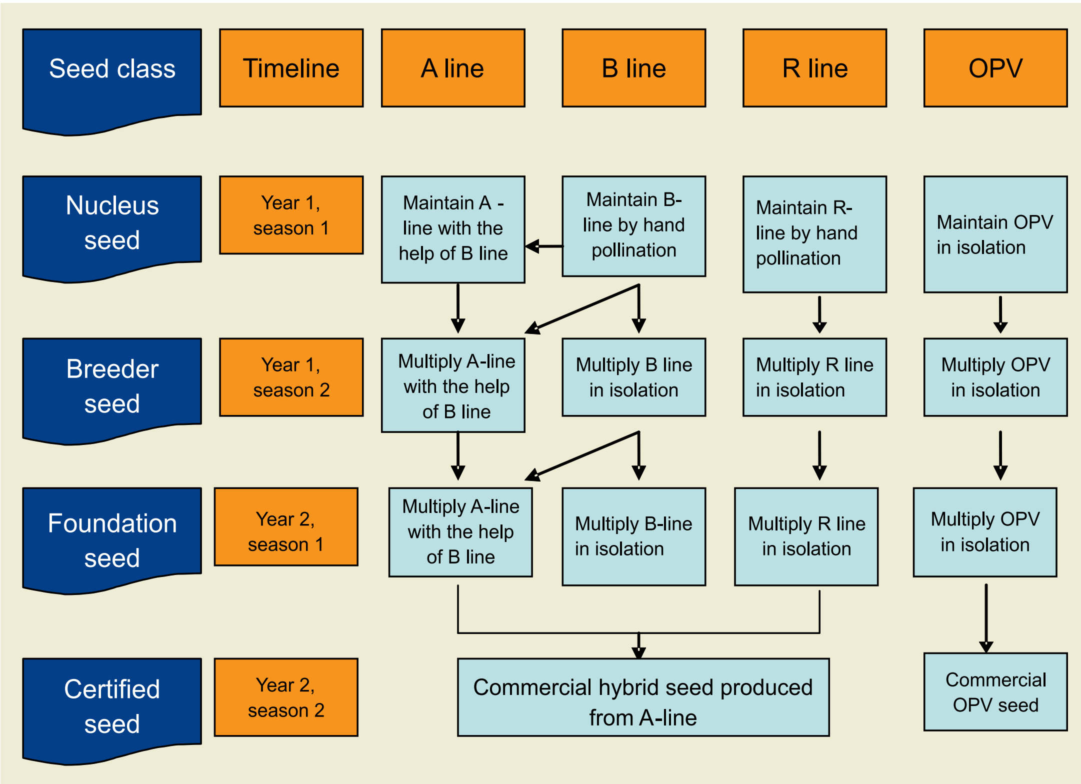

Fig. 6: Procedure and time-line for multiplication of various classes of seed in pearl millet

5.3.1 Nucleus seed multiplication: The nucleus seed production should be undertaken with excellent crop management and under expert supervision to maintain highest genetic purity. Since seed requirement for nucleus seed is very less, it is advised that multiplication of A- and B-lines should be done by hand pollination, preferably in isolation, to avoid any contamination. Pollen from the selected B-line plants is used for hand pollination of selected A-line plants. Ear-to-row progenies of A-line and B-line are planted side by side in paired row fashion. The seed of the A-line produced by hand pollination is harvested and bulked to constitute the nucleus seed of A-line. Seed from selfed B-line plants is harvested and bulked as B-line. B-line seed is multiplied by selfing/

sibbing, although it should be remembered that continued selfing for several generations may lead to degeneration of B-line. R-line is also multiplied by selfing/sibbing same way as the B-line, but in separate isolations.

It is a good practice to plant 2 rows as observation rows of each of A-line, B-line and R-Line alongside as a check for character verification. Roguing of off-type plants is essential to maintain genetic purity of A, B and R lines, and it should be done at pre-flowering, flowering and pre-harvesting stages. An additional and the most critical roguing requirement in A-line seed production is the removal of pollen shedders at the time of flowering, and should be the first activity early in the morning. Some of the A-lines have tendency of sterility breakdown and might show shedders as full plant, side tiller or sectorials. Some programmes, especially in the private sector, keep one panicle/ plant selfed but un-pollinated to validate at the time of harvesting that there is no seed-set under selfed bags of A-line implying no sterility breakdown. But it is a normal practice to keep observing tillers of the plants for pollen shedding. Main panicles crossed with B-line should be discarded if tillers show pollen shedding during the earlier process of crossing, or cross pollination in the isolation.

Even in highly homozygous parental lines of hybrids, repeated nucleus seed production over the generation by sibbing or by random mating in the isolation, leads to generation of new variability either through recombination or through mutation. These new variants often don't qualify for off-types, but for quantitative traits, they do appear as phenotypic deviants, and should be rogued out at each multiplication stage to ensure that the variability within the line remains within acceptable limit of purity.

In case of OPVs, use of the term 'genetic purity', generally used by seed producers, is not valid as OPVs are genetically variable populations with considerable phenotypic variability. However, each OPV can be described by providing the frequencies of plants for qualitative traits (e.g., anther colour, nodal pigmentation, etc.) and a good range for quantitative traits to give it a label of varietal identity. While some of these traits of economic and adaptation importance (grain and stover yield, plant height, panicle length, flowering time) can be improved utilizing residual variability, it is important that all these traits also remain within acceptable limits, lest the improved varieties become new varieties to be labelled with a different name. It is advisable to rogue out at least 10% of the plants with extreme plant phenotypes.

It is desirable to multiply nucleus seed of hybrid parents and OPVs once in three to four years to maintain purity and vigour of parental lines and identity of OPVs (Chopra, 1982). Andrews and Harinarayana (1984) suggest that the nucleus seed of an OPV should be produced once in five to six years (Fig. 7). The produce of nucleus seed may be divided into six lots of 5-10 kg each. Lots 1 to 4 are used to plant the breeder seed plots for the next four years, lot 5 is used to plant the next nucleus seed plot and lot 6 is a backup stock. The suggested isolation distance is about 1500 m for parental lines of hybrids and 1000 m for OPVs (Tunwar and Singh, 1988).

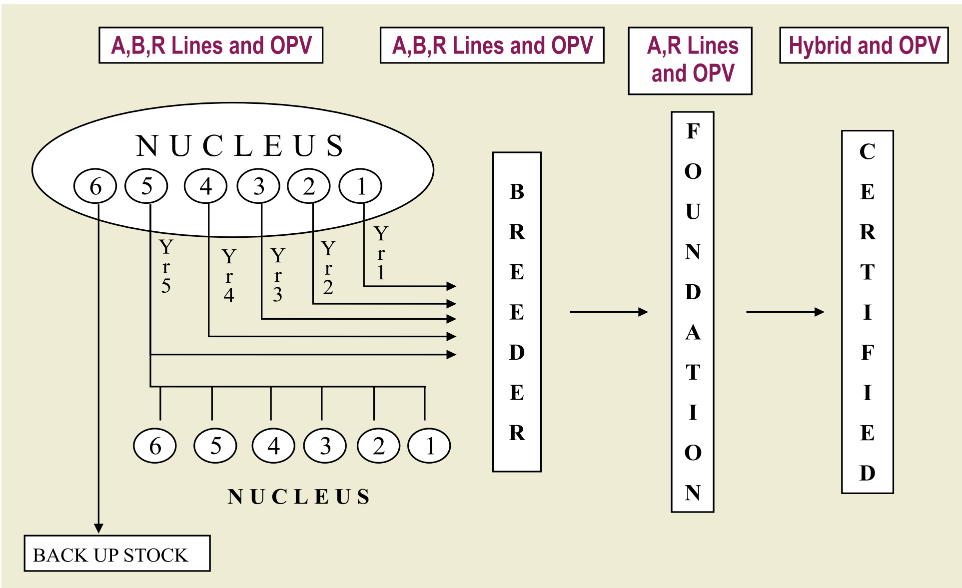

Fig. 7: Outline of scheme used in maintenance and multiplication of nucleus seed of open-pollinated varieties and parental lines of pearl millet hybrids (Source: Andrews and Harinarayana, 1984)

5.3.2 Breeder seed multiplication: Many breeders in private sector prefer to multiply breeder seed by selfing and hand pollination the same way as nucleus seed multiplication. However, if breeder seed requirement is more, it is done by planting of A-line and B-line in isolation. R-line multiplication is also done through isolation method. The preference for maintenance under open-pollination in isolation is to avoid unnecessary inbreeding and the consequent loss of vigour. Isolation distance for breeder seed production in India is 1000 m for A-, B- and R-lines, and 400 m for OPV (Table 2).

Under isolation method, A- and B-lines are planted in a row ratio of 4:2 or 6:2. Thorough roguing should be done at vegetative, flowering and pre-harvesting stages. Several inspections during pre-flowering and at flowering are recommended to remove off-type plants, including doubtful ones. During flowering, roguing should be undertaken early in the morning so that the off-types can be removed before anther dehiscence. One final inspection should be carried out at pre-harvesting stage to remove diseased plants and any other plants not conforming to the panicle and grain characteristics of the target genotype.

5.3.3 Foundation seed multiplication: Foundation seed is multiplied in isolation. Recommended isolation distance for pearl millet foundation seed production in India is 1000 m for A-, B- and R-lines, and 400 m for OPVs (Table 2). For multiplication of A-line, A- and B-lines are planted in ratios of 4:2 or 6:2. Generally 4-6 rows of B-line are planted all around the plot to ensure good seed setting on A-line. It also acts as a barrier for foreign pollen. Generally, A-line starts flowering 2-3 days earlier than its counterpart B-line. Therefore, it is advised to plant one row of B-line 3-4 days earlier than planting of A-line and rest of rows of A- and B-lines are planted the same day. This approach results in better seed set due to adequate pollen load during flowering. To avoid the risk of possible chance mixture, B-line rows are harvested immediately after pollination.

Table 2: Isolation distance for breeder, foundation and certified seed production in pearl millet

Contaminator	Minimum isolation distance (m)			
	Foundation/Breeder seed		Certified seed	
	Hybrid parents	OPV	Hybrid	OPV
Fields of other hybrids/ varieties	1000	400	200	200
Fields of the same hybrid/variety not conforming to varietal purity requirements for certification	1000	400	200	200
Fields of other hybrids having common male parent but not conforming to varietal purity requirements for certification	-	NA	200	NA
Fields of other hybrids having common male parent and conforming to varietal purity requirements for certification	-	NA	5	NA

Foundation seed stocks of B-lines, R- lines and OPVs are multiplied under bulk planting in isolation as per specified isolation distance and following other prescribed field standards (Table 3).

Table 3: Minimum field standards for pearl millet hybrid/ open-pollinated variety (OPV) seed production (specific requirements)

Unwanted factor	Maximum permitted (%)			
	Foundation		Certified seed	
	Hybrid	OPV	Hybrid	OPV
Off-types at any one inspection	0.050	0.050	0.10	0.10
Pollen shedding panicles in A-line at inspection stage	0.050	NA	0.10	NA
Plants infected by downy mildew/green ear disease at any one inspection[1]	0.050	0.050	0.10	0.10
Ergotted panicles at final inspection[2]	0.020	0.020	0.040	0.040
Panicles infected by grain smut at final inspection[3]	0.050	0.050	0.10	0.10

[1]Complete plant shall be considered as one infected unit

[2]Seed from such fields that have been reported to contain the ergot infection even within the prescribed limits at field stage shall be subjected to floatation treatment to become eligible for certification

[3]Seed fields with incidence of grain smut more than the maximum permissible level can, however, be certified if such seed is treated with an approved organo-mercurial fungicide not earlier than a month prior to its sowing.

5.3.4 Certified/truthful labeled seed multiplication: The recommended isolation distance for certified seed production in India, for both hybrids and OPVs, is 200 m. The minimum field standards for certified seed production (Table 3) are followed to ensure good seed quality. The pattern of planting of hybrid parents is the same as for the breeder and foundation seed production of an A-line except that the B-line rows are replaced by R-line rows (Fig. 8). Different row ratio (4:1, 8:2 or 6:2) are being followed in production areas. Row ratio depends on several factors like duration of stigma receptivity of A-line, pollen supply ability of R-line etc. To avoid the risk of possible chance mixture, R-line rows are harvested immediately after pollination (Fig. 9). The production of certified seed of an OPV is like breeder and foundation seed production in isolation following prescribed field standards.

Fig: 8: Schematic diagram of field layout plan (left) and actual seed production plots of pearl millet hybrid (right). In the left figure, A-line is represented by green solid line and R line is represented by red dotted line. Row ratio of A:R lines is 8:2.

Fig. 9: Chopping of male lines in seed production plot of pearl millet hybrids to avoid contamination

The most critical component in certified seed production is to ensure adequate isolation distance. This requirement is easily fulfilled through 'seed village' concept to undertake seed production programme in non-traditional area for pearl millet such as in Telangana and Karnataka during summer season. Seed is produced mostly by small farmers having farm size ranging from 1 to 5 ha under contractual arrangement with seed companies or state Seed Corporations (Fig.10). 'Seed village' approach is adopted where most farmers in a village agree to produce seed of a single hybrid/OPV. Contacting, training and negotiating terms and conditions for quality seed production with many small seed growers is a great challenge. Hence seed organizers play a key role in linking seed growers with seed producing agencies on a small payment basis. Seed production organizers facilitate production process, starting from negotiation with seed growers, arranging required acreages for seed production, distributing foundation seed of parental lines/OPVs, and assisting seed producing agencies to ensure that required package of

Fig. 10: A certified seed production organizer in seed production of pearl millet hybrid in Nizamabad district of the Telangana state

practices are followed by seed growers. Corporations/companies sign agreements with seed organizers and seed growers that will ensure procurement terms /transportation/ pre-cleaning of seeds /payment terms, germplasm protection, package of practices, other liabilities etc. Seed companies/corporations procure seed from seed growers as per the terms and conditions mentioned in seed production agreement with seed growers. Seed procurement price is decided based on several factors like seed yield potential of seed parent, income from alternate crops, supply demand scenario and competition among the seed producing agencies.

5.4 Key deliverables of efficient seed production technology

- Highest order of seed quality in terms of genetic purity, seed vigour and germinability
- Maximization of seed yield per unit area
- Reduction of production cost per kg of seed
- Freedom from inert matter, weed seed and other crops seed as per prescribed standards (Table 4)
- Freedom from seed-borne diseases
- Timely availability of seed to customers

Table 4: Minimum seed standards for various seed classes in pearl millet

Factor	Standards for each class (%)	
	Foundation	Certified seed
Pure seed (minimum)	98.0	98.0
Inert matter (maximum)	2.0	2.0
Other crop seed (maximum) (in number)	10/kg	20/kg
Weed seed (maximum) (in number)	10/kg	20/kg
Ergot sclerotia, seed entirely or partially modified as sclerotia, broken sclerotia or egrotted seed (maximum)	0.020 (by number)	0.040 (by number)
Germination (minimum)	75.0	75.0
Moisture (maximum)	12.0	12.0
For vapour-proof containers	8.0	8.0

5.5 Components of efficient seed production

To produce and deliver specified quality seed within specified period at minimum cost per unit is only possible through efficient utilization of resources, methodology and technology. Hence planning and efficient utilization of resources and techniques are very important aspects of seed production. An efficient seed production system involves several steps in planning, seed production management and seed certification (Fig. 11).

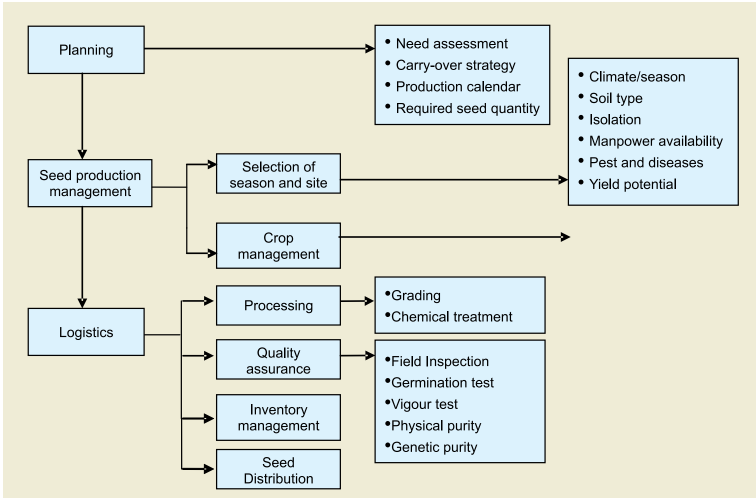

Fig. 11: Outline of activities undertaken at various stages in seed production of pearl millet

5.5.1 Production planning: Planning is the most critical component of seed production which essentially involves need assessment and carry-over strategy.

5.5.1.1 Need assessment: Need assessment is the first most important step in production planning to produce adequate quantity of all classes of seed. The Department of Agriculture and Cooperation, Government of India assesses certified seed demand every year for all states and allocates breeder seed production programmes to various research organizations. Private sector companies also make calculations of seed requirement of their own hybrids. Depending upon the sales projections of a particular hybrid or OPV and inventory stock of various classes of seed with acceptable quality, land and seed requirement for foundation and breeder seed are worked out. An example of the method for calculating quantity of different classes of seed and land requirement for pearl millet seed production is given in Table 5.

Table 5: Area and seed requirement for various seed classes to produce 22,000 tons (enough to plant 5.5 million ha) of certified pearl millet hybrid seed. The calculations assume 1000 kg/ha of seed yield in production plots, 4 kg/ha of seed rate and female: male row ratio of 4:1 (the direction of arrow indicates that planning starts from estimation of certified seed requirements) (Source: Yadav et al., 2012)

Parental line	Year 1 Season 1		Year 1 Season 2		Year 2 Season 1	
	For breeder seed (BS) production		For foundation seed (FS) production		For certified seed (CS) production	
	Area (ha)	Nucleus seed quantity (Kg)	Area (ha)	BS quantity (Kg)	Area (ha)	FS quantity (Kg)
A-line	0.352	1.408	88.0	352.0	22000	88000
B-line	0.088	0.352	22.0	88.0	-	-
R-line	0.088	0.352	22.0	88.0	5500	22000
Total	0.528	2.112	132.0	528.0	27500	110000

Fig. 12: Certified seed production of pearl millet hybrid (in the background field) and commercial crop of rice (in front) being grown in Nizamabad area of the Telangana state

Yield potential of parental lines of hybrids, OPVs is the most critical factor in determining the requirement of area and seed, although yield levels are also influenced by climate, soil conditions and crop management. During the last 25 years, seed yield levels in production plots of hybrids have increased considerably, mainly due to development of high yielding parental lines and improved crop management skills of farmers. In early eighties, average seed yields of A-lines were 0.8-1.0 t/ha where as current yield levels have been reported around 1.5-2.0 t/ha (personal communication with seed industry experts). As a result, the seed production of pearl millet hybrids has become as economical as rice cultivation in southern India and fields of both of these can be found side by side (Fig. 12).

Total annual requirement of breeder seed of A-, B- and R- lines is about 530 kg (Table 4). Total area to produce required breeder seed is 0.53 ha only which is equal to a plot size of 73m x 73m. Such small seed quantity and area needed to produce breeder seed to meet the huge certified seed demand shows the explosive seed production potential of pearl millet. Thus, only 10 tons of foundation seed of hybrid parental lines are required to fulfill the current requirement of certified hybrids. Taking advantage of two crop seasons in southern India, the whole seed production chain is completed in three season (1.5 year).

5.5.1.2 Carry-over strategy: The quantity of seed of any class produced in excess of actual requirement for the season or the year is known as carry-over seed, which is produced as a buffer stock to ensure against sudden demand or unforeseen shortfalls due to vagaries of nature. As cost is involved for maintenance of carry-over seed, seed producing agencies keep only a critical carry-over quantity which depends on the past experience of carry-over requirement, essentially based on the product and market demand. A general approximate limit of carry-over seed for different classes of seed for future use is given below:

- Nucleus seed – 100%
- Breeder seed – 100%
- Foundation seed – 50%
- Certified seed – 20%

5.5.1.3 Production calendar: The certified seed production programme is organized primarily in farmers' fields by various seed corporations and private companies, and it is undertaken largely in southern India. Almost 80% of total certified seed is produced during summer (February–April) in Telangana (Table 6). After harvesting and processing, seed is then dispatched to the target regions. This cycle of seed production reduces the overhead cost as seed storage is not required for long period. Seed is also produced during the rainy season in Telangana and Karnataka for summer season crop and to meet any shortfall for the rainy season crop. However, rainy season seed production sometimes is risky due to pollen wash caused by rains during the flowering and ends up with lower seed yields. Thus, seed quality from the rainy season crop is not as good as that obtained from summer season crop.

Table 6: Certified and truthfully-labeled pearl millet seed production calendar usually followed in India (Source: Yadav et al., 2012)

<table>
<tr><th>Month</th><th colspan="4">Jan</th><th colspan="4">Feb</th><th colspan="4">March</th><th colspan="4">April</th><th colspan="4">May</th><th colspan="4">June</th><th colspan="4">July</th><th colspan="4">August</th><th colspan="4">September</th><th colspan="4">October</th></tr>
<tr><td>Week</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td rowspan="7">Activity</td><td colspan="4">Planning</td><td colspan="16"></td><td colspan="4">Planning</td><td colspan="16"></td></tr>
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<tr><td colspan="13"></td><td colspan="5">Harvesting</td><td colspan="14"></td><td colspan="4">Harvesting</td><td colspan="4"></td></tr>
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<tr><td colspan="4"></td><td colspan="4">Dispatch</td><td colspan="8"></td><td colspan="6">Processing Dispatch</td><td colspan="12"></td><td colspan="6">Processing</td></tr>
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5.5.1.4 Required seed quantity: The quantity of indented breeder seed and its production since 2001 are given in Table 7. There has been no serious shortfall in the supply of indented breeder seed in any of the varieties or hybrid parental lines. Each year, on an average, 25,000 metric tons of hybrid seed is produced that is sufficient to cover more than 65-70% of total pearl millet area and is highest among all crops in India in which hybrids are the preferred choice of cultivar types.

Table 7: Number and quantity (q) of breeder seed of hybrid parental lines and open-pollinated varieties (OPVs), indented by the Department of Agriculture and Cooperation (Govt. of India) and produced by AICPMIP centres and ICRISAT, during 2001-2013

Year	A-lines			B-lines			R-lines			OPVs		
	Number	Indented	Produced	Number	Indented	Produced	Number	Indented	Produced	Number	Indented	Produced
2013	6	2.11	7.13	6	0.84	3.97	7	0.81	3.78	12	7.08	13.04
2012	6	2.16	5.40	6	0.88	4.17	8	0.85	10.28	13	13.06	16.98
2011	5	1.92	4.67	5	0.82	1.79	5	0.82	5.84	11	11.57	16.60
2010	7	1.34	3.15	7	0.65	1.17	8	0.67	2.44	9	7.56	15.90
2009	4	0.64	-	4	0.32	-	4	0.26	2.78	10	6.48	5.60
2008	12	4.81	9.58	8	2.34	3.35	14	2.13	4.43	10	7.00	18.65
2007	11	4.41	4.68	11	2.24	2.44	14	1.92	5.42	11	7.09	27.31
2006	11	4.62	1.05	10	2.46	0.41	14	2.06	3.54	11	11.05	11.81
2005	11	4.62	4.63	11	2.49	5.13	14	2.15	5.28	10	3.62	20.44
2004	12	3.34	9.55	12	2.80	5.00	15	3.08	5.49	12	3.95	11.00
2003	8	3.33	12.68	8	1.66	7.70	10	1.69	5.00	9	4.97	13.25
2002	9	4.08	0.65	9	2.07	0.35	12	2.18	0.69	10	4.29	68.54
2001	7	4.84	4.36	7	2.35	2.40	12	2.52	8.03	8	6.39	5.11

5.5.2 Seed production management

5.5.2.1 Selection of season: Late post-rainy season, with irrigation facility is preferred for seed production due to following reasons:

- Greater opportunity of getting good isolations as pearl millet is primarily cultivated in rainy season
- Greater sunshine, better luster and good quality of seed
- Less lodging, disease and insect problems
- Less pollen-wash and better seed set, and higher seed yield

Precautions:

- Avoid areas prone to excess rains and high humidity. Such weather conditions may also cause delayed maturity and pre-harvest germination of seed in many cases. Excessive rainfall normally results in poor seed set due to pollen wash and a higher incidence of diseases and pests, making seed production extremely difficult.
- Avoid areas prone to strong winds and hail storm as these cause lodging, leading to difficulty in roguing and reduction in yield and seed quality.
- Minimum temperature should not be less than 10°C during germination and early seedling growth and maximum should not cross 42°C during and after flowering in the crop season. Very hot and dry weather conditions and extreme cold temperatures may adversely affect seed setting. Thus, locations with extreme agro-climatic conditions are generally not suitable for seed production.

5.5.2.2 Selection of site: The requirements for an ideal seed production site are different from those used for commercial cultivation for grain production. Following criteria should be considered while selecting sites for seed production:

- Any pearl millet or its wild relative should not have been cultivated/grown during the previous season on the plot selected for seed production (and preferably within the prescribed limit of isolation distance, especially for nucleus and breeder seeds)
- Production site should have adequate irrigation, good soil (clay-loam-sandy) with proper drainage, and good fertility level
- The soil of the selected plots should be comparatively free from soil borne diseases and pests
- The plots should be free from volunteer plants, weeds and other crop plants
- The plot must be leveled and should have adequate isolation as per the requirement of certification standards
- Compact blocks should be selected for better supervision
- Progressive farmers with good seed production skills are always helpful
- High yield/unit with low cost of production

5.5.2.3 Isolation distance: As pearl millet is a highly cross pollinated crop-recommended isolation distance should be followed strictly. The seed crop must be sufficiently isolated from nearby fields of the same crop as per the requirements of certification standards (Table 2). Seed village approach is commonly followed for certified seed production to avoid isolation problem. Even after the seed crop is harvested, effective isolation of seed from different varieties is essential to avoid mechanical contamination.

5.5.2.4 Crop management: There are several aspects of crop management that are required to grow a good crop in order to harvest high yields in seed production plots (Fig. 11).

A. ***Land preparation:*** Cultivation of field two times (cross ploughing) and harrowing once is sufficient to bring field to fine tilth. Use of plank tied behind the cultivator may be necessary to break large clods and more harrows may be required in case of fields infested with weeds.

B. ***Planting method:*** Planting is done either by direct sowing of seed or transplanting the seedlings raised in nursery.

- **Direct-sowing:** Generally, tractor or bullock-drawn seed drills or bullock plough are used for sowing. A-lines are planted by machine-drawn seed drill and R-lines are planted manually by hand dibbling in rows marked with stakes. Sowing equipment needs to be thoroughly cleaned to avoid contamination during sowing.
- **Transplanting:** Transplanting enables easy adjustment in flowering time of parental lines in case they have large differences for flowering time. Transplanting saves expenditure on weeding and irrigation. It also saves time when field is occupied with any other crop. Transplanting requires 30-40% less seed than direct sowing and proper plant stand is achieved with required spacing. The parents of hybrid are sown in a nursery bed raised 10 cm above the ground level. Seed should be sown 1.5 cm deep to facilitate better germination and safe uprooting of seedlings for transplanting. Seed is sown in rows spaced 10-15 cm apart. Seedlings are transplanted in the field when they are 18-20 days old. Transplanting of seedlings older than 20 days might result in reduced tillering and low seed yield.

C. ***Field layout and row ratio:*** Ratio of male and female lines depends on height and pollen producing ability of pollinator line. Standard female:male row ratio of either

4:1 or 8:2 is followed for certified seed production (Fig. 8). Most common ratio is 8:2 due to ease of management. To ensure longer duration of pollen availability, staggered planting of male parent at more than one date is followed with a minimum gap of 3 days between two plantings of male parental lines. All sides of field should be covered with 2-4 rows of male line. For multiplication of A-lines, standard ratio of 4:2 for A-lines and B-lines is recommended.

D. ***Seed rate:*** The seed rate depends on planting method and row-to-row and plant-to-plant spacings. General seed rate recommendation for foundation seed production is 3 kg/ha of A-line and 4 kg/ha for R-line and OPV. Seed rate of 3 kg/ha of A-line and 1 kg/ha of R-line is generally recommended for hybrid seed production. For production of nucleus and breeder seed, the seed rate is about 60-70% of the foundation seed rate.

E. ***Sowing time:*** Every crop has a general sowing window in a particular geography, which is generally based on the cropping experience of farming populace. Date of sowing within the window impacts the yields. Sowing date optimization therefore, is a critical requirement for yield maximization. Optimum sowing time is site-dependent and therefore, would require conducting pilot experiments in every new geography before undertaking large scale seed production activity.

F. ***Spacing:*** Optimum population is 1,00,000 plants per hectare and hence it is recommended to follow 50 cm row-to-row and 20 cm plant-to-plant spacing in certified seed production. However, in nucleus and breeder seed production row-to-row spacing of 75 cm and plant-to-plant spacing of 20-25 cm is followed to facilitate closer look at individual plants in order to identify and rogue out off-types, including pollen shedders in A-lines. Such spacing also allows better expression of plants and facilitates roguing extreme phenotypes in OPVs.

G. ***Fertilizer management:*** Adequate amount of nitrogen, phosphorus and potassium is essential for proper growth and development of the crop. It is recommended to apply FYM @ 8-10 tons/ha and NPK @ 100:60:40 kg/ha. Basal dose of 40 kg N/ha is applied, and remaining nitrogen should be applied at tillering stage. Soils should also be analyzed for micronutrients, especially zinc, sulfur and boron, and those found deficient should be amended through proper micronutrient management.

H. ***Water management:*** Most of pearl millet seed production is taken during off season (January to April) which is rain-free period. Therefore, access to irrigation is essential to obtain good seed yields. The most critical stages of irrigation are tillering, flowering and seed development. The frequency of irrigation and amount of water supplied depend upon physical texture of the soil and crop requirements. Adequate soil moisture is also necessary for uniform seed germination in order to obtain good plant stand and high seed yields. Drip irrigation is increasingly being used in pearl millet seed production in Nizamabad area of Telangana state to optimize water use (Fig. 13).

Fig. 13: Certified seed production of pearl millet hybrid being undertaken in Nizamabad area of the Telangana state using drip irrigation

Precautions:

- Excessive moisture conditions and prolonged drought should be avoided during seed production.
- The irrigation should be stopped at hard dough stage or about 10-12 days before harvesting time to ensure dried conditions for harvesting.

I. ***Weed control:*** Production of high seed yield of high quality requires good weed control in the seed production plots. In addition to reduction in seed yield, weeds are often a source of contamination by way of admixture at the time of harvest. Weeds in the seed production plot or nearby areas may also harbor a number of pests and diseases. Effective control of weeds at all the phases of crop growth is essential. Weeds must not be allowed to flower or set seed in any case. Hand weeding, intercultural operations or chemical is necessary to control weeds. Pre-emergence spray of Atrazine @ 1g/litre controls broad-leaf weeds effectively. Manual or machine operated weeder should be used before and after earthing up.

J. ***Disease control:*** Effective control of all diseases is essential to produce a healthy seed crop. Diseases like downy mildew (*Sclerospora graminicola* (Sacc.) Schroet), blast (*Pyricularia grisea* (Cke.) Sacc.), rust (*Puccinia substriata var. indica*) and ergot (*Claviceps fusiformis Loveless*) cause heavy yield reduction and affect seed quality also. Adoption of appropriate schedules of plant protection and roguing of diseased plants and panicles from time to time are essential to further check the spread of diseases. Following are the control measures for important diseases of pearl millet:

- Downy mildew - Seed treatment with Apron 35 SD (2g a.i./kg of seed)
- Blast - Three sprays of Nativo (tebuconazole 50% + trifloxystrobin 25% WG) @ 0.4 g/l or Tilt (propiconazole 25% EC) @ 1 ml/l at 10 days intervals were found most effective in managing pearl millet blast (Sharma et al., 2012).
- Rust – One spray of Difenconazole @ 125 ml/ha) or Propiconazole @ 250 ml/ha at pre-flowering stage
- Ergot – Spray of Ziram 0.1% (300 ml/500 l water)
- Smut – Sprays of Zineb (2 ppm) at flowering stage

K. ***Insect-pest control:*** Major pests of pearl millet are armyworm (*Spodoptera frugiperda*), blister beetle (*Psalydolytta fusca* Olivier) and shoot fly (*Atherigona soccata* Rondani) that need proper control to avoid yield losses in production plots. The control measures against each of these pests include:

- Armyworm – Dust 10% Carbaryl or spray Endosulphan 35 EC (300 ml/200 l of water).
- Blister beetle – Use light traps and spray Carbaryl 50 WP (500 ml/200 l of water).
- Shoot fly – Spray Rogor (300ml/200 l of water) at 10 days interval from seedling stage to flag leaf stage.

L. ***Male-female flowering synchronization:*** Synchronization of flowering of A-line with R-line in certified seed production plots is essential in order to ensure pollen availability in the R-line when stigmas emerge in the A-line. Synchronized flowering results in good seedset in A-line and higher yields in production plots (Fig. 14). The A- and R-line may differ for flowering

Fig. 14: Correct synchronization in flowering of male-sterile line (central rows) and restorer line (outer rows) in seed production of pearl millet

due to their inherent genetic differences for this trait as well as due to their differential photo-thermal sensitivity. It necessitates generating information on flowering time of parental lines of hybrids in actual seed production areas rather than in experimental areas. Synchronization of flowering of A- and R-lines can also be enhanced by management interventions. Hastening of flowering time by 6-8 days can be achieved by 3-4 sprays of 4% urea at 2-3 days interval at boot leaf stage. Application of micronutrients also helps boost growth. Delay in irrigation to late-maturing parent creates artificial stress which is found effective in hastening flowering. If the difference in flowering time of parental lines is more, a practice of staggered sowing is followed. Removal of main shoot in early flowering parent also helps in synchronization of flowering of the parental lines. Non-synchronization results in poor seed set, low yield and thus practically a failure of seed production (Fig. 15).

Fig. 15: Wrong synchronization in flowering of male-sterile line (central rows) and restorer line (outer rows) in seed production pearl millet resulting in poor seed set in male-sterile line

In recent years, a new technology has been developed to manage synchronization of parental lines in production plots. Landec Ag's Intellicoat® Pollinator Plus® technology is being commercially used by seed companies to achieve synchronization of parental lines and to improve hybrid seed production of maize in US. When Pollinator Plus® seed coatings are applied to early flowering parental line, germination of coated seeds is delayed. By using this coating technology, seed companies can overcome the need for staggered planting of male and female lines and save on labour cost. This technology can be tested for its effectiveness in pearl millet.

M. ***Roguing:*** The process of removal of pollen shedders from A-lines and off-types from parental lines in seed production field is called roguing. Pollen shedders are male fertile plants in an A-line with similar morphology. Pollen shedders in A-line are results of mutations or mechanical mixtures. Off-types are the plants distinctly

Fig. 16: Rouging activity being undertaken in seed production plot of pearl millet hybrid

different in morphological characteristics from those with typical characteristics of the line under production. The off-type plants may arise through mechanical mixture or out crossing and rarely as mutants. Adequate and timely rouging constitutes the most important operation in seed production (Fig. 16). Rogues differing from normal plants in phenotypes should be pulled out and discarded at the earliest possible stage of plant growth, before flowering to avoid genetic contamination. In case of pollen shedders, the best time for rouging is morning hours when the A-line will have least of the exposure to outcrossing and there is little wind movement.

Precautions:

- Pollen shedders should be removed before anther dehiscence. Removal of pollen shedders should be first in the morning activity and is the important aspect of quality seed production.
- Off-type plants obviously differing in characteristics such as height, flowering time, colour of foliage, leaf size, shape, and orientation, tillering, panicle size, or any other morphological characteristic and diseased plants should be removed before flowering.

- Roguing at maturity is also necessary to remove off-types not distinguishable earlier, and contaminants affecting the physical purity of seed.
- Roguing and sorting out of harvested panicles may be necessary in case of diseased panicles.

Seed standards for off-types, pollen shedders and diseased plants are given in the Table 3.

N. ***Harvesting and drying:*** The appropriate time of harvest to ensure maximum seed yield and quality is of great significance. Fully mature seed is easily harvested and cleaned with minimal harvest losses. Delayed harvesting may result in increased losses due to lodging and seed shattering. Sun drying of seeds on clean threshing floor may be necessary to reduce moisture content, preserve viability and vigour and improve storage quality. Drying of seed to recommended moisture level of 12% is necessary to preserve its viability and vigour.

Precautions:

- In case of certified seed production, R-line should be harvested first. In case of A-line seed production, B-line is harvested after the seed setting in A-line has started.
- Field should be thoroughly checked before harvesting A- line to avoid mixture
- Ensure that the drying yard is clean and free from any pearl millet or other crop seed
- Avoid making big heap at high moisture as it may deteriorate seed vigour.
- Panicles should be dried to 12% moisture level
- Harvested material should be double checked properly

O. ***Threshing:*** Care must be taken during threshing operations to avoid any chance of mechanical mixture. Threshing should be done lot wise. Checking and cleaning of threshers before use is a must to keep seed free from other seeds. Recommended RPM should be followed to minimize mechanical damage to the seeds. Seeds should be cleaned before dispatching to processing plant by winnowing /using screens to remove chaffy /unwanted materials.

5.5.3 Seed certification: Seed certification consists of several quality control measures that ensure supply of quality seeds to farmers.

5.5.3.1 Ensuring origin of source seed: Verification of seed source is the first step in seed certification programme. Unless the seed is of high quality and from approved source and of designated class, certification agency will not accept the seed field for certification.

5.5.3.2 Key traits: Every line or cultivar has its own unique set of traits that remain stable across sites and seasons. These traits form basis of their unique identity and help in identification of lines/varieties in seed production plots. Twenty-six such traits have been identified by PPV & FRA in pearl millet (PPVFRA, 2007). The most common traits used to identify lines during inspections are panicle shape, panicle size, anther colour, bristles, plant type etc. (Annexure IV).

5.5.3.3 Field inspection: Field inspection is a necessary monitoring protocol and is a pre-requisite to ensure quality seed production. It involves recording cultivar identification, crop purity, disease incidence, general stand assessment, cultural practices, previous crop, dates and number of inspections, and roguing details. This is followed by recording of established plant population, species and cultivar purity and the establishment of rejection/selection criteria. A minimum of four inspections are made. The first inspection is made before flowering preferably within 30 days after planting in order to determine isolation, volunteer plants, outcrossed plants, planting ratio, any error in planting, incidence of downy mildew and other relevant factors. The second and third inspections are made during flowering to check isolation, off-types, pollen shedders, downy mildew/ green ear and other relevant factors. The fourth inspection is made at maturity but prior to harvesting in order to determine the incidence of downy mildew/green ear, ergot and smut and to verify true nature of plant and other relevant factors. For every specific field inspection, a detailed protocol is followed.

When the seed production field does not meet the specified certification requirement, the options are whether whole field or part of the field is recommended for grow out test (GOT). The area not meeting the requirements is harvested as seed of doubtful purity, kept separate, and final decision on the disposition of seed is made by observing genetic purity report. Plants of male line are chopped to avoid contamination. At least 25% of fields are inspected to validate the submitted male chopping report and to ensure that chopped male plants were properly destroyed or taken off the production field.

5.5.3.4 Quality testing: Certification agency draws representative samples from the seeds produced under certification programme and subjects it to germination and other purity tests required for conforming to varietal purity/identity.

A. ***Sampling –*** Any type of seed analysis begins with the sampling of the seed lot which may be of any conceivable size. Seeds [Control] Order, 1983, under Seed Act 1966 provides guidelines for taking sample, sampling intensity, labeling, packing etc. Samples of any seed class for the purpose of analysis is taken in a clean dry container which shall be closed sufficiently tight and carefully sealed to prevent seed leakage and entrance of moisture.

Bulk sampling: When seed lots are stored in bulk (heaps, bins, wagons, etc.) the following sampling intensity should be regarded as a minimum requirement for obtaining the "bulk sample":

i. Up to 500 kg - at least 5 individual samples except in case of small lots of up to 50 kg where a smaller number of samples is sufficient but at least 3 samples are taken

ii. 501 to 3,000 kg - one individual samples for each 300 kg, but not less than 5 individual samples are taken

iii. 3,001 to 20,000 kg- one individual sample for each 500 kg, not less than 10 individual samples are taken

For seed in bulk the individual samples should be distributed across the bulk and the samples should be drawn from varying depths.

Bag sampling: For seed lots in bags or other containers the following sampling intensity should be regarded as a minimum requirement:

i. Up to 5 containers - sample each container but always take at least 5 individual samples.

ii. From 6 to 30 containers - samples at least one in every three containers but not less than 5 samples are taken.

iii. 31 containers or more - samples at least in every 5 containers but not less than 10 samples are taken.

Unless doubt exists about the homogeneity of individual lots, all such primary samples should be combined to make a composite sample of the lot for submitting to the seed testing laboratory. If the individual or primary samples are not sufficiently homogeneous, they may be sent to the laboratory for a heterogeneity test.

Seed samples need to be properly labeled and addressed and packed properly as per the guidelines of seed rule (International Seed Testing Association, 2015) for dispatch to seed laboratory or otherwise.

It is very important technically as well as by national and international rules that any sample drawn for conducting seed analysis should be a representative sample. Representative sample is such a sample that any tests conducted on this sample will accurately estimate the mean value of whole lot for determining seed quality. International seed testing rules (International Seed Testing Association, 2015) also provide clear instructions on how to draw samples from a seed lot so that the sample is representative of the entire seed lot. Glass containers should not be used; they easily break in transport, allowing the samples to be exposed to the air or, worse, they get mixed up.

B. ***Physical purity test –*** This test is to find out the composition by weight of the sample being tested and by inference, the composition of seed lot; the identity of various species of seeds and inert particles in the samples. Physical purity is calculated by using following formula:

$$\% \text{ Pure seed} = \frac{\text{working sample weight} - \text{Inert weight including other species seed weight}}{\text{Working sample weight}} \times 100$$

C. ***Genetic purity test:***

Grow-out test: Grow-out test is carried out with two major purposes viz, evaluation of the varietal trueness of the lot for certification and enforcing the provisions of any seed regulation stipulating quality standards for trueness of type.

- Row to row spacing: 60 cm
- Plant to plant spacing: 10 cm
- Replications: 2
- Spacing between plots: 90 cm
- Row length: 6 m

- Plant population: 400 plants (200 per replication).
- Sample size: 100 g seed sample is drawn from each lot and divided in 4 equal parts.
    i. Sample 1 is sent to seed testing laboratory for germination and physical purity test
    ii. Sample 2 is sent to quality control laboratory for conducting grow-out test
    iii. Sample 3 is retained as guard sample by quality control laboratory
    iv. Sample 4 is retained as guard sample with the seed processing unit
- Deviations from standard sample are recorded at flowering stage to validate genetic purity.
- Minimum recommended genetic purity is 95%.

D. *Germination test -* In seed testing, germination has been defined as the emergence and development of those essential structures (radicle and plumule) from the seed embryo, which, for the kind of seed tested, indicate its ability to develop into a normal plant under favorable conditions in soil. The emerging seedlings devoid of any or both of these essential structures; showing weak or unbalanced development; and decay or damage affecting the normal development of seedling are considered as those having not germinated while calculating the germination percentage. Factors that can affect the performance of seed in germination tests include diseased seed, old seed, mechanically damaged seed, seed stored under high moisture, and excessive heating of seed during storage or drying.

In most cases, a seed treatment will improve germination of seed only if the poor quality is due to seed-borne disease or due to seed dormancy. Several kinds of tests are available depending on the type of seed to be tested, the conditions of the test, and the potential uses of the seed. The most common tests are the cold germination test, accelerated aging test, the tetrazolium test and warm germination test. Each test is designed to evaluate various qualities of the seed.

E. *Field emergence test:* A normal germination based on laboratory test is not always well correlated with seedling emergence under field conditions. Generally, an accelerated ageing test is considered to be more precise in estimating the field emergence of a lot, but this also may not hold good in predicting the actual field emergence under unfavourable climatic conditions. Therefore, a field emergence test is conducted to determine the seedling emergence ability of a particular seed lot under normal field conditions.

6. Seed processing

Process of removing undesirable material from the desired seed lot and various steps in preparation of seed for marketing is called seed processing. The objectives of seed processing include ensuring high germination/seedling vigor, maintaining good appearance of seed, ensuring high physical purity and minimizing deterioration during storage. Types of materials removed during seed processing include inert materials, common weed seeds, noxious weed seeds, deteriorated seeds, damaged seeds, other crop seeds, other variety seeds and unacceptably small-sized seeds.

6.1 Cleaning

Seed is passed through an air screen cleaner to remove inert material. Precautions have to be taken to ensure that machine is cleaned before using, desired screen is selected and samples are taken to essertian that seeds are well cleaned.

6.2 De-stoning

It separates heavy impurities, such as stones, metallic particles etc. from the seed. Gravity separators are used for grading of seeds to the highest standards of physical purity. Near-size grains are separated according to the differences in their specific weight. It helps in removing damaged seed (insect and mechanical) and premature light weight seeds.

6.3 Chemical Treatment

Seed is treated with chemicals to protect it from pests and diseases. Seed-treaters suitable for liquid/dry chemical products are used. Calibration is important for uniform seed coating. Slurry volume and dump speed are calculated for uniform coating. Seed is treated with metalaxyl 35% WS @ 2 g a.i./kg seed for controlling downy mildew when the seed is is used for planting. K-Obiol 2.5 WP (Deltamethrine) @ 0.04 g/kg seed is used for controlling stored pests. Care should be taken in metalaxyl treatment of seed that is likely to be stored at room temperature for a longer time as metalaxyl-treated seed stored at 40°C has been reported to show phytotoxic effects (Thakur et al., 2011).

6.4 Packing

After the treatment, the seed is transferred from the holding bin into the packing machine to pack it into the pouches. Samples are taken during bagging to ensure the seed meets quality assurance standards. Care is taken to ensure that each primary seed bag contains the proper quantity of seed, is sealed properly and final seed moisture doesn't exceed 12%. The samples are again tested for warm germination test and accelerated aging test.

6.5 Labeling

Information on the label should be as per country seed laws. Pearl millet bag size in India is usually of 1.5 kg and 3.0 kg. Label on each bag specifies name of crop and cultivar, seed class, seed lot number, year of production and date labeled, expiry date of validity, germination percentage, purity, seed treatment and appropriate danger signs and warnings.

6.6 Storage

Storage conditions for nucleus seed include temperature of 4°C and relative humidity (RH) of 20% as the seed is stored for use in next few seasons. For breeder seed, temperature is 10°C and RH is 20%. Foundation and certified seeds are stored at room temperature if intended to be used within one year and at -20°C if stored for two years.

Stacking procedure is very important during storage for ease of handling within the store (Fig. 17). Information on quality and quantity of stock

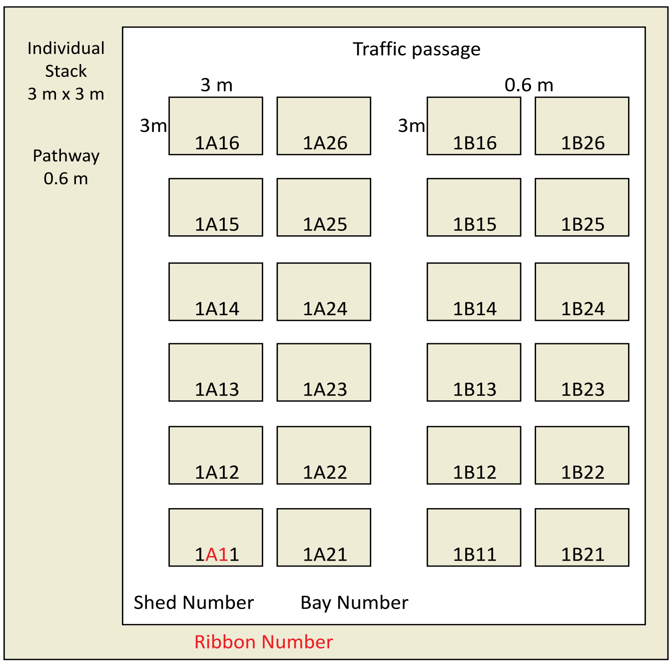

Fig. 17: Warehouse layout for stacking of processed and chemical-treated seed of pearl millet hybrid

before stacking is documented. Stacking should be done cultivar-wise, lot-wise, layer-size and section-wise to facilitate First-In-First-Out. Stacking is carried out up to six layers manually and above six layers it is done by using forklift / trolley. Stack cards are updated for each transaction. Lots pending for quality test results are stacked separately and with proper identification.

For controlling storage insect-pests, fumigation is done. All stocks are fumigated at one time. Ideal dimension of stack is 10 m × 4 m × 3 m. The seed stacks should be covered with polythene sheet. Rodent control is also critical. One cake of Roban is required for 1000 square ft. Bits of the cake are placed in corners and rodent paths. Repeat applications are required depending upon the extent of infestation, if any.

7. Commercialization

Marketing is the management process responsible for identifying, anticipating, and satisfying customer requirements profitably. Formal and organized seed system in India has developed rapidly. Until the early 1980s, the public sector dominated production and sale of certified cereal seed, with a market share exceeding 70%. In 1988, a new seed policy introduced significant deregulation and attracted several national and multinational companies in the seed business.

At present NSC and SSCs and several private companies produce and market seed of improved cultivars. More than 120 pearl millet hybrids (by name) are marketed in different parts of pearl millet growing regions. These hybrids provide high grain and dry stover yields and are resistant to downy mildew. Rainy segment targets early to medium maturity, and resistance to downy mildew, blast and stalk lodging. Summer-season segment has high priority for tolerance to high temperature during flowering time along with high grain and dry fodder yield. Providing information about new cultivars through brochures, leaflets, pocket diaries and pamphlets is a regular feature of marketing.

The pricing strategy of seed from private companies largely involves the brand value, the benefit farmers gain from growing pearl millet hybrid and cost of producing hybrid seed. On the other hand, the government agencies sell the seed that is cheaper due to subsidy provided on improved seed.

The total current annual business of pearl millet hybrid seed is around Rs. 400 crores (USD 64 million) and it has potential to grow up to Rs. 600 crores (USD 96 million).

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Annexure I

Parentage, notification details, area of adaptation, flowering time, maturity duration, grain and stover yields of pearl millet hybrids and released in India since 1986

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flower-ing	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
86M88 (MH 1816)	M162F x M164R	Recom-mended for notification	Pioneer Overseas Corp., Hy-derabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	54	86	3990	72
86M01 (MH 1790)	M096F x M149R	Recom-mended for notification	Pioneer Overseas Corp., Hy-derabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	82	3509	73
NBH 5061 (MH 1812)	NB 66A x NB 98R	Recom-mended for notification	Nuziveedu Seeds Pvt. Ltd., Hy-derabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	60	83	3356	60
NBH 5767 (MH 1785)	NB 345A x NB 97R	S. O. 268 (E) 28.01.2015	Nuziveedu Seeds Pvt. Ltd., Hy-derabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	57	89	3924	80
KBH 108 (MH 1737)	KMPS-74A x KPR-9288R	S. O. 244 (E) 24.01.2014	Krishna Seed (P) Ltd., Agra	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	56	86	3551	111
GHB-905 (MH-1655)	ICMA 04999 x J- 2454	S. O. 2815 (E) 19.09.2013	AICPMIP, MRS, Jam-nagar	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	48	79	2736	65
Nandi-72 (MSH-238) (NMH 75)	NMS 31A x NMP 75	S. O. 2815 (E) 19.09.2013	New Nandi Seeds Cor-poration, Ahmedabad	Summer growing areas of Gujarat Ma-harashtra, Rajasthan and Tamil Nadu	57	89	5274	102
86M89 (MH 1747)	M163F x M164R	S. O. 2815 (E) 19.09.2013	Pioneer Overseas Corp., Hy-derabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	53	84	3648	104
MPMH 17 (MH 1663)	ICMA 04999 x MIR 525-2	S. O. 952 (E) 10.04.2013	AICPMIP, Jodhpur	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	48	79	2835	64
HHB 234 (MH 1561)	HMS 7A x H77/833-2-202	S. O. 952 (E) 10.04.2013	AICPMIP CCS HAU Hisar	Western Rajasthan and drier part of Gu-jarat and Haryana	48	76	1756	40

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flowering	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
Kaveri Super Boss (MH 1553)	KBMS 329 x KBR 621	S. O. 2125 (E) 10.09.2012	Kaveri Seed Co. Ltd., Secundrabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	55	85	3383	83
Bio 70 (MH 1632)	11A x R 207	S. O. 2125 (E) 10.09.2012	Bioseed Research India Pvt. Ltd., Hyderabad	Western Rajasthan and drier part of Gujarat and Haryana	48	77	2023	43
Bio 448 (MH 1671)	13A x R 210	S. O. 2125 (E) 10.09.2012	Bioseed Research India Pvt. Ltd., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	52	83	3051	84
Nandi-70 (MSH 224)	NMS 31A x NMP 55	S. O. 2125 (E) 10.09.2012	New Nandi Seeds Corporation, Ahmedabad	Summer growing areas of Gujarat Maharashtra, Rajasthan and Tamil Nadu	58	89	5445	96
Pratap (MH 1642)	NB 101A x NB 152R	S. O. 2125 (E) 10.09.2012	Nuziveedu Seeds Pvt. Ltd., Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	51	84	2934	62
PKV-Raj (BBH 3)	BMS-5-23A x BR-333	S. O. 2125 (E) 10.09.2012	Dr. PDKV, ARS, Buldana	Maharashtra	49	84	2824	50
MP-7872 (MH-1610)	M002A x M004R	S. O. 1708 (E) 26.07.2012	Metahelix Life Science Ltd., Bangalore	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	53	82	3282	91
MP-7792 (MH-1609)	M001A x M004R	S. O. 1708 (E) 26.07.2012	Metahelix Life Science Ltd., Bangalore	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	52	82	3277	90
86M86 (MH 1684)	M128F x M138R	S. O. 1708 (E) 26.07.2012	Pioneer Overseas Corp., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	54	86	3405	87
CO 9	ICMA 93111 x PT 6029-30	S. O. 1708 (E) 26.07.2012	AICPMIP, TNAU, Coimbatore	Tamil Nadu	48	78	2707	60
VBBH 3040 (MH 1578)	VBBA 310089 x VBBR 330585	S. O. 456 (E) 16.03.2012	Vibha Agrotech Ltd., Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	49	82	3274	69
86M66 (MH 1617)	M124F x M118R	S.O. 2326 (E) 10.10.2011	Pioneer Overseas Corporation, Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	55	83	3305	95

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flowering	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
PAC 909 (MH 1435)	110057 x 130453	S.O. 2326 (E) 10.10.2011	Advanta India Ltd., Secundrabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	84	3487	63
RHB 173 (MH 1446)	93333A x RIB 192	S.O. 632(E) 25.3.2011	AICPMIP Jaipur	Rajasthan, Haryana, Gujarat, UP, Pubjab, Delhi, MP	49	79	3073	78
HHB 226 (MH 1479)	ICMA 843-22 x HBL 11	S.O. 632(E) 25.3.2011	AICPMIP Hisar	Dry areas of Rajasthan, Gujarat and Haryana	48	75	2081	45
RHB 177 (MH 1486)	ICMA 843-22 x RIB 494	S.O. 632(E) 25.3.2011	AICPMIP Jaipur	Dry areas of Rajasthan, Gujarat and Haryana	46	74	2047	43
86 M 64 (MH 1540)	M096F x M 117R	S.O.283(E) 7.2.2011	Pioneer Overseas Corporation, Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	52	85	3152	63
86 M 53 (MH 1541)	M096F x M 119R	S.O. 283(E) 7.2.2011	Pioneer Overseas Corporation, Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	53	86	3403	72
86 M 64 (MSH 203)	M096F x M 117R	S.O. 283(E) 7.2.2011	Pioneer Overseas Corporation, Hyderabad	Summer growing areas of Gujarat Maharashtra, Rajasthan and Tamil Nadu	55	89	5244	88
RHRBH 9808	RHRB 13A x RHRBI 1314	S.O.2137(E) 31.8.2010	AICPMIP MPKV, Dhule	Maharashtra	50	80	3013	52
Nandi 65 (MH 1549)	NMS 24A x NMP 75	S.O.2137(E) 31.8.2010	New Nandi	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP and MP	52	81	3303	85
Nandi 61 (MH 1548)	NMS 24A x NMP 64	S.O.2137(E) 31.8.2010	New Nandi	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	52	81	3432	86
HHB 223 (MH 1468)	ICMA 94555 x HBL 11	S.O.211(E) 29.1.2010	AICPMIP CCS HAU Hisar	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	46	77	2695	75
HHB 216 (MH 1421)	HMS 37A x HTP 3/13	S.O.211(E) 29.1.2010	AICPMIP CCS HAU Hisar	Western Rajasthan and drier part of Gujarat and Haryana	49	76	2300	53
Nandi 64 (MSH 199)	NMS 2-11A x NMP 4-1	S.O.211(E) 29.1.2010	New Nandi	Summer growing areas of Gujarat Maharashtra, Rajasthan and Tamil Nadu	56	88	4592	88

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flowering	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
RHB 154	ICMA 95444 x RIB 57 S/05	S.O.2187(E) 27.8.2009	AICPMIP ARS , Jaipur	Western Rajasthan and drier part of Gujarat and Haryana	48	76	2552	57
JKMS 20A x JKR 6136	JKMS 20A x JKR 6136	S.O.2187(E) 27.8.2009	JK Agri genetics Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	52	83	3006	81
GK 1051	PM 678A-II x PM 1081 R-I	S.O. 454(E) 11.02.09	Ganga Kaveri Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	54	87	3457	63
B 2095 (MH 1257)	B 0009A x B 5220R	S.O. 449(E) 11.02.09	Zurari Seeds Ltd Bangalore	Rajasthan, Gujarat, New Delhi, UP and MP	51	81	2876	77
PB 727 (Proagro 9555)	PSP 51 x PP 38	S.O.1108 (E) 8.05.08	Bayer Bio Science Hyderabad	Summer growing areas of Gujarat Maharashtra, Rajasthan & Tamil Nadu	57	88	4178	72
PHB 2168	ICMA 92333 x PIB 686	S.O. 72(E) 10.01.08	AICPMIP PAU Ludhiana	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	51	80	2914	76
HHB 197	ICMA 97111x HBL 11	S.O. 72(E) 10.01.08	AICPMIP CCS HAU Hisar	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	46	76	2959	70
GHB 732	ICMA 96222 x J 2340	S.O. 72(E) 10.01.08	AICPMIP MRS Jamnagar	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	52	81	3002	77
GHB 744	ICMA 98444 x J 2340	S.O. 72(E) 10.01.08	AICPMIP MRS Jamnagar	Rajasthan, Gujarat, Haryana, Punjab, New Delhi, UP and MP	51	80	2805	71
GHB 757	ICMA 92777 x J 2467	S.O. 72(E) 10.01.08	AICPMIP MRS Jamnagar	Western Rajasthan and drier part of Gujarat and Haryana	48	77	2365	46
GHB 719	ICMA 95222x J 2454	S.O. 122(E) 06.02.07	AICPMIP MRS Jamnagar	Western Rajasthan and drier part of Gujarat and Haryana	47	75	2406	54
NMH 68 (Nandi 62)	ICMA 97444 x NMP 48	S.O. 1703(E) 5.10.07	New Nandi Ahmedabad	Rajasthan, Gujarat, Punjab, New Delhi, UP and MP	53	82	2868	74
B 2301	B 0009A x B 5103R	S.O. 1703(E) 5.10.07	Zuari Seeds Ltd. Bangalore	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	55	88	3920	78

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flowering	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
HHB 67 Improved	ICMA 843-22x H 77/833-2-202	S.O.1566(E) 05.11.05	AICPMIP CCS HAU Hisar	Western Rajasthan and drier part of Gujarat and Haryana	41	70	2024	45
GHB 538	ICMA 95444x J 2340	S.O. 1177(E) 25.08.05	AICPMIP MRS Jamnagar	Western Rajasthan and drier part of Gujarat and Haryana	47	76	2453	42
PB 180 (Proagro-9444)	PSP 41 x PP 29	S.O.122(E) 2.02.05	ProAgro Hyderabad	Summer cultivation areas of Rajasthan, Gujarat and other states	58	86	4007	77
GHB 577	JMS A 101x J 2405	S.O.161(E) 4.02.04	AICPMIP MRS Jamnagar	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	50	81	3100	67
HHB 117	HMS 7 Ax H77/29-2	S.O.161(E) 4.02.04	AICPMIP CCS HAU Hisar	Haryana	49	73	2775	80
HHB 146	ICMA 95222 x HTP 94 / 54	S.O.283(E) 12.03.03	AICPMIP CCS HAU Hisar and ICRISAT	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	52	79	2887	74
GHB 558	ICMA 94555 xJ 2290	S.O. 283(E) 12.03.03	AICPMIP MRS Jamnagar	All India	53	81	3013	81
GHB 526	ICMA 95222 xJ 2372	S.O. 283(E) 12.03.03	AICPMIP MRS Jamnagar	Summer cultivation areas across India	59	86	4002	74
PB 172	PSP 35 x PP 27	S.O. 283(E) 12.03.03	Pro Agro, Hyderabad	Summer cultivation areas of Gujarat	54	84	4063	63
7688	PH 03 x PH 05	S.O. 92(E) 2.02.01	Pioneer, Hyderabad	All India	50	78	2545	60
PB 106 (Proagro 9443)	PSP 41x PP 6	S.O. 92(E) 2.02.01	ProAgro, Hyderabad	All India	48	78	2760	59
PB 112 (Proagro 9445)	PSP 35x PP 1	S.O.1134(E) 15.11.01	ProAgro, Hyderabad	Rajasthan, Haryana, MP, Gujarat, UP, Delhi	49	77	2715	64
RHB 121	ICMA 89111 x RIB 3135-18	S.O. 1134(E) 15.11.01	AICPMIP ARS , Jaipur	Rajasthan, Haryana, MP, Gujarat, UP, Delhi	47	75	2729	68
Nandi 35	NMS 11A x NMP 42	S.O.1134(E) 15.11.01	New Nandi Ahmedabad	Maharashtra, Karnataka, AP, TN	52	82	3009	55
CoHCu 8	732 A x PT 4450	S.O.1134(E) 15.11.01	AICPMIP TNAU Coimbtore	Tamil Nadu	46	81	2841	59

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flower-ing	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
HHB 94	ICMA 89111 x G73 – 107	S.O.340(E) 3.04.2000	AICPMIP CCS HAU Hisar	Haryana	52	73	3250	61
RHB 90	81 A x RIB 3135 - 18	S.O.821(E) 13.09.2000	AICPMIP ARS , Jaipur	Rajasthan	49	79	2206	42
Pusa 605	841A x PPMI 69	S.O.425(E) 8.06.99	IARI, New Delhi	Rajasthan, Haryana, Gujarat, MP, UP, New Delhi	48	77	2247	49
Nandi 8	NMS 5A x NMP 23	S.O.425(E) 8.06.99	New Nandi Ahmedabad	Rajasthan, Haryana, Gujarat, UP	50	80	2322	53
Nandi 32	NMS 7A x NMP 24	S.O.1050(E) 26.10.99	New Nandi Ahmedabad	Rajasthan, Haryana, Gujarat, MP, UP, New Delhi	50	78	2537	55
Pusa 415	576A x PPMI 85	S.O.1050(E) 26.10.99	IARI, New Delhi	Rajasthan, Haryana, Gujarat, MP, UP, New Delhi	48	78	2273	55
MLBH 504	36 A x MI-6 7	S.O.1050(E) 26.10.99	Mahendra	Maharashtra, Karnataka,Andhra Pradesh, Tamil Nadu	46	81	2134	63
GK 1004	GKPM 1A x GKPM 59R	S.O.401(E) 15.05.98	Ganga Kaveri Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	51	84	2845	42
7686	PH 01 x PH 03	S.O.401(E) 15.05.98	Pioneer Hyderabad	Rajasthan, Haryana, UP, Gujarat, MP	52	80	2174	52
PAC 903 (ICI 903)	-	S.O.401(E) 15.05.98	Advanta Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	81	2725	48
ProAgro 1(FMH 3)	PSP 21x PP 23	S.O. 401(E) 15.05.98	ProAgro Hyderabad	All India(irrigated in summer and rainfed in kharif)	-	-	-	76
RHRBH 8924 (Saburi)	RHRB 5A x RHRBI 458	S.O. 360(E) 1.05.97	AICPMIP MPKV Rahuri	Maharashtra, Karna-taka, Gujarat, TN	47	77	3001	42
GHB 183	81 A x J998	S.O. 360(E) 1.05.97	AICPMIP MRS Jam-nagar	Summer cultivation areas of Gujarat	51	83	5239	93
MLBH 285	11A xMI – 51	S.O. 360(E) 1.05.97	Mahendra Seeds	Rajasthan, Haryana, MP, Gujarat	51	80	2539	59
Nandi 30	NMS 3A x NMP 13	S.O. 360(E) 1.05.97	New Nandi Ahmedabad	Marashtra, AP, Karna-taka, TN	51	84	2897	50
X6	732A x PT 3095	S.O. 360(E) 1.05.97	AICPMIP TNAU Coimbtore	Tamil Nadu	55	98	2300	46
RBH 30	843A x RIB 335 / 74	S.O. 360(E) 1.05.97	AICPMIP ARS, Jaipur	Rajasthan	40	76	1683	40

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flower-ing	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
X7 (Cumbu 7)	Pb 111A x PT 1890	S.O. 647(E) 9.09.97	AICPMIP TNAU Coimbtore	Tamil Nadu	53	93	2513	49
JKBH 26	JKMS 2A x JKR 497	S.O. 662(E) 17.09.97	JK Agri genetics Hyderabad	Rajasthan, Haryana, MP, UP, Delhi	51	81	2300	53
GHB 316	405 A x J2290	S.O. 662(E) 17.09.97	AICPMIP MRS Jam-nagar	Rajasthan, Haryana, MP, Gujarat, Punjab and New Delhi	53	82	2120	64
MLBH 267	3A x 153	S.O. 1(E) 1.01.96	Mahendra Seeds	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	81	2599	57
JBH 1	81 A x ICMR 501	1996 15-7-96 Released by M.P.	AICPMIP Gwalior and ICRISAT	MP, UP	52	82	3560	64
Pusa 444	189 A x PPMI 301	S.O. 408(E) 4.05.95	IARI, New Delhi	All India	51	77	2260	39
RHB 58	81 A x RIB 20K–86	S.O. 408(E) 4.05.95	AICPMIP ARS, Jaipur	All India	51	83	2444	62
RHRBH 8609 (Shardha)	RHRBH 1A x RHRBI 138	S.O. 638(E) 2.09.94	AICPMIP MPKV, Rahuri	Maharashtra	48	82	2689	53
GHB 15	5054A x J 108	S.O. 636(E) 2.09.94	AICPMIP MRS Jam-nagar	Gujarat	51	78	2171	45
GHB 235	81 A x J 2296	S.O.636(E) 2.09.94	AICPMIP MRS, Jam-nagar	Gujarat	53	79	1992	53
AHB 251 (Devgiri)	81A x AIB 16	S.O.636(E) 2.09.94	AICPMIP RRS NARP Aurangabad	Marathwada area of Maharashtra	53	83	2661	62
MBH 160	MMS – 9 x PI 21	13-1-93	Mahyco Jalana	All India	51	82	2494	56
HHB 68	842 A x H77 / 833-2	S.O.615(E) 17.08.93	AICPMIP CCS HAU Hisar	Haryana	45	63	3000	85
Pusa 322 (MH 322)	841A x PPMI 301	S.O.615(E) 17.08.93	IARI New Delhi	All India	51	82	2451	57
ICMH 312	81A x ICMR 312	S.O. 615(E) 17.08.93	ICRISAT Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	80	2386	51
ICMH 356	ICMA 88004x ICMR 356	S.O.615(E) 17.08.93	ICRISAT Hyderabad	All India	48	78	2450	43
Eknath 301	NBMS 13A x NB 37	S.O.793(E) 22.11.91	Nath Seeds Aurangabad	All India	51	82	2487	59

Hybrids	Parentage (A x R)	Notification details	Bred at	Area of adaptation	Days to flower-ing	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
MLBH 104	53A x MI 13	S.O. 793(E) 22.11.91	Mahendra Seeds	All India	48	78	2372	60
HHB 67	843A x H77/833 – 2	S.O.386(E) 15.05.90	AICPMIP CCS HAU Hisar	All India	43	62	3100	88
VBH 4	VBMS 1A x VBR 19	S.O. 639(E) 17.08.90	Vijay Seeds Jalana	All India	52	83	2569	54
GHB 181	81A x J 2002	1989-	AICPMIP MRS Jam-nagar	-	50	80	3211	61
MBH 136	MS 2 A x PL No. 6	S.O. 280(E) 13.04.89	Mahyco Jalana	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	49	84	2257	43
ICMH 423	841A x ICMP423	S.O. 10(E) 1.01.88	ICRISAT Hyderabad	All India	50	79	3007	69
HHB 50	81A x H 90/4-5	S.O. 165(E) 6.03.87 S.O. 10(E) 1.01.88	AICPMIP CCS HAU Hisar	Haryana, TN, Gujarat	51	78	3250	60
HHB 60	81A x H77/833 – 2	S.O. 1135(E) 1.12.88	AICPMIP CCS HAU Hisar	Haryana	49	75	3250	61
GHB 30	5054 A x J 2002	S.O. 165(E) 6.03.87	AICPMIP MRS Jam-nagar	Gujarat	48	78	2793	53
Pusa 23 (MH 169)	84 1A x D 23	S.O. 834(E) 18.09.87	IARI New Delhi	All India	50	82	2312	50
MBH 130	MS 2A x Pl No. 4	S.O. 165(E) 6.03.86	Mahyco Jalna	All India	50	82	2282	58
MH 179	81A x ICMP 451	S.O. 258(E) 14.05.86	ICRISAT, Patancheru	All India	55	87	2226	58
MH 180	834A x ICMP 501	S.O. 258(E) 14.05.86	ICRISAT, Patancheru	All India	54	86	2126	56
MH 182	732A x PNBM 83099	S.O. 258(E) 14.05.86	AICPMIP, Coimbatore & Pune	All India	55	87	2175	62

Annexure II

Notification details, area of adaptation, flowering time, maturity duration, grain yield and stover yield of pearl millet open-pollinated varieties released in India since 1986

Variety	Notification details	Bred at	Area of adaptation	Days to flowering	Days to maturity	Grain yield (kg/ha)	Stover yield (q/ha)
Dhanshakti (ICTP 8203 Fe 10-2)	S. O. 1146 (E) 24.04.2014	AICPMIP, MPKV, Dhule	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Rajasthan, Haryana, MP, Gujarat, UP, Punjab	45	76	2199	53
ABPC-4-3 (MP 484)	S. O. 2125 (E) 10.09.2012	AICPMIP, Aurangabad	Maharashtra	51	85	2700	56
Mandor Bajra Composite 2 (MBC 2)(MP 489)	S.O. 2326 (E) 10.10.2011	SKRAU, A.R.S Mandor, Jodhpur	Rajasthan, Harayana, Gujarat	48	77	1478	42
Pusa Composite 612 (MP 480)	S.O. 632(E) 25.03.11	AICPMIP, New Delhi	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	49	84	2602	51
Pusa Composite 443 (MP 443)	S.O. 449(E) 11.02.09	AICPMIP, New Delhi	Rajasthan, Harayana, Gujarat	48	76	1691	45
PCB 164	S.O. 1178(E) 20.07.07	AICPMIP, Ludhiana	Punjab	49	78	2437	74
JBV 4 (MP 403)	S.O. 1178(E) 20.07.07	AICPMIP, Gwalior	Madhya Pradesh	48	76	2430	69
PPC-6 (Parbhani Sampada)	S.O. 122(E) 02.02.05	AICPMIP, Aurangabad	Maharashatra	48	77	2518	58
CoCu 9	S.O. 1177(E) 28.08.05	AICPMIP, Coimbatore	Rainfed/ irrigated conditions in Tamil Nadu	53	83	2354	60
CZP 9802	S.O. 283(E) 12.03.03	AICPMIP CAZRI, Jodhpur	Dry areas of Rajasthan, Gujarat and Haryana (Zone A1)	49	76	1303	33
HC 20	S.O. 937(E) 4.09.02	AICPMIP, Hisar	Haryana	51	80	2241	61
JBV 3 (GICKV 96752)	S.O. 92(E) 2.02.01	AICPMIP, Gwalior	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	50	80	2360	72
Pusa Composite 383	S.O. 1134(E) 15.11.01	AICPMIP IARI, New Delhi	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	48	77	2168	57
AIMP 92901 (Samrudhi)	S.O. 1134(E) 15.11.01	AICPMIP, Aurangabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	50	84	1863	37
HC 10	S.O. 340(E) 3.04.2000	AICPMIP, Hisar	Haryana	46	79	2231	79
JBV-2	S.O. 425(E) 8.06.99	AICPMIP, Gwalior	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	49	80	1840	48

Variety	Notification details	Bred at	Area of adaptation	**Days to flowering**	**Days to maturity**	**Grain yield (kg/ha)**	**Stover yield (q/ha)**
Pusa Composite 334	S.O. 1050(E) 26.10.99	AICPMIP, IARI, New Delhi	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	48	78	2171	53
Pusa Bajri 266	S.O. 360(E) 1.05.97	AICPMIP, IARI, New Delhi	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	47	77	2216	53
CZP -1C 923	S.O. 360(E) 1.05.97	AICPMIP, CAZRI Jodhpur	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	49	79	1816	44
Anantas(APS-I)	S.O. 662(E) 17.09.97	AICPMIP, Anantapur	A.P.	49	81	2927	46
ICMV 221	S.O. 615(E) 17.08.93	ICRISAT, Hyderabad	All India	44	75	2077	41
Raj 171	S.O. 814(E) 04.11.92	AICPMIP, Jaipur	All India	54	83	1934	64
ICMV155	S.O. 527(E) 16.08.91	ICRISAT, Hyderabad	Maharashatra, AP, TN, Karnataka	55	84	2096	68
Raj Bajra Chari-2	S.O. 386(E) 15.05.90	Jobner	All India	60	-	-	-
Pusa safed	S.O. 280(E) 13.04.89	AICPMIP, IARI, New Delhi	Rajasthan, Haryana, MP, Gujarat, UP, New Delhi	54	90	1872	52
ICTP 8203	S.O. 1135(E) 01.02.88	ICRISAT Hyderabad	Maharashatra, AP, Punjab	52	83	1608	46
Sangam (RHR 1)	S.O. 258(E) 14.05.86	AICPMIP, Rahuri	Rainfed areas of Maharashtra	53	85	2075	41
PCB 15 (PSB 15)	S.O. 258(E) 14.05.86	AICPMIP, Ludhiana	Punjab	57	83	1737	54
Co 7	26-11-86	AICPMIP, Coimbtore	Tamil Nadu	68	95	2500	88
Co 6	26.11.86	AICPMIP, Coimbtore	Rainfed areas of Tamil Nadu	68	97	2000	43

Annexure III

The traits and their categories recognized under criterion of distinctness, uniformity and stability (DUS) in pearl millet

S.No.	Characteristics	States	Note	Stage of observation	Type of assessment
1.(*)	Plant: Anthocyanin coloration of first leaf sheath	Absent	1	Seedling emergence (3)	VS
		Present	9		
2.(+)	Plant: Growth habit	Erect	1	Spike emergence (45)	VG
		Intermediate	5		
		Spreading	7		
3.(*)	Time of spike emergence (50% plants with at least one spike emerged fully)	Very early (<43 days)	1	Spike emergence (45)	VG
		Early (43-46 days)	3		
		Medium (47-50 days)	5		
		Late (51-54 days)	7		
		Very late (>54 days)	9		
4.	Leaf: Sheath pubescence	Absent	1	Spike emergence (45)	VG
		Present	9		
5.	Leaf: Sheath length	Short (<11 cm)	3	Spike emergence (45)	MS
		Medium (11-15 cm)	5		
		Long (>15 cm)	7		
6.	Leaf: Blade length	Very short(<41 cm)	1	Spike emergence (45)	MS
		Short (41-50 cm)	3		
		Medium (51-60 cm)	5		
		Long (61-70 cm)	7		
		Very long (>70 cm)	9		
7.	Leaf: Blade width (at widest point)	Narrow (<3 cm)	3	Spike emergence (45)	MS
		Medium (3-4 cm)	5		
		Broad (>4 cm)	7		
8. (*)	Spike: Anther colour	Yellow	3	Anthesis (50)	VG
		Brown	5		
		Purple	7		
9. (*)	Plant: Node pubescence	Absent	1	Dough grain (65)	VG
		Present	9		
10.	Plant: Number of nodes	Low (<11)	3	Dough grain (65)	MS
		Medium (11-15)	5		
		High (>15)	7		

S.No.	Characteristics	States	Note	Stage of observation	Type of assessment
11. (*)	Plant: Node pigmentation	Whitish	1	Dough grain (65)	VG
		Green	2		
		Brown	3		
		Red	4		
		Purple	5		
12. (*)	Plant: Internode pigmentation (between 3rd & 4th node from top)	Whitish	1	Dough grain (65)	VG
		Green	2		
		Brown	3		
		Red	4		
		Purple	5		
13.	Spike exertion	Partial	1	Dough grain (65)	VS
		Complete	3		
14. (*)	Spike: length	Very small (< 11 cm)	1	Dough grain (65)	MS
		Small (11-20 cm)	3		
		Medium (21-30 cm)	5		
		Long (31-40 cm)	7		
		Very long (>40 cm)	9		
15. (*)	Spike: Anthocyanin pigmentation of glume	Absent	1	Dough grain (65)	VG
		Present	9		
16.	Spike: Bristle	Absent	1	Dough grain (65)	VG
		Present	9		
17. (*)	Spike: Bristle colour	Green	1	Dough grain (65)	VS
		Brown	2		
		Red	3		
		Purple	4		
18. (*)	Spike: Girth at maximum point (excluding bristles)	Thin (<1.6 cm)	3	Dough grain (65)	MS
		Medium (1.6-3.0 cm)	5		
		Thick (>3.0 cm)	7		
19. (*) (+)	Spike Shape	Cylindrical	1	Dough grain (65)	VG
		Conical	2		
		Spindle	3		
		Candle	4		
		Lanceolate	5		
		Dumble-Bell	6		
		Club	7		
		Oblanceolate	8		
		Globose	9		

S.No.	Characteristics	States	Note	Stage of observation	Type of assessment
20. (*) (+)	Plant: Number of productive tillers	Monoculm	1	Dough grain (65)	MS
		Low (2-3 tiller)	3		
		Medium (4-6 tiller)	5		
		High (>6 tiller)	7		
21. (*)	Plant: Height (excluding spike)	Very short (<101 cm)	1	Dough grain (65)	MS
		Short (101-150 cm)	3		
		Medium (151-200 cm)	5		
		Tall (201-250 cm)	7		
		Very tall (>250 cm)	9		
22.	Spike: Tip sterility	Absent	1	Harvest maturity (75)	VS
		Present	9		
23. (*)	Spike: Density	Very loose	1	Harvest maturity (75)	VG
		Loose	3		
		Semi-compact	5		
		Compact	7		
		Very compact	9		
24. (*)	Seed: Colour	Whitish	1	Harvest maturity (75)	VG
		Cream	2		
		Yellow	3		
		Grey	4		
		Deep grey	5		
		Grey brown	6		
		Yellow brown	7		
25. (*) (+)	Seed: Shape	Obovate	3	Harvest maturity (75)	VG
		Elliptical	5		
		Hexagonal	7		
		Globular	9		
26. (*)	Seed: weight of 1000 grains	Very low (<5 g)	1	Harvest maturity (75)	MG
		Small (5.0 - 7.5 g)	3		
		Medium (7.6 - 10.0 g)	5		
		Bold (10.1 - 12.5 g)	7		
		Very bold (>12.5 g)	9		

Decimal code for the growth stages:

Code	Growth stage
3	Emergence stage
5	Three leaf stage
8	Five leaf stage
30	Flag leaf stage
35	Boot stage
45	Half bloom stage
50	Anthesis
60	Milk stage
65	Dough stage
70	Physiological maturity stage
75	Harvest maturity

Types of assessment of characteristics indicated in column seven of Table of characteristics

MG: Measurement by a single observation of a group of plants or part of plants.

MS: Measurement of a number of individual plants or part of plants.

VG: Visual assessment by a single observation of a group of plants or part of plants.

VS: Visual assessment by observation of individual plants or part of plants

Annexure IV

The most common traits used to identify lines during seed certification in pearl millet A- and B-lines

Trait		**ICMA 04999**	**ICMB 04999**
Growth habit	:	Erect	Erect
Days to 50% flowering	:	Medium (50 d)	Medium (50 d)
Anther colour	:	Yellow	Yellow
Plant height	:	Medium D2 (86 cm)	Medium D2 (83 cm)
Number of productive tillers	:	Low (3)	Low (2)
Spike exsertion	:	Complete	Complete
Spike length	:	Medium (21 cm)	Small (20 cm)
Spike girth	:	Medium (2.5 cm)	Medium (2.5 cm)
Spike shape	:	Conical	Conical
Compactness	:	Compact to Semi-compact	Compact to Semi-compact
Seed colour	:	Deep grey	Deep grey
Seed shape	:	Globular	Globular
1000-seed weight	:	Medium (9 g)	Medium (8 g)

The most common traits used to identify lines during inspections in pearl millet R-lines

Trait		**IPC 1466 (H 833-2)**
Growth habit	:	Intermediate
Days to 50% flowering	:	Medium (43-46 d)
Anther colour	:	Yellow
Plant height	:	Medium (130-150 cm)
Number of productive tillers	:	Low (2-3)
Spike exsertion	:	Complete
Spike length	:	Small (15-20 cm)
Spike girth	:	Medium (2.1-3.0 cm)
Spike shape	:	Candle
Compactness	:	Compact
Seed colour	:	Grey
Seed shape	:	Obovate
1000-seed weight	:	Medium (7 g)


IPC 1466


IPC 1466


IPC 1466

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