Developing Sustainable Seed Systems for Higher Productivity

Vilas A. Tonapi, Ch. Ravinder Reddy, N. Kannababu, Sooganna Dinni, B. Venkatesh Bhat, K. Raghunath, and Harvinder Singh Talwar

Contents

1 Introduction ... 893
2 Global Seed Systems ... 895
2.1 Seed Systems in Africa ... 895
2.2 Seed Systems in Asia ... 897
2.3 Seed Systems in America ... 898
3 Overview of Seed Systems ... 899
4 Community Seed Banks ... 901
4.1 Limitations of Formal Seed Systems ... 902
4.2 Limitations of Informal Seed Systems ... 903
4.3 Barriers to Seed Dissemination and Socioeconomic Constraints ... 903
5 Novel Strategies and Models for Sustainable Sorghum Seed Systems ... 904
5.1 Seed Sources for Informal and Formal Seed Systems ... 904
5.2 Challenges for Seed Sector in Marginal Environments ... 904
5.3 Sound Informal Seed Systems: Most Suitable for Dryland Ecosystems ... 904
5.4 Sustaining Viability of Informal Systems with Innovative Seed Delivery Models ... 905
6 Overview of Seed Constraints in Rain-Fed Crops in India ... 906
7 Seed Systems of Post-rainy Sorghum in India ... 907
8 Seed System Models ... 912
8.1 Approach ... 913
8.2 Sustaining Viability of Informal Systems with Innovative Seed Delivery Models ... 913
8.3 Roles and Responsibilities of Consortium Partners ... 916
8.4 Capacity Building ... 917

V. A. Tonapi (✉) · N. Kannababu · S. Dinni · B. V. Bhat · K. Raghunath · H. S. Talwar
ICAR-Indian Institute of Millets Research, Hyderabad, Telangana, India
e-mail: tonapi@millets.res.in; kannababu@millets.res.in; sooganna@millets.res.in; bhatv@millets.res.in; raghunath@millets.res.in; talwar@millets.res.in

C. R. Reddy
Formerly, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Telangana, India
e-mail: chrr.34@gmail.com

V. A Tonapi et al. (eds.), *Sorghum in the 21st Century: Food – Fodder – Feed – Fuel for a Rapidly Changing World*, https://doi.org/10.1007/978-981-15-8249-3_35

8.5 Seed Production 918
8.6 Main Observations and Impact of the Model 918
9 Way Forward for Sustainable Seed System 921
References 923

Abstract

One of the most pressing concerns related to seed supply mechanisms of improved varieties of rainfed crops is how to establish sustainable seed provision systems for commodities that cannot be economically supplied through a centralized, formal seed industry. The seed supply bottleneck primarily affects self-pollinating crop seeds saved and sown year after year in local systems. The restrictions imposed by national seed authorities on free exchange and marketing of seed, especially compulsory variety registration and seed certification, as practiced by many developed and developing countries are constraints on the efficient functioning of the formal seed sector and on the development of alternative seed systems. A good quality and improved variety seed can enhance production by 20% and with improved crop production practices can increase yield by 30–40%. Availability and accessibility to improved variety seed is a big task. Sorghum seed system is very unique in India with contrasting situations and systems. In the case of post-rainy season sorghum cultivated on black soils under residual moisture condition, open-pollinated varieties are the cultivar choice because of stringent quality considerations and lack of appropriate hybrids and inadequate hybrid seed production and supply chain. Ways of strengthening seed systems that could potentially address the needs and counter the vulnerabilities of smallholder farmers in these areas using specific seed delivery models need to be explored. Research and development programs of State Agricultural Universities (SAU) have developed improved varieties and are available in public domain for several years. To augment seed production and for dissemination of improved varieties, "seed consortium" model was developed with various partner institutions like the Department of Agriculture, agriculture universities, seed certification agency, state and national seed development corporations, private seed companies, NGOs, SHGs, and KVKs was brought onto one platform with a basic objective to enhance availability and accessibility of improved variety seed at right time and for right price to increase production and productivity of post-rainy sorghum. The present chapter discusses the successful implementation of seed consortium model to suggest the way forward for developing sustainable seed systems for higher productivity in sorghum.

Keywords

Community seed banks · Capacity building · Global seed systems · Seed production · Seed system models

1 Introduction

A well-functioning seed supply system is the prerequisite to make available and affordable good quality seeds to farmers at the right time. This in turn will help to ensure seed security and enhanced productivity in dryland areas. Given the critical role that improved varieties can potentially play in increasing the production of conventional cropping systems, developing an integrated and effective seed system capable of generating and delivering improved seed varieties in cost-effective ways is a challenge. Farmers' seed systems in agrarian communities have stood the test of time to enable evolution of modern agriculture. Thus the informal seed sector has ensured conservation of agro-biodiversity, at the gene, ecosystem, and farmer levels to ensure food security. Different names are used for these initiatives: community gene bank; farmer seed house; seed hut; seed wealth center; seed savers group, association, or network; community seed reserve; seed library; and community seed bank (Vernooy et al. 2015). Community seed banks can secure improved access to, and availability of, diverse, locally adapted crops and varieties and enhance related indigenous knowledge and skills in plant management, including seed selection, treatment, storage, multiplication, and distribution (Vernooy et al. 2017; Tonapi and Reddy 2017). A relatively recent analysis has led to an understanding of the crucial role that women have played in sustaining the informal seed sector and, more widely, in ensuring food security. However, this sector is solely dependent on local resources and inputs, and seed supply is highly vulnerable to disaster and sociopolitical disruptions. Sowing the seeds of innovation therefore assumes great urgency if one is to strengthen local seed systems. While the hybrid seed industry led by the private sector in formal seed systems has focused on profit-making species and crops, the informal sector has concentrated on those crops and seed systems which underpin local food production, mainly those predominantly self-pollinating and open pollinated. Given this scenario, national seed policies must devote more effort to sustaining and strengthening the informal seed sector. Most of the international support to strengthening seed systems focuses on the formal seed sector; the time has come for matching support to the informal sector. Seed supply from both formal and informal systems suffers from a series of problems due to lack of economic resources for education, research, and quality control. Farmers have little access to seeds of improved varieties. The key to overcoming this problem is to make available a range of modern varieties to farmers and train them on how to efficiently produce seeds of selected varieties, using modern technologies. Development of projects should be innovative and poverty-focused.

The dryland agro-ecosystems encompass crops ranging from cereals like rice and wheat to coarse millets, like maize and sorghum, minor millets, pulses and oilseeds, fiber, and many underutilized crops. Sorghum (*Sorghum bicolor* [L.] Moench) is grown both in rainy (kharif) and post-rainy (Rabi) seasons in India. In both the seasons, farmers are depending on rain for growing a successful crop. Hybrids are the cultivar choice in rainy season sorghum, and hybrid adoption by farmers is up to 95% in states like Maharashtra though there are wide variations in adoption across the states in India. The public and private sector seed companies developed hybrids and rule the market, and seed requirement is predominantly met by the vibrant formal seed system by private sector seed companies and public sector seed agencies. Due to poor infrastructure and institutional mechanisms to produce and disseminate improved variety seed by state extension department, the yield of the post-rainy sorghum was stagnant at 500–700 kg/ha for the last couple of decades. When cropping systems are characterized by subsistence farming, most of the crops grown are for self-consumption, where farm-saved seeds provide the bulk of the seed requirements in these areas. The actual issue is that cultivar replacement rate (CRR) is very poor; obsolete varieties and in most cases the landraces are still prominent and popular among the farmers. Therefore, seed replacement rate (SRR) is far below the state and national average (Fig. 1). In such a scenario, designing appropriate seed systems to meet the specific challenges demands clear identification of needs and strategies. Although the informal seed sector provides a dynamic and flexible system of seed supply, usage, handling, trade, and exchange, continuous use of untested seed inevitably leads to degeneration of seed quality. Though farm-saved seeds promote the use of local or traditional varieties to some extent, thus conserving the landraces, over time it doesn't provide adequate choices to the farmers to diversify their portfolio and thus improve productivity. One of the most pressing concerns related to seed supply of modern varieties is how to establish sustainable seed provision systems for commodities that cannot be economically supplied through a centralized, formal seed industry.

Despite the penetration of markets in the local economy, traditional coping strategies based on local processes of seed exchange are still important. Any successful developmental intervention aimed at increasing the resilience of seed systems should take into account these traditional exchange practices. For example, a better strategy for improving local institutions and seed exchange networks could

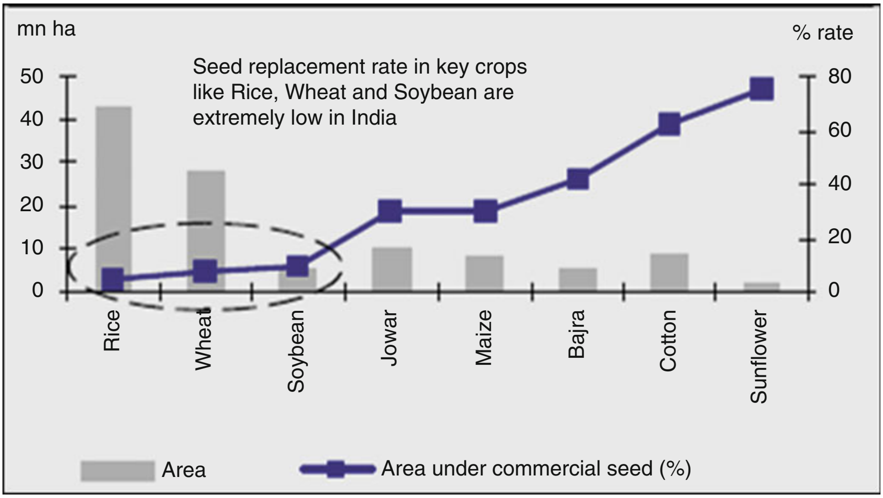

Fig. 1 Seed replacement in key food grain crops. (Source: Tonapi et al. 2012)

be aimed at increasing production and multiplication of seeds at the local level and facilitating movement of people between the two areas, rather than distributing seeds from outside to farmers. Development projects should be innovative and poverty-focused. It is crucial to reduce the poor man's vulnerability by increasing farmers' access to money and other valuable assets, which in turn are important for establishing and maintaining social relations that will help to evolve seed and food security in the long run.

This chapter attempts to analyze seed multiplication and delivery systems in sorghum while analyzing the problems associated with different seed systems for strengthening alternative seed systems and seed delivery models that address the needs and vulnerabilities of small farmers, given the constantly changing dynamics on the national, international, political, and socioeconomic fronts.

2 Global Seed Systems

Seed is the basic factor of mankind's most sought goal and agricultural abundance. Indian seed sector is one of the mature and vibrant domains in the world seed scenario. Enhanced seed replacement rates in high-volume and low-value crops like cereals, pulses, and oilseeds are the impetus that is driving, which is the result of pro-active policy support and adept execution by diverse seed stakeholders. India is showing its dominion in world seed scenario off late.

The global seed market was valued at USD 59.71 billion in 2018, exhibiting a CAGR of 7% during 2011–2018. It is further expected to register USD 90.37 billion in 2024 witnessing a CAGR of 7.9% during the forecast period 2019–2024. In 2018, the Indian seed market reached a value of USD 4.1 billion, registering a CAGR of 15.7% during 2011–2018. It is further expected to grow at a CAGR of 13.6% during 2019–2024, reaching a value of USD 9.1 billion by 2024.

This growth is mainly contemplated to Bt cotton, single-cross maize, and vegetable seeds, whereas volume of growth is due to increased SRR pertinent to high-volume crops, viz., paddy (dawn of hybrid rice) and wheat. The Indian seed market is anticipated to grow at a considerable CAGR rate due to improvement of seed replacement rate, production, and distribution of quality seeds appropriate to agro-climatic zone at affordable prices along with a determined effort to address region-specific constraints. Moreover, several factors, including increased subsidies and renewed government thrust on the use of high-yielding varieties, will lead to an increased productivity in the seed market (ICFA 2019).

2.1 Seed Systems in Africa

The informal seed sector provides over 80% of total quantity of seed planted in both developed and developing countries (Cromwell 1996). The percentage of seed obtained from informal seed systems in Africa is estimated at 85% for Ethiopia (Tafesse 1998) and 90% for whole of Africa (Lanteri and Quagliotti 1997); SADC region of Africa accounts to 95–100% (Wobil 1998). A total of 80% seed for food-feed crop of rainfed areas (semi-arid tropics) of Andhra Pradesh and water-limiting environments in India are met from informal sources. Quality declared seed (QDS) is an alternative system for seed quality assurance, developed by the Food and Agriculture Organization of the United Nations (FAO) in 1993 for countries with limited resources. It is less demanding and less expensive than full seed certification systems yet promotes a satisfactory level of seed quality. Not all countries permit QDS: in East Africa, it is currently allowed in Tanzania and Uganda, but not in Kenya (CABI 2014).

Formal seed systems in sub-Saharan West Africa are not meeting demand for seed of new improved varieties. It is this reality that has led to the informal systems reinforcing the diffusion of improved varieties parallel to formal initiatives. In most African countries, sustainable seed provision for improved varieties is often hindered by the complex steps and regulations required for producing and commercializing seed (Guéi et al. 2011). Purchase of seed can also be hampered by lack of funds (low investment capacity of the subsistent farmer), lack of knowledge about the workings of modern markets, or even socio-cultural restrictions; for example, monetary exchange of traditional cereal seed is a taboo in Mali (Siart 2008). In most of Africa, these informal systems still ensure between 80% and 100% of farmers' seed supply, as highlighted by Louwaars and de Boef (2012).

In European organic farming systems, Dawson et al. (2012) concluded that farmers' varieties could retain distinctive multiple agro-morphological traits even after several years of on-farm production. Duupa farmers in Cameroon are likewise are able to maintain sorghum landraces in mixtures through ideotype selection, in spite of pollen flow and relatively high outcrossing rates (Barnaud et al. 2008). Malian farmers have a long tradition of maintaining their varieties true to type by selecting panicles for specific phenotypic traits, such as grain, panicle and glume attributes, and flowering dates, although it has been reported that some farmers nowadays favor food grain for sowing over the time-consuming panicle selection method (Siart 2008). Local seed systems that are developed, managed, and maintained by farmers are a fundamental practice in smallholder crop production, supporting more than 80% of farmers in sub-Saharan Africa and feeding more than 70% of its population. Farmer-led seed systems have the capacity to provide quality sorghum seeds for crop production in Zimbabwe. They channel seeds of reasonable quality within comparable levels to the set certification standards. Such systems not only present opportunities to deliver seed, food, and nutritional security in sub-Saharan Africa but also have the potential to provide solutions that are resilient to changing climates. Farmer-led seed systems deserve greater recognition and support from governments and other relevant players in crop production in order to develop a tailored and appropriate seed system that meets the revolving needs of smallholder farmers in sub-Saharan Africa (Kusena et al. 2017). Seed systems in Ethiopia can be divided into two broad types: the formal system and the informal system (sometimes called local or farmer seed system) and both are operating simultaneously in the country, and it is difficult to demarcate between the two. In Ethiopia where the formal seed supply is inefficient, the informal system is extremely important for seed security of the nation. The majority of Ethiopian smallholder farmers are largely dependent on this system mainly through farm-saved seed exchange. The system is providing cheaper and readily available seeds to the farmer at village at the right time. As a result, the majority of Ethiopian farmers show a tendency of depending on the informal system. The informal seed system is more reliable and sustainable and thus needs to be strengthened with special emphasis of formalizing the system through integration with the law-regulated formal system (Atilaw and Korbu 2011). Local seed business (LSB) development is one of the components of the Integrated Seed Sector Development (ISSD) program in Ethiopia, focusing on organizing and supporting groups of farmers to produce and market quality seed of local preference. The LSB component of the ISSD focuses on transforming local initiatives in seed supply into local seed businesses. Given the diversity of the farming system, poor rural infrastructure, and a wide range of food security crops in Ethiopia, LSBs are filling the wide gap between the informal and formal seed systems. This paper argues that LSBs contribute to both the availability and accessibility of quality seeds of superior varieties in Ethiopia (Ayana et al. 2013).

2.2 Seed Systems in Asia

Smallholders depend on informal seed systems for 75–90% of their food crop cultivation. Southeast Asia, one of the world's biodiversity hotspots in the face of rapidly dwindling global genetic diversity, is at the forefront of seed system issues. Informal seed systems were strengthened through identifying potential species for commercialization, addressing technological barriers to seed analysis, and conducting seed fairs and seed banking. These activities not only strengthened informal seed systems but also significantly enhanced all four pillars of food security in the Thai and Cambodian rural communities (Gill et al. 2013).

Informal seed systems are critical for the production of a diversity of foods to ensure dietary diversity in smallholder communities. Many crop species integral to the informal seed system provide valuable macro- and micronutrients to the communities in which they are grown and consumed. In particular, informal seed systems are often the sole source of neglected and underutilized species (NUS), which are critical for providing the vast majority of essential nutrients to smallholder communities (Mayes et al. 2012). There is significant potential to extend the nutritional benefits of NUS in particular to regional and global levels to assuage the growing scourge of hidden hunger and the increasing homogenization of the global food base. Locally well-adapted germplasm also provides these communities with greater resilience in the face of significant events, including climate change, natural disasters, and political instability, pressures all too familiar in Southeast Asia. Strengthening informal seed systems that revolve around a broad genetic base thus provides an alternative paradigm to the increasing corporate control and monopolization of the global formal seed system that is resulting in an increasingly rapid reduction in global seed biodiversity (Schanbacher 2010).

The seed sector of Myanmar can be characterized by three major clusters of seed systems, i.e., (a) the informal seed system, (b) the intermediate seed system, and (c) the formal seed system. The overall performance of the present system is not in line with the objectives of the overall agricultural policy. More than 90% of the seed planted of most crops is farm-saved seed. The overview of support programs shows that most of the development partners, NGOs, and government projects concentrate on the formal, public seed system. The public-private seed system is much less developed in Myanmar. In addition, there are limited interventions in improving the informal and intermediary seed systems which still provide around 95% of seed to farmers for most crops and are crucially important for conservation and use of plant genetic resources and climate adaptation strategies (Van den Broek et al. 2015).

2.3 Seed Systems in America

Latin America is a diverse region that exhibits a high environmental, cultural, and social wealth; likewise, this region presents a variety of ways according to their agricultural production conditions, cultures, practices, and cultural, economic, and political factors; this wide variety of factors influence the levels of agricultural productivity and hence competitiveness and capacity of the region. The seed sector is different in each country and includes features, activities, dynamics, and norms according to their local contexts, and even within the same country coexist differences among seed crop sectors and/or regions. Overall, Brazil system shows an evolved system according to the Douglas (1982) classification criteria system. Colombia and Peru have more developed systems for some crops than others; the most developed systems correspond to crops with higher economic interest, while other crops rely on informal systems such as self-sufficiency. In Guatemala, the supply of seeds is largely dependent on the farmers' own production and public organizations through programs aimed at supporting small farmers.

In seed production systems analyzed here, it is quite clear that both formal and informal sectors coexist together, depending on the crop and the country. In Colombia and Peru, farmers are turning to sectors according to their particular needs; this is mainly due to the development characteristics of the systems and to the fact that governments should establish clear measures for the proper functioning and recognition of both. In Brazil the seed production system is characterized by the partnership between private companies and between public and private, ensuring the strengthening of research, training, and development of this industry. In Guatemala, the seed production systems are in a state of emerging development (Wendy Catalina et al. 2015). Seed libraries (SLs) are institutions that support the creation of semi-formal seed systems. The SLs engaged in seed system functions beyond distribution are new forms of socially motivated community science, poised to develop biological and social innovations reflecting their values and interests (Soleri 2018).

3 Overview of Seed Systems

A robust seed system guarantees the sustainability of its agriculture to ensure that the products of modern plant breeding and local farmer ingenuity are widely available. National seed systems usually include several elements. A commercial seed sector is necessary to ensure efficient seed supply. Seed systems can be grouped into two types: (1) formal seed systems and (2) informal seed systems. Informal systems are also referred to as local, traditional, or farmer seed systems. Both systems have their own limitations. Formal seed systems are easier to characterize as they are deliberately constructed, involving a chain of activities leading to clear products—certified seed of verified varieties (Louwaars 1994). The chain of activity leading to cultivar development usually starts with plant breeding and selection, resulting in different varieties, hybrid parents including hybrids and materials leading to formal cultivar release and maintenance. In practice, these systems may be constrained in their capacity to meet the diverse needs of farmers in developing countries. The framework for a performance analysis of a formal seed sector has been discussed by several authors (Pray and Ramaswami 1991; Cormwell et al. 1992; Friis-Hansen 1992). The guiding principles in the formal system are maintenance of varietal identity and genetic purity and production of seed with optimal physical, physiological, and sanitary quality. The central premise of the formal system is that there is a clear distinction between seed and grain. This distinction is less clear in informal seed systems. It has been estimated that over 90% of the crops in developing countries are still planted with farmers' varieties and farm-saved seed (Almekinders et al. 1994; Almekinders and Louwaars 1999; Maredia et al. 1999; World Bank 1998).

The formal seed sector focuses on high-value and hybrid crops and most favorable agro-ecosystems as trading in these crops and areas is most profitable. Thus open-pollinated varieties and self-pollinating crops are left to the mercy of small-scale unorganized seed companies and public sector seed companies and the informal seed systems. As the access to quality seed becomes acute, the smallholder farmers depend their seed security by saving their own seeds required for the next season, thus reducing opportunities for seed replacement with new varieties. With privatization or commercialization of public sector seed activities, the formal public sector seed activities have tended to focus on a narrow range of crops grown by larger farmers, thereby reducing supplies of seeds of new varieties of subsistence crops to smallholder farmers even further (Bengtsson 2007). Nevertheless, there are a number of examples throughout the world where seeds of cultivars are supplied by successful small- to medium-scale seed enterprises or farmer-led organizations. Some of them may have succeeded in creating a vibrant seed business and be able to respond to the demand for quality seeds. Identifying these and determining the key factors leading to their success will contribute to efforts to replicate the innovations in similar agro-ecological conditions for millets.

Village seed systems or farmer seed systems or local seed systems are different names for the informal seed system, in which farmers procure seed by different methods and practices depending on the situation and location. In an informal seed system, farmers themselves produce, disseminate, and access seed directly from their own harvest, through exchange and barter among friends, neighbors, and relatives and through local grain markets. Encompassing a wide range of variations, local systems are characterized by their flexibility. The varieties disseminated may be landraces or mixed races and may be heterogeneous. In addition, the seed is of variable quality in terms of purity and physical and physiological parameters. While some farmers treat seed specially, there is not always a distinction between seed and grain. Both public and private seed systems are relatively well developed in India; hence the possibilities of delivering plant breeding innovations to farmers are better. An unanswered question however is how do resource-poor farmers react to a complex commercial seed provision system? Recent innovations in adaptive and participatory research go a long way in addressing the first concern, but much remains to be done regarding seed system diagnosis. Even in a relatively mature seed system such as the Indian one, the movement of information between farmers and seed providers leaves much room for improvement. Seed-secure farmers tend to maintain their own varieties with limited influx of new varieties. In addition, awareness about variety selection is not always well developed in traditional farming communities. It may also reflect the fact that, in traditional self-contained seed systems, the same genetic material may be easily available from neighbors, thus reducing the risk of seed procurement and accesses. The farmers source seed off-farm from other farmers, and farmer communities often identify certain individual farmers as reliable sources of good quality seed. The proportion of the farming community involved as seed-producers-cum-distributors is very small. Furthermore, it is often difficult to establish whether these local seed suppliers are making a conscious effort to produce high-quality seed or if they are simply well-endowed farmers, they always have surplus grain to sell as "seed" during the next planting season. Seed sources have been related to wealth status, with rich farmers maintaining their own seed stocks but poor farmers having to buy or borrow seed every year.

The seed systems dealing with millets encompass formal channels for seed transactions with traders in the district market yards, where seed exchanges are through private dealers and distributors, and seeds are marketed by private companies where hybrids are in vogue. Millet seeds exchanged through agents in formal channels are often branded, the transactions are monetized, and those engaged in the business are usually full-time traders. In contrast, traders operating in shandies or village markets are part-time. Seeds traded in shandies are not branded, since they originate from farmers from the surrounding villages or communities. To some extent, the seeds are identified by their village name or, in some cases, by the farmer's name (if the farmer is reputed in the locality for the quality of seeds). The seed exchanges are monetized, but the prices are not based on "the existing market prices," nor are they "fixed"—they vary according to the demand and quality (physical purity) of the seeds. Seed dealers/distributors in the formal seed supply chain are vital links between the formal seed-producing firms and farming communities. The changing composition of cereal seed markets in dryland ecosystems refers to a point in two time periods, mostly for certified seeds. Saved seed is a dominant but declining source of seeds for all the crops. The existing millet seed systems involve the formal seed sector, which is an official or private control of seed monitored through the entire process of breeding, multiplication, processing, and storage, leading to the final product. The informal seed sector is simply the farmers themselves that provide each other and themselves with seed for sowing. This seed may be cleaned manually but is otherwise untreated and thus a potential carrier of various diseases. Therefore, strengthening of the seed system at community level should involve all possible aspects of modern seed activities. In industrialized countries, the formal seed sector provides the vast majority of seed to farmers, while both seed systems are present in developing countries. Despite large investments in formal seed systems in developing countries over the past 30 years, the seed demands of about 90–95% of smallholder farmers are still met by informal sources at the farm and community levels.

Although the informal seed sector provides a dynamic and flexible system of seed supply, usage, handling, trade, and exchange, continuous use of untested seed inevitably leads to degeneration of seed quality. Farmers depend on their own seed for sowing, not only because of inadequate access to seed from the formal seed sector but also because the formal seed sector more often provides seeds of a limited range of cultivars and varieties of food and fodder crops, which do not always fulfill the needs of farmers. On-farm growing and maintenance of locally adapted landraces, cultivars, and wild species help the farmer decrease the impact of a series of production constraints like drought, flooding, heat, cold, pests, and diseases. In many developing countries, problems created by seed-borne diseases are ignored, and control measures unknown or inadequate. The consequence is often poor seed quality, dissemination and buildup of seed-borne diseases, and yields far below potential. The quality of the seed must be known before it is sown. A farmer using healthy seed will be able to increase yield of his harvest dramatically. However, the health and quality of seed are not always apparent to the naked eye. Seed supply from both formal and informal systems suffers from a series of problems due to the lack of economic resources for education, research, and quality control.

4 Community Seed Banks

Community-level seed-saving initiatives have been around for about 30 years. These efforts have taken various forms and labels, including community gene bank; farmer seed house; seed hut; seed wealth center; seed savers group, association, or network; community seed reserve; seed library; and community seed bank (Ronnie et al. 2014). Broadly speaking, community seed banks are local, mostly informal institutions whose core function is that of collectively maintaining seeds for local use. As such, they are usually part of farmers' informal seed systems, in which the various stages of seed management like selection, conservation, exchange, and improvement take place without involvement of or control by research, development, or government agencies.

Ronnie et al. (2014) analyzed 35 cases and reported that 14 are paying particular attention to actual or expected impacts of climate change. The 14 are from Bangladesh, Bhutan, Bolivia, Brazil, Honduras, India, Mali (two case studies), Mexico, Nepal, South Africa, Uganda, the USA, and Zimbabwe. Tamang and Dupka (2015) reported that a recently established community seed bank in Bhutan is putting efforts into maintaining existing buckwheat varieties and restoring nearly disappeared ones to enhance genetic diversity in the area in situ, thereby strengthening farmers' capacity to adapt to variable agro-ecological and weather conditions. In South Africa, two newly established seed banks are in smallholder farmer area and are conserving the local varieties for long- and short-term storage and also to restore the seeds of varieties which have disappeared from the areas in the recent years. Their activities include accessing the novel diversity which is not conserved locally and collecting seeds of the crops from the areas where the crops have adapted to extreme weather conditions. The Gumbu village community seed bank in the dry area of northeastern Limpopo province is operated by 40 women farmers. The women say that community seed banks are helpful to maintain range of crop species and varieties inherited by their parents. The maintained crop diversity supports their food requirement and gives satisfaction and allows them to earn money by selling seeds. They suggest that exchange of seeds among farmers of different communities and cultures will help to stop the loss of crop diversity that is occurring in the area and a community seed bank could promote and organize such exchanges, for example, on a yearly basis (Tjikana et al. 2016).

4.1 Limitations of Formal Seed Systems

- The varieties developed are often not adopted by small farmers due to complex environment stresses and low input conditions.
- The formal seed sector has difficulty in addressing the varied needs of small farmers in marginal areas.
- They offer only a limited range of varieties.
- The formal seed sector is reluctant to produce and market varieties of the major millets because they may not be commercially feasible. Even if it does produce such varieties, they may not reach small farmers in remote rural areas.
- The interest of the private sector may cease to be served once the varieties are sold to farmers because the latter tend to save their own seed for the next season and hence will not buy again.
- Prohibitive seed prices are a limitation for resource-poor farmers.
- Poor logistics in seed diffusion and high seed demand constrain formal seed programs.
- Formal seed systems are sensitive to natural disasters and political or other turmoils.

4.2 Limitations of Informal Seed Systems

- The seed quality is often suboptimal due to biotic stresses and storage problems.
- Seed exchange is limited to a geographical area and governed by cultural barriers.
- Crop failures or low yields have a tremendous effect on the availability of seed and local prices.
- When a local seed system collapses, it is not easy to restore it in a short time. In such a situation, local varieties (landraces) are easily lost and replaced by relief-supplied seeds.

4.3 Barriers to Seed Dissemination and Socioeconomic Constraints

Poor distribution of inputs and produce in a region results from poor infrastructure. Farmers have little access to seeds of improved varieties. The key to overcoming this problem is to make available a range of modern varieties to farmers and train them on how to efficiently produce seeds of selected varieties, using modern technologies. In fact, seed and product markets should target national and regional markets. More than 60% of farmers purchase seed from the market through cash and credit. Thus, there is a need to link farmers to credit institutions. Information on seed supply and demand across has to be disseminated across countries. The approach is to maintain an inventory of variety traits, growing varieties with preferred traits for evaluation and selection by farmers and producing breeder and foundation seed of newly released varieties and those in advanced stages of testing. These are some of the ways of establishing sustainable seed systems. Besides, organizing field days and variety demonstrations at the community level, monitoring the adoption of improved varieties, identifying constraints to broaden adoption, and developing a community-based seed production system form an integral part of the strategy. Despite the penetration of markets in the local economy, traditional coping strategies based on local processes of seed exchange are still important. Any successful developmental intervention aimed at increasing the resilience of seed systems should take into account these traditional exchange practices. For example, a better strategy for improving local institutions and seed exchange networks could be aimed at increasing production and multiplication of seeds at the local level and facilitating movement of people between the two areas, rather than distributing seeds from outside to farmers. Development projects should be innovative and poverty-focused. It is crucial to reduce the poor man’s vulnerability by increasing farmers’ access to credit and other valuable production assets, which in turn are important for establishing and maintaining social relations that will help to evolve seed and food security in the long run.

5 Novel Strategies and Models for Sustainable Sorghum Seed Systems

5.1 Seed Sources for Informal and Formal Seed Systems

In fact, millet seed systems in dryland ecosystems are basically influenced by their pace of seed replacement, seed-to-grain price ratios, distance to seed sources, and the quantity of seed traded by formal and informal means. The richness of materials grown at the household and community levels is in general positively affected by the quantities of seed sold by dealers and in local weekly open-air markets, as well as the rate of seed replacement. Distances to different seed sources also influence the diversity of crops and varieties in these communities. In the marginal environments, crop and variety use decisions take place within the context of local seed markets and the national seed industry.

5.2 Challenges for Seed Sector in Marginal Environments

The major challenges the millet seed sector faces in the marginal environments are:

- The extent and persistence of farm-saved seeds
- Variation in R&D investment across season dryland crops
- Seed sector regulations, in particular the enactment of recent plant variety protection and farmers' rights legislation in India

The extent and continued use of farm-saved seeds in dryland crops, which constitute mainly the varieties, on the one hand discourages the entry of commercial sector in developing new research products and also from the perspective of public sector adds any kind of incentives for their already existing research. Though farm-saved seeds promote the use of local or traditional varieties to some extent, thus conserving the landraces, over time it does not provide adequate choices to the farmers to diversify their portfolio and thus improve productivity. One of the most pressing concerns related to seed supply of modern varieties is how to establish sustainable seed provision systems for commodities that cannot be economically supplied through a centralized, formal seed industry. The seed supply bottleneck primarily affects self-pollinating crop seeds saved and sown year after year in local systems.

5.3 Sound Informal Seed Systems: Most Suitable for Dryland Ecosystems

Scientifically developed informal seed systems are the best, where the formal sector finds seed distribution difficult and farmers cannot reach seed markets easily. They may also be appropriate in smaller, limited agro-ecological zones, where the formal seed market is disinterested or unable to cater because of limited market for specific varieties or because widely marketed varieties may not suit that region or another important reason is an economic consideration, as profit margins are lower. They are also suitable in cases where the crops involved have a high seed rate and are bulky in nature, which translates into higher transportation costs and low profits.

5.4 Sustaining Viability of Informal Systems with Innovative Seed Delivery Models

The main purpose of alternative seed delivery system is to address the seed availability problems of smallholder farmers. Hence, ways of strengthening seed systems that could potentially address the needs and counter the vulnerabilities of smallholder farmers in these areas using specific seed delivery models need to be explored. Most of the community-based informal seed production models/schemes are initiated because farmers are concerned about the non-availability of quality seeds at planting time. Many farmers do not have access to improved varieties and would not be able to afford them even if they were. So introduction of alternative seed system models must impact farmers' access to seeds of improved varieties at affordable costs. The quality of seed produced by community-based system or farmer seed systems is guaranteed only by its seller or village seed committee, because they are not processed and are uncertified. The seed so produced is low priced and available at farmers' doorsteps at the right time and provides access to all farmer groups in the village. The regulatory and legal framework of national seed rules and regulations in many countries hampers the development of informal seed systems. National seed regulations are mostly based on international standards, which are often incompatible or irrelevant to the realities of farmers' seed systems. The restrictions imposed by national seed authorities on free exchange and marketing of seed, especially compulsory variety registration and seed certification, as practiced by many developed and developing countries are constraints on the efficient functioning of the formal seed sector and on the development of alternative seed systems. On the other hand, regulatory frameworks are crucial for the development of a national seed system (Tripp 2003).

The major source of seed for small-scale farmers comes from their own on-farm savings, seed exchange, borrowings, and local traders. Nevertheless, farmer's community systems of seed supply are under pressure due to recurring natural calamities such as drought, crop failure, storage problems, and poverty. In drought situations, farmers depend on subsidized seed supply by government agencies, which meets only 30–40% seed requirement of smallholder farmers (Reddy 2005). In order to strengthen the seed delivery system, interventions are required to strengthen informal seed supply systems, such as establishing village-based seed banks as alternative seed systems for seed security. The alternate village-based seed delivery models that may enable sustainability of community seed systems in the dryland ecosystems need to have the following objectives:

- To improve seed availability and access to improved varieties of seed to small and resource-poor farmers
- Build capacity of stakeholders at the community level to enhance sustainable supply of good quality seed and timely supply at affordable prices

6 Overview of Seed Constraints in Rain-Fed Crops in India

Rain-dependent areas can be broadly split into two: "drylands," which receive less than 750 mm of rain a year, and rain-fed areas, which receive more than 750 mm. Comprising arid and semi-arid ecosystems, drylands stretch from Gujarat in the west till Eastern Madhya Pradesh and from Rajasthan till the southern tip of India. Rain-fed agriculture is described as farming practices that rely on rainfall for crop production, and their seed systems describe how farmers in these regions source seed for cultivating these crops. In India largely cereals and legumes are grown as rain-fed crops which are totally dependent on rainfall and also on residual soil moisture in rainy and post-rainy seasons, and the crops vary with soil type, rainfall, and cropping pattern. Farmers in rain-fed regions usually do not adopt easily improved crop production technologies developed by national/state agriculture research institutes and take risk of investing in inputs like improved seed and fertilizers and other agricultural practices because rain-fed crops are prone to water stress due to breaks in the monsoon during the crop growth, may be due to variability of rainfall, delay in sowing, diversity in crop management practice, and variability of the soil type which can result in partial or total failure of the crops. India ranks first among the rain-fed agricultural countries of the world in terms of both extent and value of produce. Due to population pressure on agricultural lands, the poverty is concentrated in rain-fed regions. The climate in India's rain-fed regions is characterized by complex climatic deficiencies, manifested by water scarcity for rain-fed crop production. The climate is largely semi-arid and dry sub-humid with a short (occasionally intense) wet season followed by long dry season. Rainfall is highly unreliable, both in time and space, with strong risks of dry spells at critical growth stages even during good rainfall years. The fluctuations are due to numerous factors affecting the monsoonal climate. Rain-fed agriculture occupies 67% of net sown area, contributing 44% of food grain production and supporting 40% of the population. Even after realization of full irrigation potential of the country, 50% of net sown area will continue as rain-fed. At present 95% of the area is under coarse cereals and 91% under pulses. Eighty percent under oilseeds, 65% under cotton, and 53% under rice are rain-fed. Livestock forms an integral part of rain-fed ecosystem, and two out of every three animals are thriving in these regions. These areas are spread out throughout the length and breadth of the country with semi-arid to sub-humid environments and shallow textured light soils to deep textured black and alluvial soils with varied effective crop growing periods from 90 to 180 days.

The problems in rain-fed regions are exacerbated by adverse biophysical growing conditions and the poor socioeconomic infrastructure. The uncertain climatic conditions or otherwise called climate change effects make these farmers more vulnerable. The most essential input of crop production is seed which is the cheapest of all inputs in rain-fed agriculture. A good quality and improved variety seed can enhance production by 20% and with improved crop production practices can increase yield by 30–40%. Availability and accessibility to improved variety seed in these areas is a big task. During years of drought and/or natural calamities, subsidized seed supply by government agencies or international relief programs meets the requirement of seed supply which nullifies farmer's preference and force to adopt the variety available. The problem of seed insecurity repeats in rain-fed areas due to some natural calamities like drought, floods, typhoons, etc. The SAT is the home to 38% of the developing countries' poor, 75% of whom live in rural areas. Over 45% of the world's hungry and more than 70% of its malnourished children live in the SAT. The institutional mechanisms to multiply the farmer's preferred varieties of crops grown in rain-fed regions are poorly developed, and private seed sector is not showing interest in such crops because of economic reasons. Public sector research and development organizations do develop varieties to enhance production and productivity in these regions, but their extension system and mechanism are not well versed or equipped to meet the farmer's demand. The emerging three major types of seed constraints in rain-fed crops are (1) seed insecurity due to frequent droughts and natural disaster, (2) poverty and food insecurity lead to seed insecurity, and (3) availability of quality seed and new varieties and development of appropriate seed systems.

7 Seed Systems of Post-rainy Sorghum in India

Sorghum (*Sorghum bicolor* [L.] Moench) is grown both in rainy (kharif) and post-rainy (Rabi) seasons in India. In both the seasons, farmers are depending on rain for growing a successful crop. The majority of rabi sorghum grain and stover production is concentrated in districts across the states of Maharashtra, Karnataka, and Andhra Pradesh (Trivedi 2008; Rana et al. 1999; Hosmani and Chittapur 1997; Murty et al. 2007; Pray and Nagarajan 2009). Sorghum seed system is very unique in the country with contrasting situations and systems. Hybrids are the cultivar choice in rainy season sorghum, and hybrid adoption by farmers is up to 95% in states like Maharashtra though there are wide variations in adoption across the states in India. The public and private sector seed companies developed hybrids and rule the market, and seed requirement is predominantly met by the vibrant formal seed system by private sector seed companies and public sector seed agencies like National Seeds Corporation (NSC) and state seed development corporations in different states and Mahabeej in Maharashtra. In the case of post-rainy season sorghum cultivated on black soils under residual moisture condition, open-pollinated varieties are the cultivar choice because of stringent quality considerations and lack of appropriate hybrids and inadequate hybrid seed production and supply chain. The post-rainy sorghum crop accounts for 45% of the total sorghum area under cultivation and 32% of the total sorghum production in India (Sajjanar et al. 2011). Although post-rainy (rabi) sorghum is highly valued due to its good grain quality, its yields are lower

Table 1 Region-wise area under post-rainy season sorghum cultivation and seed sources in India (2011–2012)

Region/ state	Area under cultivation (lakh ha)	Varieties under Cultivation	Seed quantity (tons)		
		Present varieties in cultivation	Total requirement	Supplied by formal sector	Supplied by informal sector
Maharashtra	32	M 35-1, Dagadi, Phule Vasudha, and Parbhani Moti	32,000	4000[a] (12.5%)	28,000[b] (87.5%)
Karnataka	13	M 35-1, Muguti (5-4-1), Annigeri (A-1), DSV-4, and DSV-5	13,000	<10%	>90%
Andhra Pradesh	2	M 35-1, Budda Mallelu, Udgir local, Saayi Jonnalu, Dagdi local, CSV216R	2000	INA	INA
Gujarat	0.1	BP 53, Surat 1, GJ 108, Malvan, Solapur, Gundari,	100	INA	INA
Other states	1	INA	1000	INA	INA
Total	48.1		48,100		

INA information not available
[a]Formal sector—supply by private/corporations (Maharashtra State Seeds Corporation/NSC)
[b]Informal sector—farmer's own saved seed, local markets, friends, relatives, government subsidized seed supply

(750 kg/ha) compared to kharif sorghum (1100 kg/ha) (AICSIP 2006). This low productivity rate of post-rainy sorghum calls for a change in production strategy including breeding, targeting varieties for different soil depths and improved seed systems to make improved variety seed available to small-scale farmers in India. The post-rainy season sorghum crop was grown on 4.8 million ha (CMIE 2007) in India. Maharashtra has the highest area of 3.2 million ha under sorghum, which requires 32,000 tons of seed at 10 kg/ha seed rate. Formal sector is able to meet ~12% of seed requirement and balance; ~88% seed supply is from informal sector, mostly from farmer's own saved seed (Table 1) (Pokarkar and Reddy 2014).

Baseline survey was conducted to understand existing seed systems and its constraints to develop a robust sustainable seed system model to meet the seed demand of post-rainy sorghum. Two locations were selected in Maharashtra state where post-rainy sorghum is cultivated in large areas. Various clusters in Eastern Maharashtra, Sanpuri (district, Parbhani) and Limbaganesh (district, Beed), and five clusters in western Maharashtra Wakulni (district, Jalna) in Marathwada area and Hivare Bazar (district, Ahmednagar), Borkarwadi (district, Pune), and Aurad (district, South Sholapur) region were selected for baseline survey. The results of the survey are presented in Tables 1, 2, 3, 4, and 5 and Figs. 2 and 3.

Table 2 Sorghum varieties released by agriculture universities in Maharashtra State, India

S. no.	Variety	Year of release	Variety released by agriculture university
1.	M 35-1	1938	MPKV-Rahuri
2.	Parbhani Moti	2002	VNMKV-Parbhani
3.	Phule Vasudha	2007	MPKV-Rahuri
4.	Phule Anuradha	2008	MPKV-Rahuri
5.	Phule Revati	2010	MPKV-Rahuri
6	Phule Yashoda	2009	MPKV-Rahuri
7	Phule Suchitra	2012	MPKV-Rahuri
8.	Parbhani Jyoti	2005	VNMKV Parbhani

Table 3 Seed production of post-rainy sorghum by state seed development corporation of Maharashtra state, India (Mahabeej) in 2012–2013

Sr. no.	Variety	Area under seed production (ha)	Seed production (in tons)
1.	M 35-1[a] (old local variety)	2336	2564
2.	Parbhani Jyoti	49.60	54
3.	Parbhani Moti	315.20	336
4.	Phule Anuradha	2.00	2
5.	Phule Chitra	30.80	20.6
6.	Phule Revati	77.20	64.7
7.	Phule Vasudha	92.40	76
8.	PKV Kranti	108.20	94.4
	Total	3011.4	3211.7

[a]Old variety

Table 4 Procurement of seed by the farmers from different sources in Maharashtra state during 2013–2014

Seed source	Percent farmers (district wise)					
	Solapur	Pune	Ahmednagar	Beed	Jalna	Parbhani
Own saved seed	93.33	98.33	98.33	93.33	95.00	92.5
Borrowed from others	0	0	26.67	1.66	0.00	0.00
Village market	8.33	3.33	18.33	1.66	0.00	0.00
Local market at Taluka level	3.33	30.00	15.00	0.00	5.00	5.00
Village landlords	0	0	1.67	3.03	0.00	2.50
Private seed company[a]	8.33	3.33	13.33	6.67	8.033	1.25
Govt. subsidized seed supply[b]	66.67	0	0	5.0	1.67	1.25
SAU[a]	0	0	18.33	0.00	0.00	10.00

[a]Multiply and supply improved variety seed
[b]Multiply and supply 80–90% local variety seed and 10–12% improved variety seed

Table 5 Post-rainy sorghum variety seed sold by seed dealers in Maharashtra state during 2013–2014

Variety	Percent of total seed sale in project areas	
	Marathwada region (Eastern Maharashtra)	Western Maharashtra
M 35-1[a] (old local variety)	78.66	77.45
Parbhani Moti	11.93	–
Parbhani Jyoti	0.49	–
Phule Anuradha	0.18	0.17
Phule Chitra	0.38	–
Phule Revati	0.77	–
Phule Vasudha	1.51	–
PKV Kranti	2.87	–
DJ 4005	0.05	–
Deccan Pearl	–	3.11
Kopargaon	–	1.86
Mahabeej	–	0.6
Suvarna	0.06	13.08
Swati	–	0.62
Vimal	3.1	3.11

[a]Old local variety and rest all improved released varieties

High-yielding and improved cultivar seed availability is not a constraint in rainy season sorghum, but major issue in post-rainy season sorghum in India is majority of the varieties are age old and are still ruling the major area under cultivation. Most notable local varieties popular among the farmers include M 35-1 (Maldandi) and Dagadi grown by 80–90% of farmers in India. However, M 35-1, a landrace selection from Maldandi, cultivated traditionally by the farmers in these areas for several decades, was selected in 1938, nearly 75 years ago, and is still dominating the post-rainy season tracts (Maharashtra, Karnataka, and Andhra Pradesh) in India (Belum Reddy et al. 2012). Several improved varieties such as Phule Yashoda, Phule Anuradha, Phule Chitra, Phule Revati, Parbhani Moti, and Parbhani Jyothi developed by SAU have been released in the recent past by the All India Coordinated Sorghum Improvement Project (AICSIP) (Table 2).

Reasons for non-availability of improved variety seed of post-rainy sorghum

- Private sector is not forthcoming for multiplying the open pollinated varieties (OPVs) of sorghum for various economic reasons.
- There are no proprietary advantages in multiplying public domain varieties.
- In the case of post-rainy season adapted varieties (or hybrids), the seed produced in post-rainy season has to be marketed in next post-rainy season which means they need to wait for 8 months to market them and hence the returns on investment are realized late.

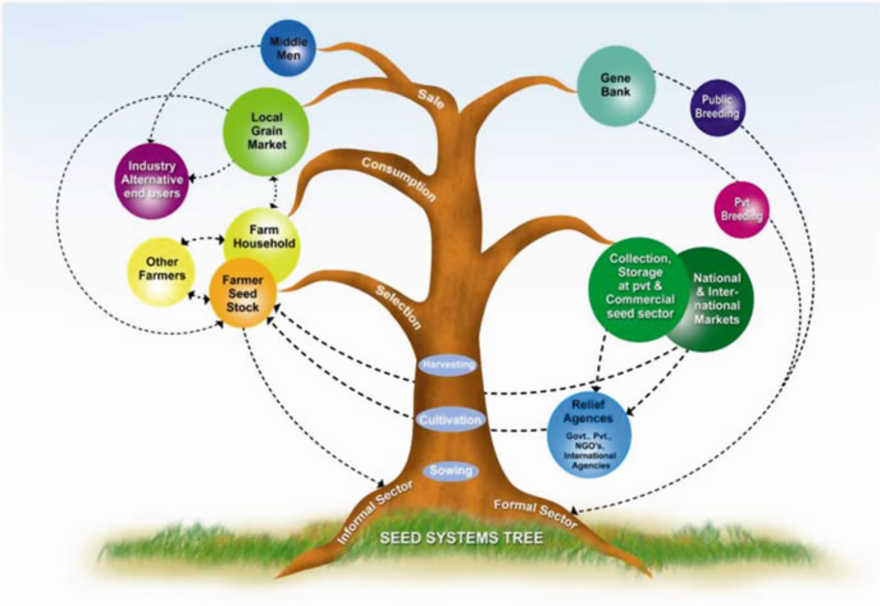

Fig. 2 Seed system tree. (Source: Reddy et al. 2007)

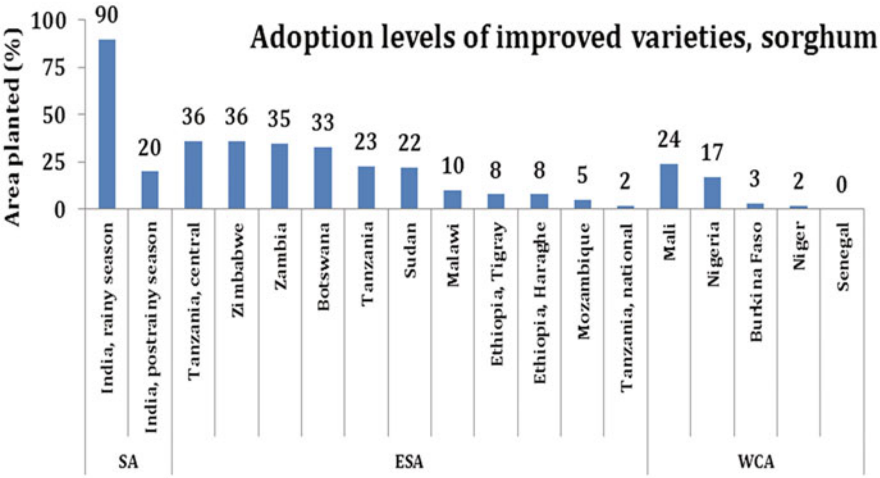

Fig. 3 Adoption levels of improved varieties of rainy and post-rainy season sorghum in India and other countries

- The margins for private seed companies are low in production and marketing of open pollinated varieties (OPVs) when compared to hybrid market, and there are not many improved hybrids with all the farmer's preferred traits in post-rainy sorghum.
- It is primarily 10–12% of total seed requirement of Maharashtra state fulfilled by the public sector seed agencies and State Agricultural Universities partially catering the needs of farmers for sorghum seed supply in post-rainy season (Table 3).
- Major portion (90%) of farmer's seed source is met from farmer's own saved seed (informal sector).

In India rainy season sorghum is cultivated in around 2.6 million ha which is predominantly grown with hybrids. The high adoption rates of hybrids up to 95% in Maharashtra state reveals the strength of seed companies, genetic material adoption in different agro-ecological zones with varied climate and soils. The scenario of hybrid cultivars shows wide variation among states (only 10% adoption in Bihar and Odisha) in adoption of improved cultivars. Similarly, the adoption of hybrids varies from 2% to 12% in Eastern and Southern Africa (ESA) and Western and Central Africa (WCA) (Fig. 3).

Post-rainy sorghum grain is staple food of Maharashtra state, and every farmer grows sorghum for his own food and stover for livestock. Hence, sorghum is an important crop in crop-livestock cropping system which feeds humans and livestock. The seed required for post-rainy sorghum is predominantly produced by the public sector (state seed development corporations and agriculture universities) organizations which meets 10–12% of total seed requirement (32,000 tons) of the state. But these organizations that produce 80% of their total production produce old varieties (Table 3). Baseline survey report (Pokarkar and Reddy 2014) reveals that 93–98% of the seed sources are from farmer's own saved seed and balance component is met by public and private sector and other informal seed sources (Table 4). Improved variety seeds are available at seed stores in the market and the takers are very few. The percentage of improved variety seed sold was 0.6–12% and old local variety was sold to the tune of 76% of the total sale of seed (Table 5).

The baseline survey revealed how farmers are sourcing the seed material from different sources and flow of genetic material from formal and informal sources (Fig. 4), leading to mixture of varieties used by the farmers over a period of time.

8 Seed System Models

Research and development programs of State Agricultural Universities (SAU) have developed improved varieties and are available in public domain for several years (Table 2). Due to poor infrastructure and institutional mechanisms to produce and disseminate improved variety seed by state extension department, the yield of the post-rainy sorghum was stagnant at 500–700 kg/ha for the last couple of decades. To augment required seed and for dissemination of improved varieties, "seed

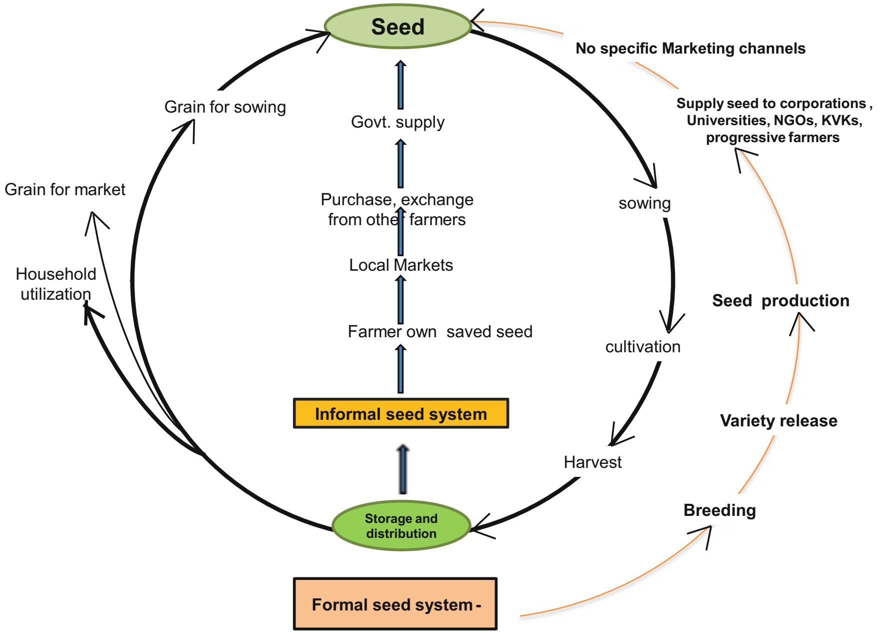

Fig. 4 *Flow* of genetic material from formal and informal systems in post-rainy sorghum in India

consortium" model was developed (Fig. 5) (Reddy et al. 2017) by involving various partner institutions like Department of Agriculture, agriculture universities, seed certification agency, state and national seed development corporations, private seed companies, NGOs, SHGs, and KVKs.

8.1 Approach

The proposed conceptual and organizational approach, strategies, and partners and the linkages and support from formal sector institutions were planned and developed a "seed consortium model" which includes private and public sector seed companies, State Agricultural Universities (SAU), Krishi Vignana kendras (KVKs), self-help groups (SHGs), non-governmental organizations (NGOs), and farmers and their associations. Specific roles and responsibilities are delineated to consortium partners for effective implementation of the project.

8.2 Sustaining Viability of Informal Systems with Innovative Seed Delivery Models

The main purpose of alternative seed delivery system is to address the seed availability problems of smallholder farmers. Hence, ways of strengthening seed systems

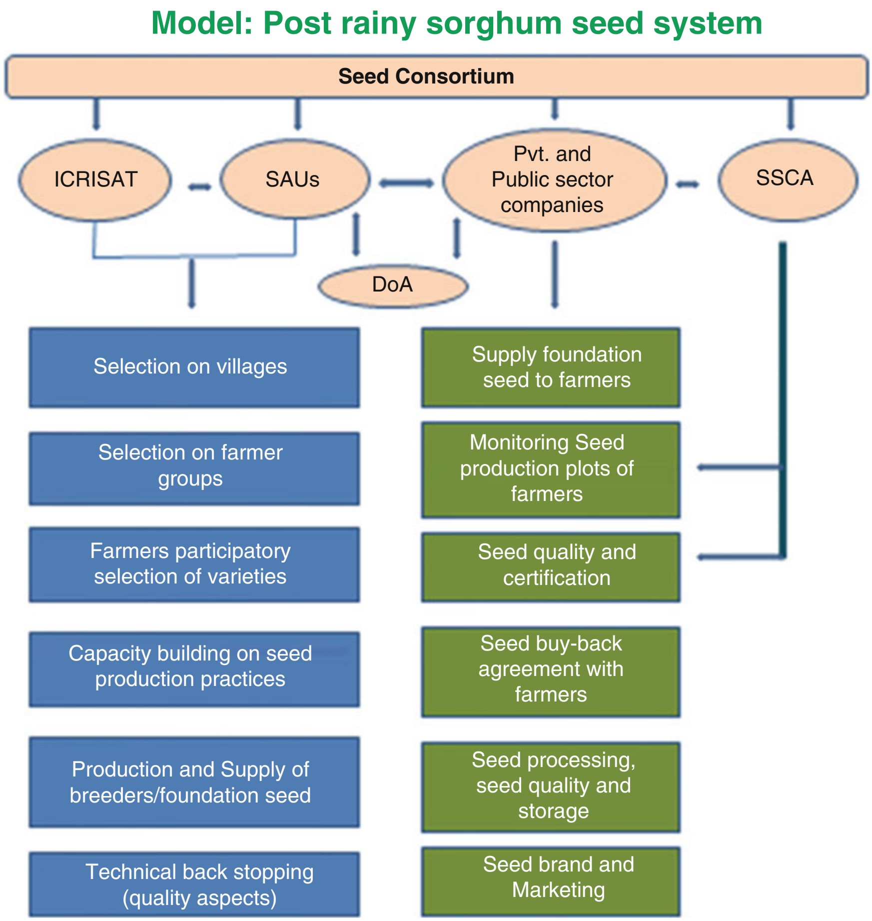

Fig. 5 Seed consortium model

that could potentially address the needs and counter the vulnerabilities of smallholder farmers in these areas using specific seed delivery models need to be explored. Most of the community-based informal seed production models/schemes are initiated because farmers are concerned about the non-availability of quality seeds at planting time. Majority of farmers do not have access to improved varieties and would not be able to afford them even if they were. So introduction of alternative seed system models must impact farmers' access to seeds of improved varieties at affordable costs. The quality of seed produced by community-based system or farmer seed systems is guaranteed only by its seller or village seed committee, because they are not processed and are uncertified. The seed so produced is low priced and available at farmers' doorsteps at the right time and provides access to all farmer groups in the village. The regulatory and legal framework of national seed rules and regulations in many countries hampers the development of informal seed systems. National seed regulations are mostly based on international standards, which are often incompatible or irrelevant to the realities of farmer seed systems. The restrictions imposed by national seed authorities on free exchange and marketing of seed, especially compulsory variety registration and seed certification, as practiced by many developed and developing countries are constraints on the efficient functioning of the formal seed sector and on the development of alternative seed systems. On the other hand, regulatory frameworks are crucial for the development of a national seed system (Tripp 2003). The major source of seed for small-scale farmers comes from their own on-farm savings, seed exchange, borrowings, and local traders. Nevertheless, farmer's community systems of seed supply are under pressure due to recurring natural calamities such as drought, crop failure, storage problems, and poverty. In drought situations, farmers depend on subsidized seed supply by government agencies, which meets only 30–40% seed requirement of smallholder farmers (Reddy 2005). In order to strengthen the seed delivery system, interventions are required to strengthen informal seed supply systems, such as establishing village-based seed banks as alternative seed systems for seed security. The alternate village-based seed delivery models developed and described their operations, potentiality, and limitations (Reddy et al. 2007) for various crops. The experience of implementation of a new seed system model to meet the seed requirement of post-rainy sorghum for 3.2 million ha in Maharashtra state is presented in this chapter.

Based on the finding of baseline survey on existing seed systems of post-rainy sorghum in Maharashtra, a seed consortium model (Fig. 5) developed to multiply improved varieties and distribute to farmers was implemented. The formal sector (private seed companies) is very week and is unwilling to participate in the system for reasons of economic benefits. The public sector usually more inclined and governed by government support and policies has become boon to rain-fed agricultural crop seed supply in India. This model envisaged a decentralized seed production and centralized seed procurement and distribution in initial years but eventually shifted to decentralized seed production and distribution. The public sector research and development institutions like ICAR, SAUs, SSDC, and ICRISAT in development of improved cultivars play a critical role in seed production, procurement, and dissemination. This is akin to the rainy season hybrid seed production and distribution in the country, which is one of the most successful examples in the developing world for having a strong seed system. In a way a sustainable commercial model to replicate to strengthen the post-rainy sorghum seed value chain was developed.

The seed consortium developed a work plan to produce a total of 29,000 tons of improved variety seed over a period of 4 years to meet the requirement of 3.2 million ha of post-rainy sorghum area in Maharashtra. Early adoption studies on improved varieties by the farmers conducted by ICRISAT revealed that secondary dissemination of seed is very active in the region; each farmer on an average shares seed with two to six other farmers across the districts in the state. The trends of secondary dissemination of seed by the farmers will be able to meet the seed requirements of farmers in Maharashtra, covering 3.2 million ha by the end of a 4-year project duration.

8.3 Roles and Responsibilities of Consortium Partners

The consortium partners implementing the project developed integrated post-rainy sorghum value chain by harnessing the power of genetics, crop management, value addition, and markets under the HOPE project (2008–2013) (http://www.cgiar.org/consortium-news/hope-leads-to-increased-sorghum-yields/). Based on the strength of achievements under HOPE project for post-rainy sorghum productivity enhancement, a "seed consortium" was formed during 2013 under the chairmanship of commissioner of Agriculture, Maharashtra state, involving private and public sector partners to sustain HOPE interventions. Under the consortium, an innovative seed system model developed and delineated responsibilities to partners for achieving seed production targets fixed during the meeting.

1. *State Agricultural Universities:* Two agriculture universities MPKV and VNMKV are the members of the consortium, and they have developed varieties. The breeder and foundation seed of selected released varieties namely Phule Vasudha, Phule Chitra, Phule Revati, and Parbhani Mothi were multiplied on research farm and supplied to public sector seed company (Mahabeej) for production of certified seed. The cost of foundation seed production was borne by the project. The university Scientists and Mahabeej company scientists jointly selected villages and farmers for seed production. The government of Maharashtra is encouraging farmers by paying an incentive of Rs. 500/- per quintal of seed under seed village scheme (Anon 2009).
2. *Public sector seed company (Mahabeej):* Mahabeej has agreed on the work plan (Table 6) and also agreed in principle to reduce gradually production of local variety M 35-1 (Maldandi) to promote improved released varieties. They have entered into buy-back agreement with farmers with a prefixed minimum price of seed procurement and agreed to pay 20% more over the grain price in the market at the time of procurement. The seed harvesting and transportation to processing plant are the responsibility of farmers, and processing, grading, branding, and marketing are Mahabeej's responsibility.
3. *NGOs, KVKs, and FA:* These organizations agreed to promote farmers in growing seed in addition to village seed program to meet the target area under seed production. However, the organizations have a program of seed development which was merged with seed consortium, and they are benefited by access to foundation seed supply, training programs for farmers, and other crop production incentives and market linkages through consortium.
4. *State seed certification agency:* Mahabeej has taken responsibility to register farmer's name and area for seed certification. The main objective of seed certification agency is to monitor purity of the variety and certify the quality and quantity of seed produced by the farmers. The expenses incurred for monitoring

Table 6 Quantity of certified seed produced during project period 2013–2016 by the consortium partners

Year	Partner	Seed production area (ha)	Quantity of seed produced (tons)	Area covered under improved varieties (ha)
2013	MPKV	256	294	29,400
	VNMKV	98	166	16,600
2014	MPKV	850	900	90,000
	VNMKV	272	363	36,300
2015	MPKV	2135	1400	140,000
	VNMKV	546	324	32,400
2016	MPKV	3000	4500	450,000
	VNMKV	659	790	79,000
Total		7816	8737	873,700

the seed crop and issuing the certificate for seed produced by the farmer were borne by the project.

5. *Department of Agriculture:* The involvement of the Agriculture Department in extension services was aimed of help the rural community to achieve higher productivity in agriculture. Introduction of intensive agriculture, comprising large-scale use of improved seed, fertilizers, pesticides, and available water, helped in increasing agriculture production. Later on, considering the need for providing guidance to the farmers for proper and judicious use of these inputs, training and visit scheme was launched. Valuable contribution of this scheme through effective implementation of programs like crop demonstrations, field visits, corner meetings, workshops, fairs, exhibitions, etc. aimed at transfer of technology from agriculture universities to farmer's fields was evident from the increased agricultural production.

8.4 Capacity Building

Training programs were conducted on-station (university) and on-farm (in the villages) by technical staff of universities jointly by seed certification officials. Mahabeej staff joined the programs to announce their buy-back agreement and assurance of seed procurement to develop confidence levels in seed producers. During seed production period, university technical staff used to visit the farmers' fields and give technical advice to farmers on crop production. Most of these villages were earlier adopted under HOPE project. Hence, almost all farmers in the villages are well-versed with improved crop production technologies which have given fillip to the seed production program.

8.5 Seed Production

The first seed consortium meeting was conducted at Pune in April 2013, under the chairmanship of commissioner of Agriculture. The members of Department of Agriculture, University's Vice chancellor, Director of Research, Adviser for Dry Land Agriculture Mission, seed certification agency director, general manager of Mahabeej, and private seed company's representatives participated in the meeting. There was consensus among the consortium partners to develop robust seed system for post-rainy sorghum in Maharashtra, and the commissioner of Agriculture has extended all support under seed village program for the benefit of seed-growing farmers (Anon 2009). Agriculture universities geared up with production of required breeder and foundation seed and supplied to seed development corporation for production of certified seed. Seed certification agency in consultation with corporation registers seed-producing farmers and monitors seed production fields for seed quality and certification. However, the quantity of certified seed produced in 4 years (Table 6) did not meet the planned target production due to administrative and natural calamities.

8.6 Main Observations and Impact of the Model

The low productivity of 750 kg/ha in post-rainy sorghum is low compared to kharif sorghum (1100 kg/ha) and this situation calls for a change in production strategy including breeding, targeting varieties for different soil depths and improved seed systems to make improved variety seed available to small-scale farmers in Maharashtra state. The post-rainy season sorghum crop is grown in 4.8 million ha in India; Maharashtra has highest area of 3.2 million ha, which requires 32,000 tons of improved variety seed every year. The formal sector is able to meet ~12% of seed requirement and balance ~88% seed supply comes from informal sector, mostly from farmer's own saved seed. The private sector is not forthcoming for multiplying the open pollinated varieties (OPVs) as there is no proprietary advantage. Due to poor infrastructure and institutional mechanisms to produce and disseminate improved variety seed by public sector, government agencies, corporations, and state extension department, the yields of the post-rainy sorghum were stagnant at 500–700 kg/ha for the last couple of decades in spite of improved varieties available with agriculture universities. To augment seed production and for dissemination of improved varieties, "seed consortium" model was developed involving various partner institutions like Department of Agriculture, agriculture universities, seed certification agency, state and national seed development corporations, private seed companies, NGOs, SHGs, and KVKs by bringing them on one unified platform with a basic objective to enhance production and availability of improved variety seed at the right time and for right price to increase production and productivity of post-rainy sorghum in India which was successfully implemented.

Availability and accessibility to improved variety seed of post-rainy sorghum is a big task. During years of drought and/or natural calamities, government subsidizes seed or international relief programs meet the requirement of seed supply which nullifies farmer's preference and forces farmers to adopt the variety available. But it's a temporary relief for farmers that year, and again the problem of seed security repeats in rain-fed regions. The institutional mechanisms to multiply the farmer's preferred varieties of sorghum grown in rain-fed regions are poorly developed, and private seed sector is not showing interest in post-rainy sorghum because of economic reasons. Public sector institutions and research organizations have developed varieties to enhance production and productivity in rain-fed regions, but public sector extension mechanisms are unable to disseminate the technologies available to small-scale farmers in India. Some public sector and NGOs developed and promoted community-based decentralized seed system models for production and dissemination of improved varieties of cereals and legume developed by national research programs which could make a limited impact in small areas of India. Despite a wide range of reform initiatives in agricultural extension in India in the past decades, the coverage of, access to, and quality of information provided to marginalized and poor farmers are uneven. Sorghum is grown in rainy season purely under rain-fed conditions, and in post-rainy seasons, it is grown on receding soil moisture condition in Maharashtra state. The seed system operating in rainy season is 95% formal, and acquisition varies from place to place; hybrid cultivars are main choice of farmers. On the contrary, 93% of post-rainy sorghum seed are sourced informally. Farmers in Maharashtra are acquiring post-rainy sorghum seed through various modes (Table 4) in varying proportions depending upon the variety, rate of seed replacement, social networks, and market integration. This indicates that the seed accusation by farmers varies greatly during seasons and across eco-regions. The proportion of seed accusation by the farmers varies within the system and among the regions of the state (Table 4). Majority of post-rainy season sorghum farmers in Maharashtra save their own seed and use it for sowing next year; this practice likely alters the sourcing of seed from other two modes (purchasing and sharing) of accusation. Farmers living in the vicinity of SAU procure improved variety seed from SAU sales counter, and mostly they are big farmers and are aware of varieties and sources of seed by virtue of their location and accessibility to seed source.

It is not uncommon practice with the innovative farmers using seed (cultivars) from formal and informal sectors (relatives, neighbors, own-saved seed) growing on the same piece of land separately for testing and selecting good variety for next season. In the process, sorghum being a cross-pollinated crop, contamination from other pollen is inevitable on farmers' fields where they do not practice isolation distance. Farmers select the variety and save the seed for next season sowings and continue year after year; the good variety seed shared with their friends and relatives is a common practice. Varietal purity and identity frequently become blurred through several process, and all those processes, frequent and ongoing, serve to muddle the identity of the old and new, pure or not, local and modern varieties. With this sort of farmer's practice, the purity of the good old variety M 35-1 (Maldandi) released during 1938 is questionable. Still farmers prefer the variety and covers 80% share in post-rainy sorghum cultivation. The components of formal and informal seed systems of post-rainy sorghum operating in India (Fig. 4) and the flow of the genetic material from one system to other are inevitable. It is perhaps this melding of formal and informal seed systems that is of prime interest for those striving to create stable, resilient, and dynamic post-rainy sorghum seed system in India—systems on which farmers can actually relay. The seed consortium has grown seed crop on 7816 ha and produced 8737 tons of certified seed (Table 6) (average production 1.11 tons/ha) distributed to farmers covering 873,700 ha with improved varieties during the project period. To mitigate isolation distance problem in seed production, every effort was made to take large areas in each village under single variety. However, the consortium could not achieve the targets of seed production due to various administrative and financial problems in addition to climatic variations and natural disasters. The probable reasons for not meeting the targets are (1) deficit in supply of breeder and foundation seed by the universities because of administrative and financial reasons, (2) deficit in rainfall and low soil moisture, (3) damage of basic seed production plots by natural calamities (gales and high speed wind with heavy rain), (4) deficit in budget to meet facilitation, input supply toward seed production expenses, (5) rejection of seed production plots by certification agency due to noncompliance of specified isolation distance by the farmers, (6) inadequate staff for project implementation, and (7) political and social affiliations of farmers in the villages leading to cross sales of seed and tampering isolation distance. The replacement of old varieties with new varieties is the major task for government extension department to make availability of new variety seed in time on regular basis to the farmers. Usually, the seed production by State Seed Development Corporation (largest seed-producing agency of post-rainy sorghum) produces improved variety seed for only 2% of total seed production (Table 3), because there is no uptake of improved variety seed by the farmers; the social reason for not preferring new varieties is that the people prefer the taste of the roti they make from old variety and animals like the fodder of old variety. But, during the project tenure, we have demystified the myth of quality of grain and fodder and proved that there is no difference in old and new variety.

Cultivar replacement indicates how effectively seeds of new cultivars are adopted by the farmers and produced and supplied by the seed agents. The factors which determine the rate of replacement are how government popularizes the cultivar, superiority of new cultivars to the existing ones which they intend to replace, and uptake and dissemination of new cultivars by the private and public sector seed companies depend on the demand for seed. The higher and quicker replacement depends on superiority of the cultivar base yield, price of seed, and deterioration of seed quality of farmer's saved seed. The farmers did not adopt improved varieties released by AICSIP over a period of 7 years (Table 2) in spite of higher yields of grain and fodder for the reasons mentioned above. Assessing varietal or cultivar replacement rate (CRR) is not very easy, and many indices of varietal replacement have been proposed (Brennan and Byerlee 1989; Byerlee and Heisey 1990), but these indices can be obtained from statistics on breeder seed or certified seed production data and field surveys on adoption of new varieties (Witcombe et al. 1998). In India the data on breeder's seed production is centralized, and seed producers first submit indent to directorate of seeds, Department of Agriculture and cooperation. Statistics are also maintained on allocation and production of breeder seed.

Measures that can enhance the performance of informal seed networks include

1. Improving adoption and dissemination processes for short-duration sorghum varieties is important for enhancing the ability of farmers to cope with increasingly variable seasonal climatic conditions. Investments and capacity building in informal seed networks, seed system recovery from climate shocks, and participatory plant breeding and variety selection would help to improve these prospects in rain-fed environments, which are often not serviced by formal breeding system.
2. Improvement of village seed storage technologies and facilities that can reduce seed store losses from rodents, insect pests, and diseases.
3. Development of farmer or village seed enterprises targeted at local and small-scale commercial seed production.
4. Access to credit that allows farmers to acquire improved seed and to prevent consumption of grain stores just prior to planting.
5. Maintain strategic seed stocks locally and regionally as a hedge against disaster.
6. Support for rebuilding seed networks in post-disaster recovery through an institutional mechanism that exposes farmers to new varieties and new technologies.

Under the HOPE project implemented in 2008–2013 in Maharashtra state, in the first 5 years of project implementation, the project directly covered 33,000 farmers, and the impact of the interventions reached more than 300,000 farmers in Maharashtra state. The implementation of technologies led to significant increase in grain productivity by 39% and stover productivity by 29% in project villages. The early adoption study results indicated that the HOPE interventions enhanced technology adoption rates, reduced the yield gaps (by 30%), increased the productivity, and gave higher returns to farmers (36–41%). They also indicated that for every single farmer covered by HOPE project directly, five to six non-HOPE farmers benefitted. Dissemination of seed and technologies (improved crop production) through secondary channels like farmer to farmer, relatives, or friends and gifts to their kith and kin spurred the production.

9 Way Forward for Sustainable Seed System

Important issues providing way forward for sustainable seed value chain to meet the demand of improved variety seed of post-rainy sorghum in India are as follows:

1. Varietal de-notification
   (a) A review of existing list of released and notified varieties does reveal that old varieties still find place in package of practices.

   (b) Continued production of seed of old varieties by state corporations is rather counterproductive.
   (c) De-notifying old and obsolete varieties irrespective of whether they are from public or private sector to allow the seed multiplication of the released improved cultivars.
2. Cultivar replacement rate (CRR)
   (a) State must ensure production of breeder/foundation seed of rain-fed crops and multiplication and replacement of seed to increase CRR progressively.
   (b) CRR will happen through technology upgradation and extension work and government policies.
   (c) For achieving the desired levels of CRR, adequate quantities of improved variety seed have to be produced and made available to farmers.
   (d) Varietal replacement rate is a continuous process; the new varieties released from time to time should flow into seed value chain and will improve the raising farming income and profitability.
3. Seed mission
   (a) Developing and implementing rain-fed agriculture seed mission with a built-in mechanism of supporting the cost of seed production for 5 years by the government by adopting public-private partnership with effective coordination and convergence mechanisms
4. Advocacy
   (a) By increasing access to high-yielding varieties/hybrids on priority basis to enhance adaptation rate to bridge the productivity gap and increase production
5. Selection of cultivars
   (a) Appointing a joint committee comprising of Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), public and private seed sector representatives, and farmer groups to select rain-fed crop varieties/hybrids suitable for different agro-ecological areas
6. Seed production
   (a) Promoting contract seed production program by advance indenting of the seed of specific improved cultivars to both public and private sector seed companies including KVKs and community-based organizations with technical support and capacity building program for production of quality seed
7. Policy and funding support frame
   (a) An enabling policy environment does help in production and dissemination of improved variety seed of rain-fed crops.
   (b) Provision of funds and support for seed multiplication and dissemination activities at least for 5 years.
   (c) Strengthening extension services for creating awareness and demonstration of rain-fed agricultural technologies.

References

AICSIP (2006) All India Coordinated Sorghum Improvement Project (AICSIP). Coordinating research report, pp 1–120

Almekinders CJM, Louwaars NP (1999) Farmers' seed production: new approaches and practices. Intermediate Technology Publications, London

Almekinders CJM, Louwaars NP, De Bruijn GH (1994) Local seed systems and their importance for an improved seed supply in developing countries. Euphytica 78:207–216

Anon (2009) Guidelines for implementation of seed village scheme. Joint Secretary (Seeds) DAC, New Delhi. Ministry of Agriculture and Cooperation. https://seednet.gov.in/Material/Prog-Schemes.htm#ii

Atilaw A, Korbu L (2011) Recent development in seed systems of Ethiopia. In: Alemu D, Kiyoshi S, Kirub A (eds) Improving farmers' access to seed empowering farmers' innovation, vol 1, pp 13–30

Ayana A, Borman G, Subedi A, Abay F, Mohammed H, Nefo K, Dechassa N, Dessalegn T (2013) Integrated seed sector development in Ethiopia: local seed business development as an entrepreneurial model for community-based seed production in Ethiopia. In: Ojiewo CO, Kugbei Bishaw SZ, Rubyogo JC (eds) Community seed production. FAO, Ethiopia, ICRISAT, Rome, Addis Ababa, pp 88–97

Barnaud A, Trigueros G, McKey D, Joly HI (2008) High outcrossing rates in fields with mixed sorghum landraces: how are landraces maintained? Heredity 101:445–452

Belum Reddy VS, Reddy S, Sadananda P, Elango Dinakaran AR, Ashok Kumar A, Deshpande SP, Srinivasa Rao P, Sharma HC, Sharma R, Krishnamurthy L, Patil JV (2012) Post-rainy season sorghum: constraints and breeding approaches. SAT E J 10:1–12

Bengtsson F (2007) Review of information available on seed security and seed aid interventions in Ethiopia, Eritrea, Mali and Sudan. DCG report no. 51. Drylands Coordination Group, Oslo. Available from: http://www.drylands-group.org/Articles/1323.html. Accessed 24 Nov 2009

Brennan JP, Byerlee D (1989) Measuring the rate of crop varietal replacement. Draft paper. CIMMYT, Mexico

Byerlee D, Heisey PW (1990) Wheat varietal diversification over time and space as factors in yield gains and rust resistance in the Punjab. In: Heisey PW (ed) Accelerating the transfer of wheat breeding gains to farmers: a study of the dynamics of varietal replacement in Pakistan. CIMMYT research report no. 1. CIMMYT, Mexico, pp 5–24

CABI (2014) Good seed initiative a strategy for CABI-led work on seed systems in Sub-Saharan Africa and South Asia, 2014–2019. CABI, Wallingford

CMIE (2007) Agriculture. Centre for Monitoring Indian Economy, Mumbai. 360 pp

Cormwell E, Friis-Hansen E, Turner M (1992) The seed sector in developing countries: a framework for performance analysis. ODI, London, p 114. https://www.cabdirect.org/cabdirect/abstract/19926786279

Cromwell E (1996) Governments, seeds and farmers in a changing Africa. CAB International, in association with ODI, Wallingford

Dawson JC, Serpolay E, Giuliano S, Schermann N, Galic N, Chable V, Goldringer I (2012) Multi-trait evolution of farmer varieties of bread wheat after cultivation in contrasting organic farming systems in Europe. Genetica 140:1–17

Douglas JE (1982) Programas de Semillas. Guía de planeación y manejo. Centro Internacio-nal de Agricultura Tropical CIAT., Cali-Palmira

Friis-Hansen E (1992) The performance of the seed sector in Zimbabwe: an analysis of the influence of organisational structure. Overseas Development Institute Regent's College, London, pp 1–70. https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/6971.pdf

Gill TB, Bates R, Bicksler A, Burnette R, Ricciardi V, Yoder L (2013) Strengthening informal seed systems to enhance food security in Southeast Asia. J Agric Food Syst Commun Dev 3 (3):139–153

Guéi RG, Bentley JW, van Mele P (2011) A full granary. In: Van Mele P, Bentley JW, Guéi RG (eds) African seed enterprises: sowing the seeds of food security. CAB International, Wallingford, pp 1–7

Hosmani MM, Chittapur BM (1997) Sorghum production technology. University of Agricultural Sciences, Dharwad

ICFA (2019) Report on seed industry scenario, Indian council of Food and Agriculture (ICFA). World seed trade and technology congress, 18–21 September Bangalore. https://www.seedworld.in/pdf/SeedWorld2019-Report.pdf

Kusena K, Rachel W, Claid M (2017) Do smallholder farmer-led seed systems have the capacity to supply good-quality, fungal-free sorghum seed? Agric Food Secur 6:52

Lanteri S, Quagliotti L (1997) Problems related to seed production in the African region. Euphytica 96:173–183. https://doi.org/10.1023/A:1002958325142

Louwaars N (1994) Seed supply systems in the tropics: international course on seed production and seed technology. International Agricultural Center, Wageningen

Louwaars NP, de Boef WS (2012) Integrated seed sector development in Africa: a conceptual framework for creating coherence between practices and policies. J Crop Improv 26:39–59

Maredia M, Howard J, Boughton D (1999) Increasing seed system efficiency in Africa: concepts, strategies and issues. Michigan State University International development working paper. Department of Agricultural Economics—MSU, East Lansing, MI, pp 12–13

Mayes S, Massawe FJ, Alderson PG, Roberts JA, Azam-Ali SN, Hermann M (2012) The potential for underutilized crops to improve security of food production. J Exp Bot 63(3):1075–1079

Murty MVR, Singh P, Wani SP, Khairwal IS, Srinivas K (2007) Yield gap analysis of sorghum and pearl millet in India using simulation modeling. Global theme on agroecosystems report no. 37. International Crops Research Institute for the Semi-Arid Tropics, Hyderabad. 82 pp

Pokarkar VG, Reddy CR (2014) Baseline Scenario of post-rainy season sorghum seed systems in Western Maharashtra. Mahatma Phule Krishi Vidyapeeth, Rahuri, p 20

Pray CE, Nagarajan L (2009) Pearl millet and sorghum improvement in India. In: Vision 2020, IFPRI discussion paper 00919, pp 1–24. http://www.ifpri.org/sites/default/files/publications/ifpridp00919.pdf

Pray CE, Ramaswami B (1991) A framework for seed policy analysis. IFPRI, Washington, DC

Rana BS, Rao MH, Indira S, Singh BU, Appaji C, Tonapi VA (1999) Technology for increasing sorghum production and value addition. National Research Centre for Sorghum (Indian Council of Agricultural Research), Hyderabad

Reddy CR (2005) Alternative informal seed systems models for seed security. In: National Partners Workshop of Fodder innovation project, February 25, 2005. ILRI, ICRISAT Centre, Hyderabad

Reddy CR, Tonapi VA, Bezkorowajny PG, Seetharama N (2007) Seed system innovations in semi-arid tropics of Andhra Pradesh. Fodder innovation project. International Livestock, Nairobi

Reddy CR, Ashok Kumar A, Gadakh S, Chavan U, Kalpande HK, Tonapi VA (2017) Seed system for rainfed crops: developing post rainy sorghum seed system in India. Proceedings of ISST XIV National Seed Seminar. ICAR-IARI, New Delhi, pp 95–109

Ronnie V, Bhuwon S, Gea G, Pitambar S (2014) The multiple functions and services of community seedbanks. Resources 3:636–656

Sajjanar GM, Biradar BD, Biradar SS (2011) Evaluation of crosses involving rabi landraces of sorghum for productivity traits. Karnataka J Agric Sci 24:227–229

Schanbacher WD (2010) The politics of food: the global conflict between food security and food sovereignty. Praeger, Santa Barbara, CA

Siart S (2008) Strengthening local seed systems: options for enhancing diffusion of varietal diversity of sorghum in Southern Mali. Margraf Publishers, Weikersheim. 185 pp

Soleri D (2018) Civic seeds: new institutions for seed systems and communities—a 2016 survey of California seed libraries. Agric Hum Values 35:331–347. https://doi.org/10.1007/s10460-017-9826-4

Tafesse (1998) Towards seed industry development in Ethiopia. Proceedings of the international workshop on seed security and food security. Food and Agriculture Organization of the United Nations, Rome

Tamang A, Dupka G (2015) Bhutan: the Bumthang community seed bank. In: Vernooy R, Shreshta P, Sthapit B (eds) Community seed banks: origins, evolution, and prospects. Routledge, Oxford, pp 69–73

Tjikana T, Dibiloane A, Maluleke N, Moila P, Phora G, Sthapit B, Vernooy R (2016) Sharing diversity: establishing and supporting community seed banks in South Africa (Pilot Phase 2013–2015). Bioversity International, and Pretoria: Department of Agriculture, Forestry and Fisheries, Rome

Tonapi VA, Reddy CR (2017) Strategies to build sustainable millet seed systems. In: Patil JV (ed) Millets and sorghum biology and genetic improvement. Wiley & Sons Ltd., West Sussex. ISBN 9781119123057

Tonapi VA, Reddy CR, Tomar BS (2012) Strategies to build viable community seed systems in dry land ecosystems for sustainable seed and food security in India. Directorate of Seed Research, Kaithauli. 44 pp

Tripp R (2003) How to cultivate a commercial seed sector. Paper presented for symposium Sustainable Agriculture in the Sahel, December 1–5, 2003, Bamako, Mali

Trivedi TP (2008) Handbook of agriculture. Directorate of Information and Publications of Agriculture. Indian Council of Agricultural Research, New Delhi

Van den Broek JA, Subedi A, Jongeleen FJJ, Lin Oo N (2015) Pathways for the developing Myanmar's seed sector: a scoping study. Wageningen UR (University & Research Centre). Report CDI-15-018. Centre for Development Innovation, Wageningen UR (University & Research centre), Wageningen

Vernooy R, Shrestha P, Sthapit B (2015) Community seed banks: origins, evolution and prospects. Routledge, Oxford

Vernooy R, Sthapit B, Otieno G, Shrestha P, Gupta A (2017) The roles of community seed banks in climate change adaption. Dev Pract 27:316–327. https://doi.org/10.1080/09614524.2017.1294653

Wendy Catalina AC, Carlos Iván CC, Margarita B (2015) Analysis of seed systems in Latin American countries. Acta Agronómica 64(3):223–229

Witcombe JR, Packwood AJ, Raj AGB, Virk DS (1998) The external and rate of adoption of modern cultivars in India. www.envirobase.info/PDF/RLPSRbookchap5.pdf

Wobil J (1998) Seed policy and programmes for Sub-Saharan Africa. Proceedings of the international workshop on seed security and food security. Food and Agriculture Organization of the United Nations, Rome

World Bank (1998) Initiatives for sustainable seed systems in Africa. In: FAO, seed policy and programmes for Sub-Saharan Africa. Proceedings of the Regional Technical Meeting on Seed Policy and Programmes for Sub-Saharan Africa, Abijan, Côte d'Ivoire, November 23–27, 1998. http://www.fao.org/ag/AGP/agps/abidjan/Paper12.htm#Initiatives