

India's Pearl Millet Seed Industry: Prospects for High-Iron Hybrids

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India's Pearl Millet Seed Industry: Prospects for High-Iron Hybrids

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Abstract

In this paper, we seek to understand the current structure of the pearl millet seed sector in order to formulate recommendations about how best to position the marketing strategy for soon-to-be-released, high-iron hybrids. We conduct a thorough review of the literature, with reference to both qualitative and quantitative information. We focus on the evolution of the industry structure for pearl millet seed, documenting changes that have occurred in procedures for variety release and registration over time. We shed light on issues such as why some varieties are more popular than others; the role of companies in promoting varieties; and whether the rights of a high-iron hybrid should be exclusive to one company. We also explore the implications of the fact that neither farmers nor consumers can observe the high-iron trait for marketing and promoting new varieties. Our review leads us to recommend the development of a range of high-iron hybrids with varying genetic base and adaptation, as well as food and fodder traits. Demand-pull mechanisms should be integrated into the current public distribution system, and private seed companies incentivized through various means. The role of pearl millet in the livestock feed industry is worth of policy attention by HarvestPlus and partners.

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1. INTRODUCTION

India is the second center of millet diversity (Nagarajan 2004), after tropical western Africa, the largest millet producing country in the world, and harvested more than 10.3 million tons of the world's 29.8 million tons in 2012 (FAO 2014). Application of the IMPACT model developed by the International Food Policy Research Institute indicates that at current rates of yield growth, income growth and demand structure, India will account for over 25% of all millet produced globally in 2015 (Bhagatavula et al. 2013).

Of the various forms of millet grown in India (including pearl millet, finger millet, foxtail millet and little millet), pearl millet is the most widely grown. The state of Rajasthan, followed by Maharashtra, Gujarat and Uttar Pradesh, account for an estimated 90% of the acreage planted in pearl millet (Yadav et al. 2012). Most of the crop is grown in the rainy (*kharif*) season (June-September), although some is cultivated during summer (February-May) and in the post-rainy (*rabi*) season (November-February) on a small scale in Maharashtra and Gujarat.

Pearl millet is also one of the most important staple food crops in India, where it is consumed primarily in the form of breads and porridges, and both its grain and fodder are also used to feed livestock. Long recognized by rural people in India for its nutritional value, the crop is now considered a "nutra-cereal" because it contains high levels of energy and protein, a more balanced amino acid profile than maize or sorghum, and relatively high densities of iron and zinc (Yadav et al. 2012). Pearl millet is potentially advantageous for adaptation to climate change because it is well-adapted to uncertain and low rainfall conditions, uses water relatively efficiently, and tolerates above-optimal temperatures. Like barley, the crop tolerates salinity well (Yadave et al. 2012).

The public sector in India released its first pearl millet hybrid in 1965, making pearl millet one of the first hybridized crops⁵ in the world (Lele and Goldsmith 1988; Pray and Nagarajan 2010). By contrast, the well-known Green Revolution crops of 1960s-70s in South Asia were semi-dwarf, improved varieties of wheat and rice, rather than hybrids. Public, private and international research institutions have all contributed to millet improvement over the past decades, but a vibrant seed industry has played a pivotal role in diffusing high-yielding germplasm to farmers (Pray and Ramaswami 2001). Evenson and Gollin (2003) report that crop improvement impacts have been less pronounced in millet growing regions of India relative to wheat and rice, but recognize the contribution of the private sector in the case of millet. Research and development in the pearl millet industry have become increasingly privatized—a diversified, entrepreneurial industry composed of small and medium-scale enterprises.

In 2003, Thakur et al. estimated that hybrids represented over 50% of the area planted to pearl millet in India. In 2006, over 70 hybrids covered more than 60% of the area sown to pearl millet, of which more than 80% are varieties developed by the private sector (Pray and Nagarajan 2010); interviews with key informants suggest that the adoption rate and proportional share of hybrids is even higher today. Historically, the highest adoption rates for high-yielding millet, most of which was hybrid, were recorded for Gujarat and Maharashtra (99% and 94%, respectively, in 1994, according to Deb, Bantilan and Rai 2005). A more recent study conducted by HarvestPlus revealed that 93% of farmers cultivate hybrid pearl millet varieties on 94% of the land areas allocated to pearl millet in Maharashtra (Asare-Marfo et al., 2010). According to the same study, hybrid adoption rates are lower in Rajasthan, with 65% of farmers growing hybrid varieties on 51% of the pearl millet area. The largest pearl millet areas have been

⁵ Maize was the first hybridized crop marketed on a large scale during the 1930s in the US.

and are still found in Rajasthan, followed by Maharashtra (Deb, Bantilan and Rai 2005; Yadav et al. 2012). Together, these two states account for 72% of pearl millet production in India (Bhagavatula et al. 2013).

Smallholders continue to dominate the production of pearl millet, and high adoption rates for hybrid seed are explained not only by early maturity and higher yields of grain and fodder (Deb, Bantilan and Rai 2005), but by a norm of annual seed replacement, market orientation of growers, and the low seeding rate of the crop. Benefit-cost ratios for pearl millet hybrids have been high (Pray and Nagarajan 2010). According to Tripp and Pal (2000), pearl millet is a crop whose seed requirements per acre are so low that even the cost of the most expensive commercial hybrid remains affordable for most growers.

Matuschke and Qaim (2008) found that for 98% of hybrid growers they surveyed in Maharashtra, seed price was not a criterion for adoption, and 96% did not consider regular seed replacement disadvantageous. Their survey also revealed that while most smallholders in their survey grew pearl millet for home consumption, 27% also sold part of their harvest in the market—as compared to none of those who grew landraces or improved, open-pollinated varieties.

As part of its global effort to alleviate micronutrient malnutrition through the development and delivery of micronutrient enriched staple food crops, HarvestPlus is targeting India with high iron pearl millet varieties, among other crops (www.harvestplus.org). Iron deficiency rates are rampant in India with over 75 percent of preschool children suffering from anemia, one of the outcomes of iron deficiency (Gragaloti et al. 2005; von Grebner et al. 2008). One potential solution to improving iron status is the introduction of iron-rich pearl millet. This could be a cost-effective means of reducing iron deficiency, especially among rural people who produce and

consume significant quantities of pear millet, and who do not have regular access to dietary supplements, iron fortified processed foods and diverse diets rich in micronutrients (Meenakshi, et al. 2010; Birol et al. 2014).

This paper summarizes the evolution of the pearl millet seed industry in India based on a review of the historical literature and key informant interviews undertaken in the state of Maharashtra. Maharashtra was selected as a focal point for seed company interviews because of its historical preeminence in ascribing policy importance to pearl millet, and the leading role of the crop and of hybrid seed adopters in this state. Our objective is to draw implications from these information sources to help guide high iron pearl millet development, delivery and promotion strategies by the Government of India and HarvestPlus and its partners.

The key questions investigated in this paper include: how the industry structure has evolved over time, along with procedures for variety release and registration; why some varieties become more popular than others; the role of companies in promoting varieties; whether the rights of a high-iron hybrid should be exclusive to one company; and the implications for delivery and promotion of the fact that iron is an invisible trait. That is, neither farmers nor consumers can recognize a high iron variety based on observable characteristics. In the next section, we present an overview of the evolution of the pearl millet seed industry. In section III we summarize the interviews with various pearl millet companies, and in the final section we discuss the implications of these findings for high iron pearl millet development, delivery, and promotion efforts.

2. HISTORICAL PERSPECTIVE ON THE PEARL MILLET SEED INDUSTRY

Inception

The history and achievements of the pearl millet improvement program, now known as the All-India Coordinated Pearl Millet Improvement Project of the Indian Council of Agricultural Research (AICPMIP) have been documented in detail by Yadav et al. (2012), and also summarized in terms of adoption and economic impacts by Bantilan and Deb (2003), Deb, Bantilan and Rai (2005) and Pray and Nagarajan (2010). Lele and Goldsmith (1988) documented the origins of the program when describing the role of the Rockefeller Foundation and the Indian government in facilitating the international scientific exchange that led to the Green Revolution.

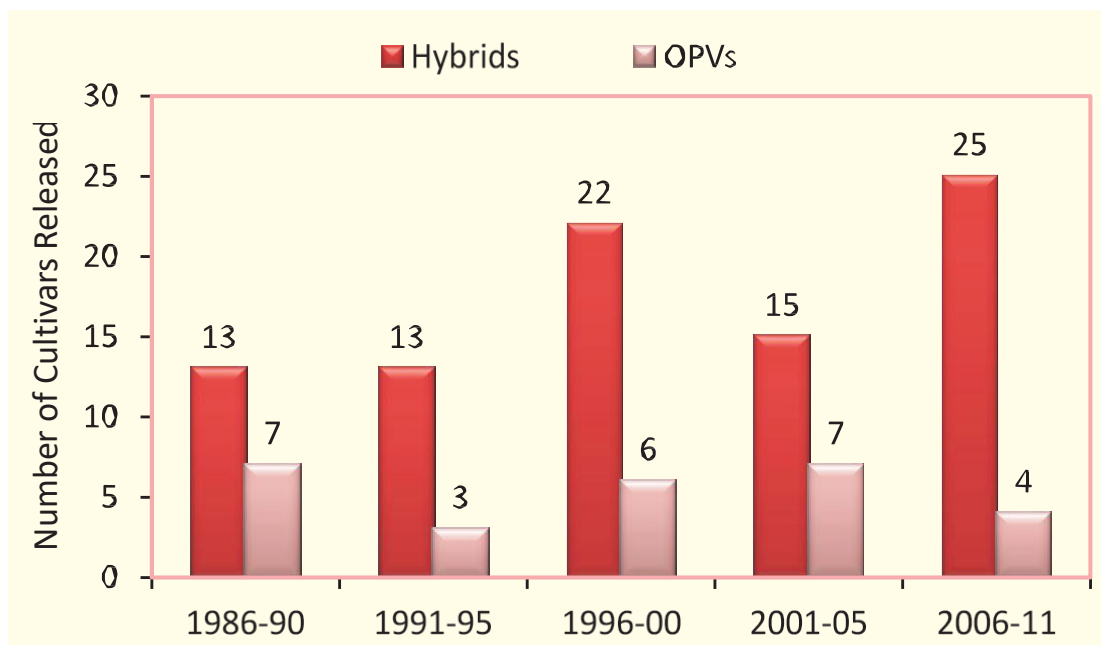
As was the case in other Indian breeding programs, initial efforts were based on simple mass selection with local materials, though introductions from African countries provided some useful varieties for Indian conditions. Given the fact that pearl millet has high rates of outcrossing, attempts were made in the 1950s to exploit the potential for hybrid vigor through heterosis. This was not possible until the discovery of cytoplasmic-nuclear male sterility and the release of male-sterile lines that were made available to the Indian program.

India produced the first pearl millet hybrid using cytoplasmic male sterility in the 1960s. One of the hybrids released by the Indian program, HB 3, became very popular due to early maturity and adaptation to drought stress. Lele and Goldsmith (1988) note that some scholars considered the technical progress achieved in pearl millet during the 1960s to be “revolutionary,” but although there was an evident “yield expansion,” it was short-lived due to an outbreak of downy mildew (1988: 315). Downy mildew is a plant disease that destroys the panicle (ear) and can result in devastating losses.

Research later revealed that the epidemics of downy mildew that thwarted yield gains during the 1970s and 1980s reflected the narrowness of genetic diversity in the parental lines (e.g., Hash et al. 1997). Diversification of parental lines, and breeding improved open-pollinated varieties (IOPVs) were approaches followed by the All-India Coordinated Pearl Millet Improvement Program of the India Council of Agricultural Research (ICAR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) of the Consultative Group on International Agricultural Research (CGIAR).

By 2012, according to Yadav et al. (2012), over 100 high-yielding and disease resistant cultivars of pearl millet had been produced in India by the public sector. A total of 115 improved cultivars were released after 1986, three-fourths of which were hybrids (Figure 1). On average, 3-4 cultivars were released per year, per zone, with no evident differentiation by zone.

Figure 1. Number of Improved Cultivars of Pearl Millet Released in India Since 1986



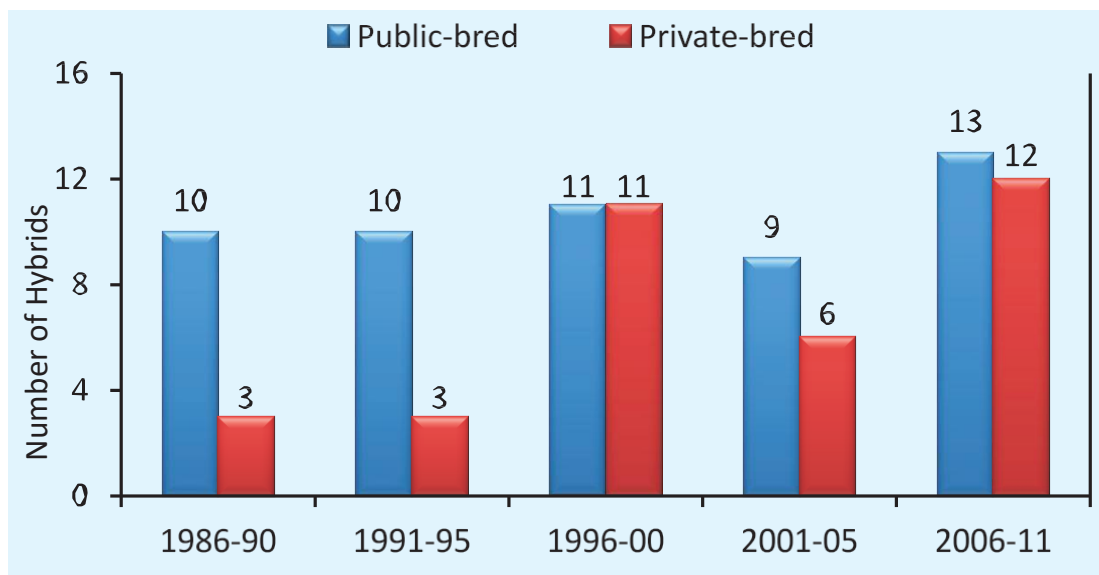
Source: Yadav et al. (2012).

In addition, Yadav et al. (2012) reported the large number of pearl millet hybrids that have been commercialized by the private sector as truthfully labeled seed⁶. As a consequence, pearl millet growers have a broad range of traits combinations from which to choose when seeking to meet their agronomic requirements and consumption preferences. Yadav et al. (2012) reported that at the time of their publication, over 125 (named) hybrids and IOPVs were available for pearl millet farmers in the Indian national market. Of these, the public sector cultivars tend to be oriented toward the rainfed ecology, while the private sector aims for the more commercialized market in the irrigated environments. Figure 2 shows that since 1986, 53 hybrids from the public sector and 35 from the private sector have been notified (officially released).

⁶ In India, the quality of truthfully labelled seed is guaranteed by the producing agency rather than the certification agency, and in addition to notified varieties, this category is applicable to released varieties. TLS is tested only for physical purity and germination.

Source : <http://vikaspedia.in/agriculture/agri-inputs/seeds/classes-of-seeds>.

Figure 2. Number of Pearl Millet Hybrids Released (Notified) By Public And Private Sectors Since 1986



Source: Yadav et al. (2012).

Estimates reported by Verma (2012) indicate that among other field and vegetable crops, the contribution of publicly-bred hybrids was relatively higher for sorghum and millet than for other crops, but still comprised less than 20% of seed marketed for millet.

Yadav et al. (2012) and Bantilan and Deb (2003) describe the significant contribution of ICRISAT to the national pearl millet improvement program, particularly in the provision of diverse parental lines and evaluation of breeding materials in multi-locational trials. Other advanced research institutions, including the Centre for Arid Zone Studies, the Institute for Grassland and Environmental Studies, and the John Innes Center (all in the UK) have provided strategic information and analysis in the area of molecular markers for identifying pathotypes and sources of resistance to downy mildew.

Overall, several stages of diffusion of improved pearl millet cultivars are portrayed in the literature. The first public hybrids constituted the first stage, which corresponded roughly to 1965 through 1974, when these became susceptible to downy mildew. According to Khairwal et al. (1999), the second-stage hybrids then released were not only susceptible but lower-yielding than their predecessors. Another set of hybrids released from 1977 to 1985 became popular but also succumbed to downy mildew. After 1986, with advances in breeding and seed market liberalization, diffusion of improved pearl millet cultivars rose sharply. Landmark shifts in India's seed policy, and the implications of these for the pearl millet industry, are summarized next.

Privatization

Pray and Ramaswami (2001), Pray, Ramaswami and Kelley (2001), Kolady et al. (2012), and Verma (2012) provide major insights into India's general seed policies and related institutions. Tripp and Pal (2000) and Matuschke and Qaim (2008) examine aspects of the pearl millet seed industry in Rajasthan and Maharashtra.

According to Pray and Ramaswami (2001), the Indian government established the National Seed Corporation and State Seed Corporations in 1963 to meet the demand for seed generated by the Green Revolution in wheat and maize, but also the technical breakthroughs achieved in pearl millet and to a lesser extent, sorghum. The World Bank supported seed corporation development, beginning in 1975 (National Association of Seed Industries (NSIA)). After the first Seed Act (1966) and Seed Rules (1968) were passed, engagement of the private seed sector was curtailed by restrictions, including a ban on commercial imports of agricultural inputs that were also produced in India (seed of field crops) and also on seed exports. Indian firms with more than Rs 1 B in asset values were restricted to "core" industries by the 1969 Industrial Policy Act; the seed industry did not meet this criterion (Pray and Ramaswami 2001). Today, large industries are defined by the industrial enquiry committee as having assets valuing more than Rs. 350 M, but the only agricultural input that is included among the "core" industries is fertilizer.

An abrupt shift in the structure of the seed industries began in 1986s when barriers to entry of foreign firms and larger Indian companies were rescinded (Pray and Ramaswami 2001). The New Seed Industry Development Policy of 1988 allowed seed firms to import commercial vegetable seeds with no quotas, to import commercial seeds of foreign varieties of coarse grains and oilseeds for only two years (after which seed companies had to produce the seed inside India), and made it easier to import germplasm for research purposes. In 1991, regulations on technology transfer and foreign investment for the entire economy were reduced. A time series of estimates collected by Pray and Nagarajan (2012) shows that overall, the seed industry in India has become more competitive while foreign ownership has increased since 1987. The share of the top four seed companies in the private sector declined from 70 percent to 36 percent; the share of foreign ownership increased from 10 to 40 percent.

Verma (2012) depicts three stages of development in the Indian seed industry. The first phase (1960s-1980s) is characterized by research and development (R&D) in the public domain, minimal private sector engagement and restrictions on imports and exports of seed. The seed industry "boomed" after 1988, when foreign direct investments and importation of germplasm were encouraged. NASI (website) views

1975 as a turning point, marking the formation of an organized industry; the New Seed Development Policy “transformed the character” of the seed industry.

In 2012, Verma reported that the private sector accounted for 80% of seed marketed annually. He estimated that nearly one-third of seed companies had global partnerships. On average, seed companies spent 10-12% of their budgets on R&D, with overall budgets of medium-sized companies growing at more than 20% per annum. Pearl millet ranked fourth as a crop value share (in USD) of the hybrid seed market, after cotton, maize and rice.

In 1991, Pray et al. estimated that in the late 1980s private investments in pearl millet improvement were roughly equal to those of the public sector, Comparing across crops, Verma (2012) reported that in 2008 the private sector contributed 100% of hybrid seed marketed for field and vegetable crops, with the exception of pearl millet, sorghum, rice and maize. Among these, publicly-bred hybrids represented a larger share of the market for pearl millet and sorghum. However, the public share of hybrid seed marketed in 2008 was still less than 20% for pearl millet.

According to Verma (2012), the Indian seed sector (across crops) was the sixth largest in the world in 2008, and was growing at a more rapid rate than the global seed industry. Citing Rabobank (2006), Kolady et al. (2012) report that India’s commercial seed industry ranked fifth largest in the world in 2008-9, with a growth rate of 12-13% during the mid-2000s. Private sector involvement was most noteworthy in the cereal crops, and in particular, maize and pearl millet. Private investments remained more limited in self-pollinating crops, and the seed replacement ratio (including replacement of the same cultivar with recently purchased seed and adoption of more recent releases) was less rapid than is desired to maintain yield potential on farms (Verma 2012).

The analysis by Matuschke and Qaim (2008) negates the common notion that privatization of seed markets hampers technology progress in the small farm sector, suggesting that even in the production of subsistence crops, such as pearl millet, the private sector can play an important role. A review of the evidence indicates that the “benefit-cost ratio of shifting from public hybrids to private hybrids was much higher for small farmers than for large farmers” (Pray and Nagarajan 2010: 305).

Pray and Ramaswami (2001) conclude that changes in seed policies had little impact on seed trade, but induced competition in the seed industry. The number of companies active in pearl millet seed markets more than doubled in a decade, 1987-88 to 1997-98 (Naik, 2001). Many of these new market entrants

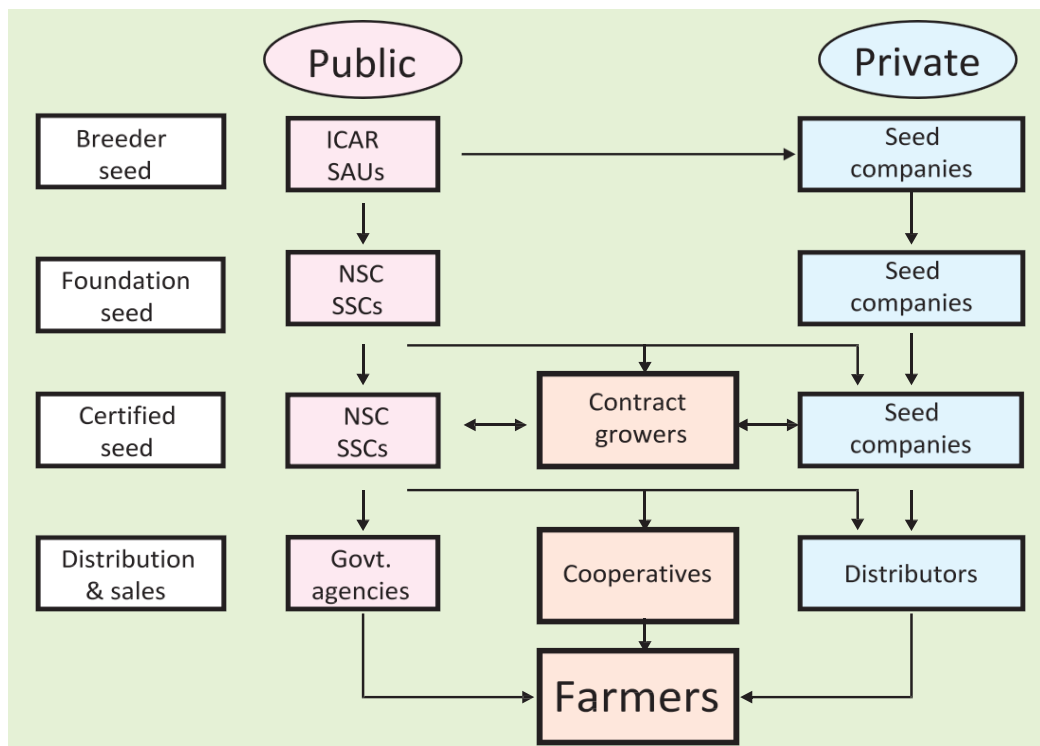
also started operating their own in-house breeding programmes. The first successful private pearl millet hybrids were commercialized in 1989. At the time of their study, Pray and Ramaswami (2001) describe the emerging role that small-scale Indian firms played in plant breeding research on pearl millet and sorghum—spurred by the availability of public sector materials and a growing market for hybrid seed. They conclude that “reform was a very important factor accounting for the increase in private research in India” (2001: 414); in this regard, the importance of ICRISAT as a source of germplasm in pearl millet breeding is prominent. The reliance of the emergent private sector on ICRISAT and AICPMIP materials in pearl millet breeding (particularly male-sterile lines and restorers) is also emphasized by Bantilan and Deb (2003) and Pray and Nagarajan (2010). Pray and Nagarajan report that in the 1990s the seed market was dominated by ICRISAT-based hybrids.

A strong incentive for the participation of private firms in the seed industry was the Indian policy of truthful labelling (TFL), through which private firms could multiply and sell seeds to farmers without the certification process required for notified varieties and hybrids. The development of privately-bred hybrids has not slowed by seed certification procedures, which can be lengthy. The legislative origin of TFL in India was Seeds Act in 1966 (NASI website). Kolady et al. (2012) also note the significance of the Protection of Plant Varieties and Farmers’ Rights Act (2001), which they argue provides an effective system for protection of plant varieties, incentives to strengthen the seed industry and assure the availability of high-quality seed for farmers.

NSAI (website) identifies twenty growth drivers in the history of the Indian seed industry. Among these, those of relevance to the introduction of iron-rich pearl millet hybrids include the acceptance and commercialization of new seed technology; sharing of germplasm among public and private sector institutions and import of germplasm under minimum restrictions; co-existence of public and private sectors, including equity participation by multinational corporations; concentration of seed production in the most favorable areas, combined with free movement of seed among states. Paroda (2013) contends that the private sector should play a greater role sharing their germplasm with public sector institutions for research purposes, and that partnerships between public and private sector institutions need to encompass not only commercialization of varieties, but also evaluation of germplasm for biotic and abiotic stress tolerance, as well as quality traits.

Today’s pearl millet seed supply chain is shown in Figure 3, which illustrates a multiplication process which involves various classes of seed.

Figure 3. Seed Supply Chain for Pearl Millet in India



Source: Yadav et al. (2012).

Commercial seed production begins with production of breeder seed by AICPMIP, the State Agricultural Universities (SAUs), ICARISAT, and private seed companies. Drawing from MoA data, Pray and Nagarajan (2012) report that the number of notified new/hybrids originating in the private sector increased from 38 in the 1980s, to 45 in the 1990s, and 51 in the 2000s. Foundation seed of IOPVs and parental lines of hybrids is produced by the National Seed Corporation (NSC), the State Farms Corporation, and some seed companies. Certified seed of released and notified cultivars is mainly produced by State Seed Corporations (SSCs) and the NSC, following established procedures. Production is monitored by the state Departments of Agriculture, which enact seed legislation to ensure quality standards and licensing provisions.

The private sector not only produces the seed of publicly-bred hybrids and proprietary hybrids on a large scale, multiplying and distributing certified seed of notified varieties, but also produces large quantities of truthfully labeled seed, although these amounts have not yet been measured and their impacts assessed. Paroda (2013) cites evidence that from 2003 to 2010, the private sector produced between 39 and 48% of certified seed ("quality" seed) alone, but also that the seed replacement rates are lower than optimal for most field crops (Singh and Chand, 2011). However, Kolady et al. (2012) compile data showing that seed replacement ratios (new seed purchase as a proportion of all seed planted) is higher for pearl millet

(56%) than for rice (25%), wheat (18%) or even for maize, which, like millet, is a heavily outcrossing plant (36%).

Nagarajan et al. (2007) report data showing an abrupt increase in the sale of proprietary hybrids of pearl millet (over nine fold increase in the 1990s) and maize, as well as sorghum. They estimated that proprietary seed represented 19 percent of the pearl millet seed market in 1998-99 as compared to only 2 percent in 1990-91; the share of publicly-bred hybrids dropped from 15 to 11 percent over the same time period. IOPV seed represented only 10 and 6 percent of the seed market in the endpoint years. The authors included saved seed in the total market, estimating that it represented 74 to 64 percent of seed consumed in 1990-91 and 1998-99, respectively (2007: 14). In contrast, sales of publicly bred pearl millet hybrid declined considerable, as was the case for sorghum. Publicly bred sorghum hybrids continue to be important, which they attribute to less efficient research by private companies on sorghum as compared to pearl millet. Pray and Nagarajan (2012) indicate that between 2005 and 2010, the number of TFL privately-bred hybrids totaled 97 in pearl millet, as compared to only 48 notified public varieties released in the same period. Data provided by the Government of Maharashtra shows that from 2010 through 2013, in *kharif* season, an average of only slightly over 2 percent of hybrid seed sold was supplied by the public sector, as compared to about half of the IOPV seed. The same figures indicate that hybrid seed represented 70% of the total sales of improved pearl millet seed in that state (Annex 2).

Adoption and Impacts

Estimates of adoption rates for improved cultivars of pearl millet vary by source (sample and state), but also over time as a function of downy mildew infestation. Deb et al. (2005) summarized the findings of in-depth, on-farm adoption studies conducted in the late 1990s with a sample of 1683 farmers from 154 villages in 39 districts of Gujarat, Haryana, Maharashtra, Rajasthan and Tamil Nadu. Adoption of improved cultivars of pearl millet reached over 80 percent in most districts of Maharashtra, Gujarat and Tamil Nadu, and 40 districts of India overall by 1992-94. By 1996, they estimated that only 6 percent of pearl millet area was planted with local varieties in the state of Maharashtra, compared to 44% in Eastern Rajasthan, only 1% in Gujarat, 14 % in Haryana, and 23% in Tamil Nadu. Based on data from 2006, Pray and Nagarajan (2010) reported that more than 60% of the total pearl millet area in India was planted with over 70 hybrids, of which at least 80 percent were hybrids originating in the private sector. Similarly, Yadav et al. (2012) report that nearly 65% of pearl millet area is under hybrids and a few IOPVs. A study conducted by HarvestPlus in *kharif* 2009, found that in the State of Maharashtra, 94% of pearl millet area was planted in hybrids, 4% was planted in IOPVs, and 2% in *desi* (local) varieties; by contrast, in Rajasthan, only 51% of

the pearl millet area was planted in hybrids (Asare-Marfo et al., 2010). Reddy et al. (2013) report data from the Directorate of Economics and Statistics (2011) which shows adoption rates of 96% in 2011 in the State of Gujarat. Kolady et al. (2012) report that an adoption rate of 60 percent of a total of 9.6 M ha of pearl millet in India over the 2003-8 period, with an average crop yield of 1.04 t/ha, and rate of yield increase of 17.3% from 1998 to 2008 (p. 366). The yield growth rate in pearl millet surpassed that of rice (15%) and wheat (6%) during the same period, but fell under that of maize (26%, *ibid.*). A recent study by Kumara et al. (2014) reviews adoption and diffusion data, also analyzing yield growth and variability in great detail.

Numerous factors have contributed to adoption of improved pearl millet cultivars. A recurrent theme, however, is the positive influence of privatizing the seed industry. In addition to the role of farmer education, good market infrastructure, and short distances to main information sources (input dealers, other farmers, and to a lesser extent, public extension services), the expanding role of private seed companies appears to have accelerated the effect of technology diffusion in pearl millet production in Maharashtra (Matuschke and Qaim 2008). Confirming the findings of Bantilan and Deb (2003), the majority of the farmers in the study conducted by Matuschke and Qaim (2008) reported that hybrids mature earlier than IOPVs, offering yield advantages in terms of both grain and fodder. Farmers surveyed by HarvestPlus in *kharif* 2009, identified grain yield, flour quality and taste as the most important variety attributes they consider when choosing a variety (Asare-Marfo et al., 2010). Yadav et al. (2012) attribute large-scale adoption of hybrids to the range in maturity they provide (60-90 days), the recovery of seed cost by farmers with even as low as 10% grain yield advantage over local varieties, and the effectiveness of contractual hybrid seed production, which contributes to a profitable system for producing and marketing commercial seed. In their survey research, Deb et al. (2005) found both higher grain and fodder yield among improved cultivars of pearl millet. They estimated that improved cultivars of pearl millet had a 43-47% lower total (variable and fixed) cost of production and per unit cost of production. Adoption of improved cultivars increased the demand for labor, which generates important social welfare effects in communities. Overall, their analysis indicates negative income with production of pearl millet using local cultivars, and positive net income when improved cultivars are grown, increasing net income up to a multiple of five.

Generally speaking, Verma (2012) cites low adoption rates for hybrid seed in more marginal growing areas, although this is clearly refuted by the case of pearl millet. Bhagatavula et al. (2013) enumerate the constraints to millet production in India, including the fact that these crops are typically cultivated on

small, fragmented landholdings. Unreliable rainfall and thin local markets for pearl millet grain both encourage the production of pearl millet and provide a disincentive for use of complementary inputs, such as fertilizer, pesticides, and irrigation. They also note that despite the release of hybrids with good performance, quality improved seeds are not always available at the right time because marketing channels are not fully developed in more marginal regions of India.

On this theme, Tripp and Pal (2000) assessed farmers' knowledge of pearl millet seed and the provision of information in the commercial (hybrid seed) market of Rajasthan. They found that farmers had a limited knowledge of the characteristics of the hybrids available to them, and companies' efforts to provide information were inadequate. According to Tripp and Pal (2000), farmers' information sources remained largely socially-based (other farmers, observation or discussion). Farmer reliance on social networks for information on new varieties was also found by Asare-Marfo et al (2010) in both Maharashtra and Rajasthan. Tripp and Pal (2000) also concluded that brand awareness developed slowly. Companies provided little trait-specific information, and the flow of information back from farmers to breeders was deficient. Nevertheless, Tripp and Pal (2000) concluded that the expansion of the commercial (hybrid) seed market in Rajasthan during the 1990s was beneficial. Incidences of fraudulent seed sales were rare. They suggested that the market could be made more efficient if private firms spent more on information delivery and understanding the needs of their smallholder clientele, but only if farmers themselves become more articulate in their demands as seed consumers. As has been argued elsewhere, they ascribe much of the "positive character" of the Indian seed market to "a long tradition of public agricultural research" (2000, 143).

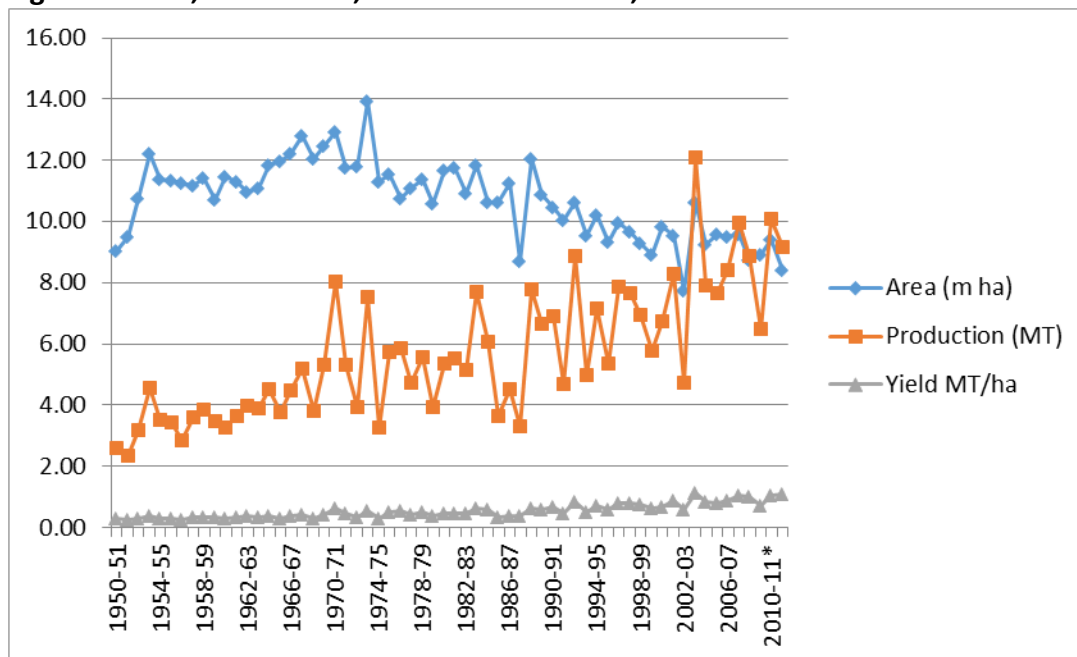
To our knowledge, the first published study to examine the benefits of private hybrids in India was Pray and Ramaswami (2001). The authors found that the yields of private pearl millet and sorghum hybrids were higher than public hybrids and public open pollinated varieties in trials conducted by the AICPMIP and in farmers' fields, also concluding that farmers earned more of the benefits from adopting improved pearl millet cultivars than did seed companies. In an econometric analysis of maize, sorghum, and pearl millet yields in central and southern India, Pray et al. (1991) reported that area under private hybrids significantly raised district yields, controlling for other factors in a fixed effects regression. Kolady et al. (2012) used a state-level panel dataset on crop yield, rainfall and real farm harvest prices for pearl millet, maize, rice and wheat over the period 1966–2007, modeling yield. They concluded that pearl millet yields grew significantly from 1987 to 2007, attributing yield growth to significant structural changes and

accompanying growth in use of privately-produced and marketed hybrids following the passage of policy reforms.

Yadav et al. (2012) associate the diffusion of pearl millet hybrids with a more than 70% increase in crop productivity between 1986 and 2010. The authors cite estimates that pearl millet yield increased by 6.3 kg/ha per year on average from 1960 to 1985, and over 20 kg/ha per year on average from 1986 to 2010. They attribute yield gains not only to the private sector, but to more rapid release and replacement of numerous materials that were resistant to downy mildew. Yadav et al. (2012) underscore two aspects of these gains: 1) they include marginal, rainfed areas with smallholder farmers; 2) they reflect far less investment in infrastructure and human resources than other crops, such as rice and wheat.

National statistics confirm these historical trends. Crop area planted to pearl millet expanded from 1950-01 through the early 1970s, but has declined since then at the same time that production has increased (Figure 4). Production growth is thus entirely attributable to yield gains; in fact, higher yields appear to enabled farmers to switch from this food staple with relatively low commercial value to the production of alternative crops.

Figure 4. Area, Production, Yield of Pearl Millet, 1951-2012.



Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation. <http://www.milletindia.org/data-on-millets.php> (accessed April 21, 2014).

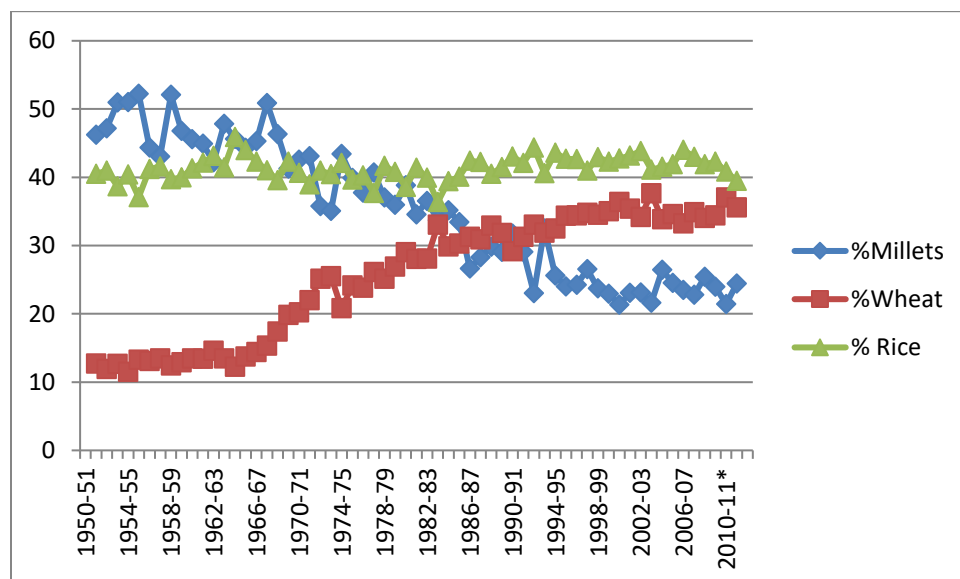
To place these figures in a global perspective, according to Bhagavatula et al. (2013), global area planted to all types of millet decreased slightly from 1980 to 2007, due primarily to a decline in millet areas in developed countries, although these represent a minority of the world's total millet area. Area planted to millet increased in the Sahel, but stagnated in other developing countries, which represent nearly 98% of the world's total millet area. Pearl millet area in India declined at a rate of about 0.9% per annum between 1980 and 2007 (Bhagavatula et al 2013). While global millet yields rose over this same period at an average annual rate of 0.7%, Asia exerts most of the influence on this upward trend, with an average yield growth rate of 1.2%, largely due to growth in India, at 2.8% on average 1980-2007. Bhagavatula et al. (2013) note that there are considerable differences in yield growth by soil type, rainfall, and adoption rate, but show that the share of yields over 1 million tons/ha has grown from 8% to 37% (2013: 48). Yield variability is also relatively high for pearl millet relative to other cereals.

Pray and Nagarajan (2010) depict rising yield trends for pearl millet in terms of three trends: 1) post-independence (1947-1965), when yields rose only slightly, remaining below 400 kg/ha on average; 2) public-supported growth (1966-85), which includes an abrupt increase during the initial adoption of hybrids, followed by a plateau; and 3) a continuous growth period (1986-present), driven by the private sector. Similarly to Yadav et al. (2012), they emphasize the fact that like the better-known, heavily-invested Green Revolution crops (rice and wheat), pearl millet yields on drylands have been stable over the past five decades. Specifically, millet and sorghum combined occupy less than 10 percent of India's irrigated land. Data series maintained by the Directorate of Economics and Statistics show that while irrigated area under pearl millet has increased from only about 3% of the crop's area in 1950-51, the 5-year was 9% in 2004-2009, the last year for which data are presented (<http://www.milletindia.org/data-on-millets.php>, accessed April 21, 2014).

An important recent trend is a declining annual per capital consumption of pearl millet in India, which Pray and Nagarajan (2010) relate to changing food habits but also to the increasing availability of fine cereals (rice, wheat) at subsidized prices through the Public Distribution System (PDS) funded by the government. An offsetting pattern is a rising demand for millet to feed poultry (laying hens) and livestock, which is predicted to continue as Indians consume more meat.

FAO's statistical database does not differentiate pearl millet from other types of millet⁷, which limits the utility of the database for charting national trends in India. Data series shown in Figure 5 also include all millet crops, but depict the declining share of millets in the supply of cereals in India.

Figure 5. Relative Shares of Millets, Wheat and Rice in Total Cereals Production, 1951-2012.



Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation. <http://www.milletindia.org/data-on-millets.php> (accessed April 21, 2014).

Both Bhagavatula et al. (2013) and Basavaraj et al. (2010) examine consumption trends for major cereals, including pearl millet, based on Indian national statistical surveys. According to Bhagavatula et al. (2013), consumption of pearl millet in India has always shown significant differences “along the urban and rural divide” (p. 53), which is explained in part by the short shelf life of processed flour. They and Basavaraj et al. (2010) find a strongly declining pattern in the consumption of pearl millet in both rural (59%) and urban areas (67%) between 1972 and 2005. On the other hand, consumption of rice and wheat remained stable. Similarly to Pray and Najarajan (2010), Basavaraj et al. (2010) ascribe the decline to the availability of rice and wheat through the PDS. In addition to the PDS, Basavaraj et al (2010) also cite the shorter preparation time for fine cereals, and the persistent belief that pearl millet is an inferior grain (consumed less as

⁷ In some databases, sorghum is included among millet crops. In general, however, scientists in India recognize pearl millet (produced in India and West Africa); finger millet (grown in India and in various regions of Africa); common or Proso millet; little millet; Kodo millet and foxtail millet (important in Asia, used as a rice substitute in China and Japan, consumed as beer in Russia and as bird seed in the UK, hay or silage in the USA (Bhagatavula et al. 2013).

income rises) among the reasons for the decline of the availability of pearl millet. However, both sets of authors note that the downward trend appears to plateau in the late 1990s, and in the final early years of the 2000s. In fact, Basavaraj et al. (2010) show a slight increase in pearl millet consumption during that period in the states of Rajasthan and Maharashtra.

The longstanding perception that pearl millet is a less important grain for high income households is borne out to some extent in the analysis presented by Basavaraj et al. (2010), although the largest consuming categories are middle-income households. Among rural consumers of pearl millet, only 9% were classified as high income, while half were middle income and 46% were low income. Only 4% of consumers were high income in urban areas, a quarter were low income, and two-thirds (67%) were medium income. These are consistent with the figures reported by Bhagavatula et al. (2013), who included a later round of consumer surveys (2009-10).

In addition, Basavaraj et al. (2010) also depict a rising trend over time in non-food uses of pearl millet (from 0% in 1970 to 50% of total consumption in 2005). Other uses include feed use, alcohol production, food processing and other industrial uses. Bhagavatula et al. (2013) report that use of pearl millet in commercial brewing and distillation is very limited, and trade in millets remains thin (less than 1% of total production). However, they cite the emerging importance of pearl millet as cattle feed in northern states like Haryana and Punjab, as well as Rajasthan. The crop's fodder is so economically valuable that it is grown under irrigation in Punjab, Haryana and Western Uttar Pradesh. Pearl millet straw is stored and used throughout the year in the arid areas, "particularly in the summer months where other feed resources are scarce" (p. 54).

Several other structural features of today's pearl millet industry have also been noted in the literature. Although prices fluctuate widely in Mali, they are relatively stable in India, although they have been rising along with the prices of other food crops since 2004, and more steeply since the global food price crisis of 2008, as suggested by trends in major markets (Bhagavatula et al. 2013: 57). Increasing demand in other uses explains this pattern, but in general, price variability in the pearl millet market derives from the fact that it is a staple food crop, and amounts entering local markets fluctuate.

In terms of production trends, a recent analysis has explored the economics of pearl millet production in northwest India (particularly Gujarat) as a summer (*rabi*) crop compared to a rainy season (*kharif*) crop (Reddy et al. 2013). The authors find that while the bulk of production continues to be grown in the rainy season with low yields and low use of inputs, there is some good commercial potential for pearl millet in

the summer because of higher yields and good grain quality under irrigated conditions, as well as some export potential. In Gujarat, the *kharif* crop must compete with guar, green gram and cotton. Summer (*rabi*) production represents only 25% of area but 44% of the annual pearl millet crop. Dual purpose (grain-fodder) cultivars are recommended for both *kharif* and summer (*rabi*) crops.

Finally, while the literature cited above views the increasing role of the private sector as a positive development for the structure of the seed industry and smallholder farmers, opposing views have also been expressed. For example, Shiva and Crompton (1998) predicted growing concentration of sales in fewer companies due to greater use of hybrid seed that is privately produced by large companies, departure of smaller companies as larger companies merge and buy them out, and growing production of transgenic crops, which incur high development costs that only larger companies can afford. The authors cite the extensive use of public hybrids of pearl millet as an example of the continued strength of the public sector, but content that this reflects the limited interest of the private sector in pearl millet due to declining area planted to the crop.

Based on a survey of 22 firms in Andhra Pradesh and Karnataka during 2004, Nagarajan et al. (2007) found that millet and sorghum seed sales ranged from 5 to 18 percent of total firm sales depending on the size of the firm, representing a greater share for medium- and small-sized companies than for large-sized companies. Further, they found that almost all large-sized firms engaged in research and development, as did some medium-sized ones, but none of the small-sized companies. Most of the larger firms were either multinational companies or had partnerships with foreign companies. Maharashtra based Mahyco (Maharashtra Hybrid Seeds Company Limited) led the state and national market. Nonetheless, public institutes were still “an attractive proposition” for private firms, as in the case of a consortium formed by ICRISAT, because they can benefit from their “massive infrastructure and scientific manpower” (2006: 17). However, representatives of larger firms complained that smaller firms have lower overhead expenditures since they could corner profits by acquiring licensing and marketing permits.

The discovery and utilization of cytoplasmic male sterile lines led to the development of the world’s first hybrid crop, pearl millet, in India. Later, exploitation of genetic diversity was necessary to ensure resistance to downy mildew, a major disease of pearl millet. Once that was achieved, India’s seed policies favored the development of a strong, competitive private seed industry, the effects of which were visible in rising adoption rates of hybrid pearl millet and yield gains in farmers’ fields. The contributions of the germplasm and of privatization of the seed industry are well documented “success” stories in agricultural

development (e.g., Bantilan and Deb 2003; Pray and Nagarajan 2010). Current concerns include the declining area planted to pearl millet in India, which has implications for seed demand; growing concentration of market shares in a few major companies, including mergers and buyouts of smaller companies and their dealer networks, which reduces the very competition that favored high rates of hybrid adoption; and the changing share of pearl millet in the diet, although most of the shift has been toward livestock feed and fodder, and there are some signs of a plateau or upward shift in Maharashtra, as well as the growing recognition among higher income consumers of the grain's nutritional qualities in specialized health food markets.

The next section presents the summary of key informant interviews conducted with representatives in the pearl millet seed industry in early 2014.

3. SEED INDUSTRY INTERVIEWS

Maharashtra as a focal point

To investigate the current structure of the pearl millet seed industry and implications for the introduction of high iron improved cultivars, we focused on the state of Maharashtra. After Rajasthan, Maharashtra has the second largest area planted with pearl millet. Maharashtra also has a higher rate of hybrid use than Rajasthan, although the highest adoption rates are in Gujarat and Haryana (Yadav et al. 2012). Maharashtra ranks third, after Rajasthan and Gujarat, in terms of per capita consumption of pearl millet (Basarajev et al. 2010). From 1972 to 2004, per capital consumption of pearl millet by rural households increased in Maharashtra by 33%, as compared to other states, where it declined (ibid.). More than 50% of the farms in this state are smaller than 5 acres; at the same time, seed distribution (Matuschke and Qaim 2005, based on data from Government of Maharashtra).

A proactive government stance toward pearl millet production dates to the 13th century, when records show that the Chief Secretary of the King Yadavas (Pradhan, named Hemadpant) sought to popularize the crop (Bhave 1954: 48). Pearl millet was recognized as a staple crop, especially for poor people, by the British colonial government (Watt 1890: 255). The fourth Chief Minister of Maharashtra, Mr. Vasant Rao Naik, encouraged the private sector to participate in the Green Revolution as a means to employ youth, as well as to boost productivity (Wattamwar and Mundada, pers. comm.). Maharashtra based Mahyco was established during this same period with funding and support from the Rockefeller Foundation and the World Bank, along with three other companies, of which one is still in operation (Nimkar Agricultural Research Institute), but does not produce pearl millet seeds (Dr. Bhapat, pers.com).

The Government of Maharashtra (GoM, 2013) reports the establishment of the State Seed Certification Agency in Maharashtra in 1970, and the State Seeds Corporation in 1976, following the passing of the national Seeds Act of 1966 and the adoption of the Seed Rules in 1968. The certification agency became autonomous in 1982.

The size of the seed industry in Maharashtra is staggering. The seed programme involves both the National and State Governments, the ICAR and SAU system, as well as public and private institutions. The Maharashtra State Seeds Corporation, 194 Taluka (block-level) Seed Farms and more than 250 private sector seed companies produce seed, each registered with the state Department of Agriculture (GoM, 2014). Five seed testing laboratories are utilized to assure quality and certify seed, with over 1000 seed inspectors. There are over 36,000 points of seed sales at vendors of the Maharashtra State Seeds Corporation, including cooperatives, private and public institutions. The GoM reports that seed replacement ratios for most crops are above national targets, and that there has been a fourfold increase in total seed distribution in the last 20 years, with the private sector leading in supply of hybrids and the public sector in improved varieties. Recent seed distribution records indicate a 55 percent share of the private sector in total seed distribution. (This report, however, does not make special mention of pearl millet seed or hybrids). According to Asare-Marfo et al. (2010) 91.7% of pearl millet farmers in Maharashtra planted hybrid pearl millet seed produced by the private sector on 93% of the area planted to pearl millet. In fact two thirds (67%) of taluka (block-level) agricultural extension officers interviewed as part of the Asare-Marfo et al (2010) study stated that they have seen a shift in farmers' demand for pearl millet seed produced by private seed companies relative to public ones in the past three to five years prior to the survey (which was implemented in *kharif* 2009).

Apte and Dhume (2012) report detailed area and production estimates for the districts in the state of Maharashtra. Their data suggest that the 3-year average area planted with pearl millet in *kharif* declined by 27.5% between 2002-5 and 2007-2010, as did the area under sorghum. The area planted to maize and cotton grew by 84.5% and 17%, as did the area under soybean (78%). Productivity of pearl millet, however, increased, and the authors concluded that gains in area and productivity for cotton and maize appeared to be at the expense of sorghum and other crops.

A final consideration is that Maharashtra is a target state for HarvestPlus and partners in their work with pearl millet improvement. The first high-iron variety of pearl millet (ICTP 8203 Fe) was developed for and is grown extensively in this state.

GoM interviews

Initial interviews with GoM seed sector representatives were conducted in August and October of 2013 in order to obtain contextual information. Respondents reported that in any one growing season in Maharashtra, from 5-10 pearl millet hybrids will enter the commercial market; often sharing similar characteristics. The economic life of a popular new hybrid is 3-5 years.

New seed is typically advertised in the local language through trial and demonstration plots, farmer visits and exhibitions. Farmer are also paid to test seed, two years before the product is introduced to the market. For the introduction of iron-rich hybrids one route recommended by the GoM seed sector representatives is the concept of the “seed village,” where farmers produce their own seed. Examples of this approach are found with roundup ready soybean and onions. By this means, the cost of hybrid seed production will be considerably lower, and knowledge about the seed will travel rapidly among farmers. Incentives to vendors, based on reasonable margins earned by the wholesalers and vendors, are also important factors in any commercialization strategy. One suggestion is a distribution of 3% to the wholesaler, 10% to the secondary wholesaler, and 20% to the retailer.

In Maharashtra farmers can sue seed companies for compensation if seeds do not perform as advertised, although wholesalers and retailers share some responsibility. Seed companies obtain advance payments from wholesalers, of 150-200% of the value of the volume to be sold. At the close of the season, the wholesaler will refund the company the amount above the sales value as an advance on the next season.

In India, decisions, processes and legislation reside within the jurisdiction of state governments, with the central (i.e., national) government acting as a facilitator, providing direction and policy guidelines. The central government is the final authority for certified (notified) varieties and hybrids. The overall approach of the central government since the 1990s has been to promote public-private partnership with the aim of forming a more market-oriented, vertically-integrated seed industry that co-exists with public institutions. Balancing institutional roles and responsibilities has posed challenges.

Each of the 247 seed companies in the state of Maharashtra must provide stock and sales data to the government. Seed companies operate through vendors, which must also register. According to the Department of Agriculture, of the 100,000 vendors registered, only 60,000 are active.

Two options are available for labeling and commercializing seed. In the case of notified varieties, certification is accomplished by the central government through an independent agency that evaluates

the results of inspections conducted at four stages: 1) selection of the trait at the research lab; 2) research trials; 3) multi-locational trials, and 4) adoptive trials. The certification agency bears some responsibility for seed performance.

TFL seeds also involve the same four stages of inspection, but these are conducted by the seed company rather than the independent agency. The state authority or the commissioner of agriculture in the state of Maharashtra is the granting authority for this category. Since 2009, a “Variety Scrutiny Committee” was established that consists of the commissioner of the Agriculture, Technical Officer, and heads of SAU departments of plant breeding. The meeting of this committee is held every month, where seed companies present their findings in monthly meetings of this committee. Based on findings, the commissioner grants the permission to the company to label the seed as a TFL variety and the company is solely responsible for its performance.

The baseline survey conducted by HarvestPlus during *kharif* 2009 in Maharashtra confirms that the current market for pearl millet seed in Maharashtra is dominated by hybrids (see Asare-Marfo et al., 2010). Of the most popular hybrids identified through surveys of farmers and agri-input suppliers in 2009-10, the top four were common across both sources: Mahyco 204, Pioneer 86M32, Mahyco 2210 and Nirmal 9. All of these are hybrids produced by private companies. As estimated by area shares allocated to each variety grown by farmers surveyed, Mahyco captured a major share of the seed market (38.2%, with 5 different varieties of which 3 were in the top 10), followed by Pioneer (17.9%) and Nirmal (14.6%). Among the top 10 was Mahabeej ICTP 8203, which is an IOPV developed by ICRISAT and produced by Maharashtra State Seeds Corporation. Other varieties which were believed to be cultivated widely in Maharashtra, including Mahabeej Shraddha 8609 and Mahabeej Saburi, were not identified among the top 10 pearl millet varieties grown by farmers surveyed in *kharif* 2009. The top 5 varieties cultivated in summer of 2010 (*rabi*) coincided largely somewhat with those listed above, although the relative rank differed. With over 100 high-yielding varieties of pearl millet in the market, most of which are hybrids, estimating the share of TFL seed is challenging. Notified hybrids are more likely to be those produced by larger companies or the public sector.

Seed company interviews

Next, we interviewed seed company representatives. The seed industry in Maharashtra has numerous players; the Department of Agriculture, Government of Maharashtra lists 247 operating in the state’s seed industry. These include multinational corporations such as Bayer and Pioneer, Indian companies like

Mayhco with linkages to multinational corporations (e.g., Monsanto), and many start-up, locally-based companies.

Given the proliferation of companies, and findings concerning the most widely grown varieties (Asare-Marfo et al. 2010), we purposively selected seed companies based on two criteria: market size and market type (small, medium, large; multinational, local or indigenous; public or private limited). Combined, based on variety names in the baseline survey, we estimate that these companies account for an estimated 60% of pearl millet seeds in Maharashtra.

Under legislature related to Indian companies, the terms “public” and “private” refer to different classes of companies or structures. A private limited company is held closely by owners, and risk and profits of the operations are distributed among shareholders. Balance sheets and other accounts information is retained in the private domain. Public limited companies are usually larger in size (sales and asset values), and listed on the stock exchange. These companies are required to comply with more detailed corporate law provisions. For example, they are expected to post balance sheets in the public domain. Only public sector companies can be listed on the shares market.

Each of the representatives interviewed in private seed companies had previous employment with or professional linkages to the public sector. Public sector experience among senior personnel is viewed as beneficial, even among smaller-scale, younger companies. Thus, the public sector seed industry in India has and continues to have an influence not only in terms of being the primary source of germplasm, but also in terms of human and social capital that influence institutional development.

A second shared characteristic that is evident and valued among all seed company representatives interviewed is a spirit of entrepreneurship. Representatives are technically trained as plant breeders or graduates in agricultural sciences, but also demonstrate an aptitude for enterprise development which differentiates them from other scientists or technicians. Their capacity to “decode” seed technology in terms of seed production and processing, and their aim to reach dispersed, smallholder farmers (“taking it to the last mile”), contributes to a vibrant seed industry. Interviewees noted that without the extensive dealer networks of smaller-scale seed companies, MNCs alone would not have succeeded in diffusing hybrids as widely as was the case during the 1980s-90s.

On the other hand, as noted by Shiva and Crompton (1998), today’s seed technology (or in particular transgenic technology) requires larger capital investments, favoring MNCs over SMEs. Respondents noted

that the seed industry has recently witnessed many mergers and acquisitions, with a trend toward greater market concentration over the past decade or so. Dealer and vendor networks are part of the acquisition, enabling more extensive penetration of rural markets.

The group of companies we interviewed is shown in Table 1, along with key characteristics and top pearl millet hybrids. The semi-structured questionnaire is shown in Annex 1. Mahyco, Pioneer, Nath, Dhanya and NSL represent large companies, with multinational linkages (MNCs), whereas Nirmal and Ajeet are medium-sized, nationally-owned companies, and Mahodaya and Eco are small-scale companies. Chief marketing personnel of Mahabeej and National Seeds Corporation, which are public sector companies, were also interviewed (but not listed in Table 1).

Ajeet is a leader in the cotton market and has numerous other businesses, including two sister seed companies. Established in 1986 in Aurangabad, Ajeet represents a mid-level, emerging company. Four top hybrids were reported by Ajeet, carrying the company's name.

Dhanya is part of the Tata group and the fastest growing seed company in Maharashtra, with technology provided by its parent company, Metahelix Corporation. Established in 2001, Metahelix now has a 15000 Dealer Network. Four numbered hybrids of pearl millet were cited by the Dhanya representative.

Mahyco was the first private seed company in the state of Maharashtra. Established in 1964, the company is known as "the original seed family of India." The founder of Mahyco, Dr. B. R. Barwale, won the World Food Prize in 1998. Mahyco produces 350 different hybrids, of which only a few are shown in Table 1. Once the leading company in sales of pearl millet seed, Mahyco is currently focused on Bt cotton development in partnership with Monsanto.

Nath is the leading company in floriculture, the first company to receive funding under the New Seed Development Policy of 1988, and a public limited company. Nirmal, a private limited company, is a partner of HarvestPlus, and also founded around the time of Mahyco. Nirmal is known for its innovative approach and medium size, with a number of top hybrids sold in Maharashtra.

Pioneer is a well-known, established multinational corporate with global reach that began in the US seed industry, and a member of the pearl millet consortium established by ICRISAT and AICPMIP. The two smallest firms, Eco and Mahodaya are young enterprises, although the owner of Mahodaya has 50 years of experience in the seed industry.

Table 1. Characteristics of Seed Companies Interviewed

Name	website	type	Comments	Pearl millet hybrids marketed
Ajeet	www.ajeetseed.co.in	Private limited	Leader in cotton market, has many other businesses as well as two sister seed companies. Established in Aurangabad, represents a mid-level emerging company	Ajeet 27, Ajeet 35, Ajeet 37, Ajeet Shakti
Dhanya	www.dhaanya.com	Private limited	Part of Tata group company, fastest growing seed company, technology-driven, markets proprietary seed for its parent company, Metahelix Life Sciences	PM 7792,7882,7872,7899
Eco	No website	Private limited	Representative of small enterprises, established in 2010	
Mahodaya	www.mahodayaseeds.com	Private limited	Young company but the owner has 50 years of seed industry experience	Mahodaya 318, Mahodaya312
Mahyco	www.Mahyco.com	Public limited	First private seed company of Maharashtra, produces 350 different hybrids, founder won World Food Prize in 1998, once the leading company in pearl millet, now focused on cotton	Caliber(MRB 204),Tower(MRB2210), MRB2240, MRB2232
Nath	www.nathseeds.com	Public limited	Leading company in floriculture , first company to receive funding after the 1988 liberalization	Eknath 301, NBH05,NBH1188, NBH1717
Nirmal	www.nirmalseedsindia.com	Private limited	HarvestPlus partner, innovative in approach, medium scale company	Nirmal-9,-10,- 40, - 1651, -1579 (Tulaja), - 2475 (Sindhu), -2798
Nuziveedu (NSL)	www.nsl.com	Private limited	Established in 1973. New company but leader in cotton market, growing company, especially in south of India, member of the consortium	
Pioneer	www.pioneer.com	Public limited, wholly owned by Pioneer	Multinational company, part of the consortium, the largest company in India	86M86,86M33,86M66, 86M52,86M64,86M11

All the company representatives were extremely reluctant to share any data on seed quantities marketed and market shares. Only two provided information, and it was partial. Based on their responses, we can observe that, as expected: 1) the seed market for pearl millet in Maharashtra is dominated by private hybrids, and by TFL seed rather than publicly certified seed of notified varieties or hybrids. Current estimates are consistent with those cited in the literature, or 80% of the seed marketed for pearl millet is produced by the private sector. The total private sector market size for pearl millet in India is estimated at 15,000-20,000 tons, of which the share of Maharashtra follows Rajasthan and Gujarat, and reaches about 2,500-3,000 tons. Rajasthan leads in terms of market size because of the larger areas planted to pearl millet, despite lower adoption rates. Respondents confirmed that Mahyco, Pioneer, and Dhanya are the major players in the pearl millet seed market in Maharashtra, each with an average share of about 20%. However, pearl millet is no longer a part of Mahyco's research and development portfolio. Bayer Proagro is a new market entrant that is more popular outside of the state of Maharashtra.

The size of the commercial market for pearl millet seed has been declining over recent years with declining area planted, with some fluctuations at the national scale, but a steady decrease in the state of Maharashtra. Rajasthan is considered to be the most promising market for hybrid seed of pearl millet because of its production scale. Respondents also confirmed an interest in the summer (*rabi*) season market because irrigation contributes to higher yields and post-monsoon rains appear to be more frequent. This market is mainly in the state of Gujarat, and in some parts of Maharashtra. Clearly, the size of this market is limited by the scale of irrigation. The size of pearl millet seed market varies with the timing and intensity of rainfall, and the crop is still preferred in a drier season with late rains, but if rainfall is more substantial and early, maize and cotton are planted instead.

Though the variety-wise sales were not disclosed by the companies during our discussions, some respondents suggested that one variety occupied nearly 70% of seed sales in Maharashtra; although other suggested that several varieties shared the lead. It is noteworthy that flyers and advertisements do not mention the region or reasons for which a hybrid is best suited. Hybrid ages in farmers' fields differ according to the dynamics of adoption and seed replacement, but seed company representatives stated that their goal is to launch new hybrids every five years. The average longevity reported by Asare-Marfo et al. (2010) is only two years.

Responses to qualitative questions were more complete among seed company representatives. In terms of the importance of pearl millet in the overall portfolio, all companies confirmed its importance except Mahyco and Ajeet, given expected changes in their marketing plans. The continued importance of the pearl millet market in the private seed industry, according to respondents, reflects its adaptation to harsher conditions and years of poorer rainfall, its global economic significance, and the fact that it is an integral part of existing product baskets. However, pearl millet seed sales generate little for companies in terms of value given the cheapness of the seed and small amounts farmers need to reproduce the crop.

Most respondents welcome new breeding opportunities, such as biofortification—particularly since they have noticed stagnating yields. Nutritional benefits, already recognized for pearl millet, would be well received by urban, middle-income households in the emerging health food market, which could act as a demand-pull mechanism. The size of this market is evident such as in the study by Basarajev et al. (2010) which is based on data from the early 2000s. The size of this market, and its growth potential in a country with an ever-growing middle income population, is as yet uncharted (Ernst and Young 2006; McKinsey Global Institute 2007). Concerns expressed in with regards to generating a market for high iron varieties include the invisibility of the iron-enriched trait. Moreover, market arrivals of pearl millet grain are bulked, therefore unless the value chain for these varieties are differentiated and certified or branded by a reliable third part, consumers cannot recognize the grain of varieties or hybrids with high iron trait. Pearl millet value chains would need some mechanisms or processes for variety recognition or segmentation to enable consumer recognition. Given that rice and wheat distributed via the Public Distribution System have contributed to the decline in demand for coarse cereals, such as the pearl millet, this system, or public actions such as minimum support prices, may be conducive for market creation.

With the exception of Ajeet and Mahyco, who are reallocating investment resources away from pearl millet research and development, all seed company representatives expressed readiness to participate in partnerships for biofortification of pearl millet, also mentioning the pearl millet consortium facilitated by ICRISAT. Both of the smaller companies interviewed, in particular, commented that no current consortia include opportunities for SMEs. All representatives acknowledged the original contribution of ICRISAT and public institutes to their germplasm stock.

Promoting new varieties is based on the principle that “seeing is believing.” Companies rely heavily on the social networks of farmers (also supported by Asare-Marfo et al., 2010) and on demonstration plots established in visible locations. In the jargon of literature about adoption of agricultural innovations, farmers ‘learn by doing’ and ‘learn by observation.’ Agronomic traits most recognized by farmers include yield of grain and fodder, resistance to downy mildew and other diseases, and heat tolerance. Consumers (who are also smallholder farmers) appreciate grain and bread (roti) quality. Dealer incentives are important factors to consider in promoting new materials, and companies reported that they spend roughly 5-7% of seed sales turnover on activities related to promotion.

4. CONCLUSIONS AND PROGRAM IMPLICATIONS

High-iron hybrids will not be delivered directly to farmers by HarvestPlus, but will be sold through partnerships with seed companies. Below, we discuss our conclusions in the context of this future partnership.

Several factors underscore the importance of breeding a range of different hybrids, with varying genetic base, and maintaining this diversity with the pipeline. The history of genetic susceptibility to downy mildew, the harshness of many of the production environments for pearl millet, and the various food and fodder traits that smallholder farm families demand is a foremost consideration. A second consideration is the competitiveness of the seed industry in Maharashtra and in India in general, the key role that the liberalization of the seed market has played in the diffusion of high-yielding seed of pearl millet and other crops, and the high turnover rates for new hybrids. The average rate of hybrid turnover for pearl millet in Maharashtra is similar to that of maize hybrids in the US. Thus, from both a crop improvement and a marketing perspective, diversifying the options available to pearl millet growers (in the form of different types of hybrid seed) is well-advised.

Including high-iron pearl millet in PDS as a demand-pull mechanism would add a market segment, while also mitigating the effects of promoting fine grain consumption by subsidizing fine as compared to coarse grains. While coarse grain consumption has declined over the past decades as incomes as India have increased, the share of pearl millet in coarse grain consumption has

grown (NRAA 2012). Clearly, PDS also targets the poorest rural families who are also those with low quality diets.

Other demand-pull mechanisms might relate to emphasizing the nutritional benefits of pearl millet products, targeting the growing Indian population in the middle income bracket. For some time, non-governmental associations such as the Swaminathan Foundation have promoted the development of niche markets for millet products, including minor millets, by focusing on their health-related advantages. Though viable, lessons from such initiatives suggest it may be important to link these with value-addition industries to ensure sustainability in the longer run (e.g., Hindustan Lever). On the supply side, the potential for production of pearl millet in the rabi season might constitute another market and also ensure that high-iron grain would be available year-round. Another policy option that would expand effective demand would be to recommend that a government authority responsible for certifying seed include the high-iron attribute as a non-negotiable trait, as was accomplished for resistance to downy mildew.

There are at least two ways to engage private seed companies in this process. One would be to provide interested companies with free access to high-iron breeding materials from ICRISAT. This approach is consistent with the history of ICRISAT's role as a producer of international public goods in the CGIAR system. Another way would be for private seed companies themselves to invest in research and development of high-iron hybrids, while HarvestPlus supports them in publicly-funded promotional campaigns. One strategy does not exclude the other; a combination may be feasible depending on economic incentives.

For example, since 2009, HarvestPlus and ICRISAT have provided 14 private seed companies with high pearl millet cultivars for testing and commercialization, while also supporting the testing by companies of their own lines for iron content. Several companies have since initiated breeding programs for high-iron pearl millet. Buy-in by the private sector buy-in was facilitated by the extent of variation in iron content among popular commercial hybrids. Latent variation—frequently among hybrids from the same company—provided early proof-of-concept that high-iron content does not have any negative effect on yield or other attributes. Moreover, in India, varieties can be commercialized by private seed companies as truthfully labeled seed without official release. Hence, by commercializing via private sector partners, HarvestPlus is dramatically shortening time-to-market (Wolfgang Pfeiffer, personal communication, November 23, 2015).

The emerging significance of pearl millet in the livestock feed industry is worthy of some policy attention by HarvestPlus and partners. Are there implications of these trends for livestock health, or for the adequacy of diets among poor people who cannot afford to consume livestock products and rely on pearl millet grain as a food staple? The feed industry might offer opportunities for pearl millet to compete with maize as a cash crop among smallholders. Iron-rich fodder could be an asset for livestock production and livestock producers, also selling at higher prices during the summer season; on the other hand, production for high-iron feed may compete with production for consumption of high-iron food on farms.

Finally, in promoting high-iron hybrids, because the high-iron trait is not observable to farmers or consumers in the plant or products, mechanisms will need to be devised to differentiate these from other pearl millet hybrids in the seed market. Label color, or even seed color, or obvious candidates for such mechanisms.

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Annex 1. Semi-Structured Questionnaire

1. Do you see pearl millet as an important part of your product portfolio? If yes why and if not why not?
2. How many bajra varieties you sold in the (a) last year (b) last 5 years and how old are they? (Life in years)
3. Top 3 most popular varieties (a) last year (b) last 5 years and its %share in your sale
4. For top 3 varieties in which locations (state) they are most popular and why
5. Least popular varieties (a) last year (b) last 5 years and why these varieties were not popular?
6. Most important traits farmers look for in new varieties
7. Your comments on the pearl millet seed market of India
 - a. Do you think it is promising, will increase in future? Is it saturated?
 - b. What patterns have you observed in pearl millet seeds for last five years?
 - i. Changes in volumes across the states e.g. some states sale has increased
 - ii. Changes in across the seasons e.g. summer sale is increasing
 - iii. If the pearl millet seed is the loser in the market, who is gaining, is it replaced by maize, soya?
8. Your perspective on future trends such as biofortified pearl millet varieties? Do you think it will increase pearl millet demand? Will you be ready to go for public private partnership for the same?
9. How much of your pearl millet germ plasma are from public institutes? Like universities or ICRISAT?
10. Most important traits farmers look for in new varieties
11. Promotion of new varieties – what kind of promotion methods you think work well for pearl millet seeds
12. Approximate sale of total pearl millet seed sales by your company in last three years

Annex 2. Sales of Pearl Millet Seed by the Government of Maharashtra, 2010-2013, Kharif season

Crop	2010			2011			2012			2013		
	Public	Private	Total	Public	Private	Total	Public	Private	Total	Public	Private	Total
Hybrid seed (qtls)	224	21026	21250	97	15956	16053	860	11604	12464	114	12605	12719
Hybrid seed share (%)	1.05	98.95	100	0.60	99.40	100	6.90	93.10	100	0.90	99.10	100
Improved seed (qtls)	4427	893	5320	99	12758	12857	2006	1792	3798	3192	1608	4800
Improved seed share	83.21	16.79	100	0.77	99.23	100	52.82	47.18	100	66.50	33.50	100

Source: Authors, based on data provided by the Government of Maharashtra.