No. 24

HarvestPlus Working Paper | May 2016

Understanding the Adoption of High-Iron Varieties in Maharashtra, India: What Explains Popularity?

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ABSTRACT

Pearl millet is one of the most important food staples of poorer populations in the drylands of India. India's first pearl millet hybrids were released during the Green Revolution. Low seed costs and the privatization of the national seed industry spurred diffusion of pearl millet hybrids once resistance to downy mildew had been achieved. Across Indian states, adoption rates for pearl millet hybrids are among the highest in the State of Maharasthra, where the government has encouraged a dynamic, competitive seed industry.

To our knowledge, no recent large-scale adoption studies have been conducted in Maharashtra. With the aim of better understanding the potential market for high-iron, pearl millet hybrids, we explore factors associated with growing pearl millet, and those that influence whether farmers grow major (popular) hybrids, as compared with minor cultivars. We test the relationships among cultivar choice, seed, and information sources.

The data confirm that pearl millet is more likely to be grown by poorer households in drier, drought-prone areas. Scheduled castes are more likely to grow popular hybrids, and less likely to grow minor cultivars, but are no less likely to acquire seed from commercial vendors (including agro-dealers and agri-service centers) than less privileged people. Farmers who grow major (minor) hybrids also ascribe less (more) importance to marketing traits then either consumption or production traits. Iron content is not an observable trait. Thus, de facto, popular pearl millet varieties are likely to reach less privileged farmers. To attach adoption potential, popular hybrids could be targeted for iron enrichment, and commercial marketing strategies should be pursued.

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1. INTRODUCTION

India's national research system released its first pearl millet hybrid nearly a half-century ago (Lele and Goldsmith 1989). Though promising, the initial group of pearl millet hybrids released in India succumbed rapidly to downy mildew disease. Thereafter, adoption rates rose and fell, until susceptibility to downy mildew was eventually overcome through genetic diversification of parent materials (Hash et al. 1997; Pray and Nagarajan 2009). Public, private, and international research institutions have all contributed to the improvement of pearl millet in India, but a vibrant, competitive seed industry has also played a pivotal role in diffusing pearl millet hybrids to farmers (Pray and Ramaswami 2001; Kolady, Spielman, and Cavalieri 2012).

Historically, the highest adoption rates for high-yielding pearl millet seed, most of which have been hybrids, were recorded for Gujarat and Maharashtra (Deb, Bantilan, and Rai 2005). The State of Maharashtra has also pursued a proactive policy to encourage private-sector involvement in the pearl millet industry. Seed company representatives in Maharasthra state that their goal is to launch new hybrids every five years, which is the average longevity of any particular hybrid in farmers' fields (Karandikar et al. forthcoming). A large number of pearl millet hybrids have been commercialized by the private sector as truthfully labeled seed (Yadav et al. 2012). Thus, pearl millet growers can choose from a broad range of trait combinations when seeking to meet their agronomic requirements and consumption preferences.

Pearl millet hybrids are also relatively inexpensive for smallholder growers. In their detailed analysis of survey data collected from 266 pearl millet farmers in Maharashtra, Matuschke and Qaim (2008) found that while most grew pearl millet for home consumption, more than one-quarter of them also sold part of their harvest in the market—suggesting a strong market orientation. The authors reported that for 98 percent of hybrid growers they surveyed in Maharashtra, seed price was not a criterion for adoption, and 96 percent did not consider regular seed replacement disadvantageous. 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. Similarly, Kolady, Spielman, and Cavalieri (2012) compile data showing that seed replacement ratios (new seed purchased as a proportion of all seed planted) are higher for pearl millet (56 percent) than for rice (25 percent), wheat (18 percent), or even maize (36 percent).

In this highly competitive seed industry, what determines the popularity of a new pearl millet hybrid? How can HarvestPlus and partners reach poorer, disadvantaged families with high-iron, pearl millet hybrids? These questions are pertinent for HarvestPlus and partners, who seek to introduce high-iron pearl millet varieties as a means of alleviating iron deficiency in western India, where an estimated 66 percent of children suffer from anemia (HarvestPlus 2010). Introduction of high-iron pearl millet could be a cost-effective means of reducing iron deficiency, especially among rural people who do not have regular access to dietary supplements, iron-fortified processed foods, and/or diverse diets rich in micronutrients (Meenakshi, et al. 2010; Birol et al. 2014). It is therefore crucial to understand what pearl millet attributes farmers are currently looking for and what are the least-cost, most effective delivery and promotion mechanisms for maximizing the adoption (and hence consumption) potential of these varieties by rural, pearl millet-producing households.

In this paper, we ask why some cultivated varieties of pearl millet are more popular than others, in order to better understand the potential scope for adoption of high-iron types. Popularity is defined according to frequency of planting among farmers surveyed in the State of Maharashtra, where most cultivars are truthfully labeled hybrids, as compared with officially, released, or "notified" varieties. Our regression specification is motivated by a trait-based model of cultivar choice grounded in the theory of the agricultural household. Consistent with the adoption paradigm of social learning and the empirical pattern reflected in survey data, we also test for the linkages among sources of seed information (external versus internal to the farming community), seed sources (commercial versus social), and cultivar choice. To do so, we estimate multivariate probit, recursive and seemingly unrelated, regressions. We also address the potential for selection bias in cultivar choice that might arise from choosing to grow pearl millet by estimating a preliminary Heckman probit model.

In Section 2 we describe the data sources. In Section 3, we summarize highlights of previous literature about cultivar choice among pearl millet growers in India, and provide some contextual information based on descriptive analysis of the data. The conceptual basis of the adoption model follows in Section 4. The empirical strategy is discussed in Section 5, econometric results are shown in Section 6, and conclusions are drawn and implications are provided in the final section.

2. DATA SOURCES

Data were collected by personal interviews in a survey conducted by HarvestPlus during the *kharif* (2009) season in the State of Maharashtra. The sample design consisted of several stages, based on stratified random sampling with probability proportionate to size.

In the first stage, based on background research, two of the nine agroecological zones in the State of Maharashtra were identified as conducive to production of pearl millet. In each of the two zones, all blocks in which pearl millet was produced during the most recent census (2007/2008) were listed. These comprised 184 blocks out of the total 446 blocks in Maharashtra.

In the second stage, the 184 blocks were ranked in ascending order according to the total area under pearl millet production and split into four strata based on 25, 50 and 75 percent cut-off points of total land under pearl millet production. In each stratum, 7–13 blocks were randomly selected, with oversampling in areas with more than 50 percent and 75 percent of total land planted in pearl millet.

Third, four to six villages were randomly selected from each stratum according to the distance to the center of the block. That is, two or three villages are situated closer to the block market center, and two or three villages are located farther away. Finally, in each village, depending on the population of the village, 10–20 households were randomly selected using a cross-sampling method. In total, in Maharashtra, 2,069 households were interviewed across nine districts, 38 blocks and 199 villages (Asare-Marfo et al. 2010). For the purpose of this analysis, 5 households were dropped for missing household identifiers.

The survey instrument was developed in consultation with colleagues at the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) and the All-India Pearl Millet Improvement Program (AIPMP), following informal interviews with key actors in the pearl millet supply chain. Modules covered household identification and composition, nutrition and food consumption, agricultural production, variety choice and farmer assessment of the importance of variety traits, and how well varieties performed with respect to each trait. The survey instrument was administered through computer-assisted personal interviews with the use of personal digital assistants. Following an initial training, instruments were pretested and finalized. Data were collected by 20 enumerators and three field supervisors between October 12, 2009, and the end of December 2009.

In addition to the household survey data, we utilize secondary data sources for crop prices and features of the farming system or agro-ecology. Historical district-level product price data for key crops like cotton, maize, and pearl millet were obtained from the Agmarknet database of the Directorate of Marketing & Inspection, Ministry of Agriculture, Government of India. The database provides crop wholesale prices for the years 2006–2009 in rupees (Rs.) per quintal, by district (Agmarknet 2014).

Monthly rainfall data in millimeters (mm) were obtained from the "Climatic Research Unit (CRU) Time-Series (TS) Version 3.21 of High Resolution Gridded Data of Month-by-month Variation in Climate (Jan. 1901–Dec. 2012)." The data provide a month-by-month variation in climate over the last century (Jones and Harris 2013), assembled from meteorological stations. The monthly Palmer Drought Severity Index (PDSI) for 2008 is a proxy of lateness of rains. The index was developed by the Climate and Global Dynamics Division, which is part of the National Center for Atmospheric Research Earth System Laboratory's climate analysis section (CGD 2012).

The block-level data sets were assembled from various sources. The total cropland area in each block is drawn from Ramankutty et al. (2008), while irrigated land area is from Siebert et al. 2013. The travel time to major cities with populations greater than 100,000 is obtained from the data compiled by HarvestChoice (2011). The rural population density is from the Socioeconomic Data and Applications Center. The average precipitation from 195 to 2000, average maximum temperature of 12 months, elevation data, and maximum temperature in 20 months are obtained from Hijmans et al. (2005).

Next, to enable us to better understand farmer decision making with respect to pearl millet cultivars, we summarize contextual information drawn from relevant studies and these data sources.

3. CONTEXT

3.1 Relevant Studies About Farmer Use of Millet Varieties In India

Analyses by Nagarajan and Smale (2006) and Nagarajan, Smale, and Glewwe (2005) focused on the determinants of millet diversity in semi-arid regions of Andhra Pradesh and Karnataka, including pearl millet, sorghum, and minor millets. Findings demonstrated the importance of seed system parameters—such as rates of seed replacement, seed-to-grain price ratios, and the quantity of seed traded via formal and informal channels—on the richness of materials grown per household and community. Farmer education, the number of plots managed, livestock ownership and locational features also contributed to variation in numbers of millet varieties grown among households. For pearl millet, in particular, adult literacy rates and a strong market infrastructure (kilometers of paved road, seed quantities traded in local markets, seed replacement rates) influenced pearl millet diversity when measured at the community scale.

In their landmark review of returns to investment in crop improvement in developing agriculture, Evenson and Gollin (2003) concluded that, in comparison with major food crops such as rice and wheat, crop improvement impacts are less discernible for millet-growing regions of India. More recently, other researchers have underscored the successful history of scientific research to improve pearl millet (Yadav et al. 2012; Pray and Nagarajan 2010; Deb, Bantilan, and Rai 2005). This success, the high benefit-to-cost ratios of pearl millet hybrids for smallholder farmers, and the key role that liberalization of the seed industry has played in promoting the use of pearl millet hybrids have been extensively documented (Pray and Ramaswami 2001; Pray, Ramaswami, and Kelley 2001). Tripp and Pal (2000) examined the performance of the pearl millet industry and farmer knowledge of hybrids, as the industry commercialized in Rajasthan. They found that farmers were willing to experiment with new seed, despite limited knowledge. Also in Rajasthan, studying informal seed systems, Christinck (2002) and vom Brocke et al. (2003) analyzed the relationship of farmer knowledge and seed management practices to the genetic structure of pearl millet.

Most relevant to this study are the analysis by Matuschke and Qaim (2008), and the initial analysis of the dataset we employ here (Asare-Marfo et al. 2010). Matuschke and Qaim (2008) applied a duration model to analyze the dynamics of hybrid adoption among 266 pearl millet growers in Maharashtra. They found that education, short distance to input dealers, and good market infrastructure speeded adoption of hybrid seed by pearl millet growers. Production traits, such as early maturity and more straw for fodder, were mentioned by farmers as reasons for adopting hybrids, in addition to higher yields. Presence of private seed companies had an accelerating effect on hybrid diffusion. Contrary to findings of most adoption studies conducted in India and elsewhere, farm size had no significant effects on the speed of adoption. The authors noted that the cost per acre for pearl millet seed is relatively low, so that cash or credit constraints are of lesser importance. They also reported that 207 out of 266 farmers interviewed had adopted hybrids, and all of these but one were privately bred. Nearly one-third of farmers had adopted hybrids within one or two years of their availability.

The top five most popular cultivars grown by farmers surveyed in Maharashtra, measured in terms of percentage of total area planted to pearl millet, were Mahyco 204, Pioneer 86M32, Mahyco 2210, Nirmal 9, and Mahalaxmi 308 (Asare-Marfo et al. 2010). Each is a hybrid developed by private seed companies. Mahyco and Nirmal were both established in the State of Maharashtra early in the process of seed sector liberalization. The main sources of seed planted by farmers surveyed were commercial agri-input suppliers in the highly competitive, private seed industry, followed by agri-service centers (originally publicly funded, and now private), and other farmers, through social networks. However, though agri-input suppliers consider themselves to be important sources of information about new cultivars, most farmers reported that they rely most heavily on neighbors, friends, relatives, and farmers in cooperatives. Turnover of hybrids was high—new hybrids were adopted and grown for an average of only two to three years.

Not all farmers surveyed cultivated pearl millet during the year preceding the survey. Major reasons cited for not growing pearl millet were related to the prices or profitability of alternative crops. Less than 5 percent of farmers grew more than one pearl millet cultivar per season in 2009 or 2008. For this minority of farmers, explanations for growing more than one variety included experimentation, specific adaptation to agroecological conditions, or contrasting traits (e.g., consumption quality versus sales price).

Most evidence suggests that variety traits are important in choosing among pearl millet hybrids and varieties. 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). Most of the crop is grown in the rainy (*kharif*) season (June–November). Although some is cultivated during the summer (February–May) and in the post-rainy (*rabi*) season (November–February) on a small scale in Maharashtra. 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 (Yadav et al. 2012).

A choice experiment conducted by Birol et al. (2015) explored farmer preferences for and trade-offs among key pearl millet attributes, including early maturity, the color of roti (unleavened bread), the presence of high-iron content, and seed price. Findings demonstrated the heterogeneity of the preferences of the pearl millet-growing and -consuming population in Maharashtra. Larger households with lower-quality diets expressed greater preferences for early maturity, presence of high-iron content, and light- or medium-colored roti, but expressed no response to seed price. These households clearly depend on pearl millet for consumption, selling a negligible share of their harvest. In contrast, more sales-oriented producers were less interested in consumption-related traits, responding strongly to seed price. In terms of farm and household size, and farm income as a share of total income, they were similar to the first segment. A third segment consisted of smaller-scale producers, who also depend on their harvest for consumption, valuing early maturity relatively more and nutritional value relatively less than the first segment. A major conclusion of this analysis was that to meet farmer demand for pearl millet seed in Maharashtra, seed suppliers should offer a pool of high-iron pearl millet varieties that provide different combinations of attributes.

3.2 Descriptive Analysis of Survey Data

3.2.1 Descriptive Statistics

Considering the full sample of farmers interviewed, 60 percent planted pearl millet in the main rainy season (*kharif*) of 2009. On average, pearl millet growers allocated a similar share of their total cultivated area (62 percent) to the crop, with a mean of 0.75 hectares (ha), ranging from tiny plots of only 20 square meters to a maximum of 12 ha (Table 1).

About one-third (34 percent) of all pearl millet growers in that season also grew cotton, and just over one-fifth (21 percent) also grew maize (Table 2). Considering only farmers who grew pearl millet, average areas allocated to cotton were 1.92 ha. Mean areas planted in maize were about 1 ha (0.965).

Maize and cotton are key cash crops in Maharashtra, competing on a larger scale for crop area. In keeping with the national trend, Maharashtra has witnessed rapid growth in maize cultivation since the 1970s, with an annual growth in area planted to maize of 12 percent in the 1990s. Estimates of the percentage of Maharashtra's production in the national total for maize relative to pearl millet have risen from a ratio of less than 1 to 10 percent to nearly equal shares of 11 and 12 percent. In Maharashtra, a larger

Table 1. Percentage of Farmers Growing Pearl Millet: Area and Share of Cultivated Area

Variable	Sample statistic	
Grew pearl millet in kharif 2009?	**Frequency**	**%**
Yes	1,233	59.7
No	831	40.3
Total	2,064	100
Area planted by growers	**Mean**	**Standard deviation**
Pearl millet area (ha)	0.752	0.612
Share of pearl millet in cultivated area (ha)	0.617	1.98

Source: Authors, based on HarvestPlus survey data. Growing season is *kharif* 2009.

Table 2. Percentage of Pearl Millet Growers Who Also Grew Maize And Cotton

Grew pearl millet in 2009?		Grew maize		Grew cotton		All
		No	Yes	No	Yes	
No	n	634	197	516	315	831
	%	76.2	23.7	62.1	37.9	100
Yes	n	996	237	832	401	1,233
	%	80.8	19.2	67.5	32.5	100
All farmers	N	1,630	434	1,348	716	2,064
	%	78.9%	21%	65.3%	34.7%	

Source: Authors, based on HarvestPlus survey data. Growing season is kharif 2009.

Table 3. Rainfall and Irrigation Features of Area Surveyed, by Block *(Taluk)*

Block name	Irrigated land share of block area	Mean irrigated area per farm	Long-term annual rainfall (mm)	Long-term average rainfall June (mm)	Palmer Drought Severity Index June 2008
Ambad	0.218	2.45	746	140	-1.20
Ashti	0.134	2.28	633	124	-1.39
Aurangabad	0.081	1.03	750	136	-1.22
Badnapur	0.015	1.75	728	140	-1.20
Bhokardan	0.077	2.60	761	140	-1.20
Chandwad	0.131	0.54	611	135	-1.27
Dhule	0.119	1.35	603	109	-1.08
Gangapur	0.286	1.02	711	136	-1.22
Ghan sangvi	0.239	2.12	774	140	-1.20
Jaffrabad	0.107	1.40	754	140	-1.20
Jath	0.036	1.00	659	95	-1.18
Junnar	0.251	2.25	940	151	-1.57
K.Mahankaal	0.004	0.79	650	95	-1.18
Kannad	0.093	1.08	814	136	-1.22
Khed	0.069	1.96	1,166	151	-1.57
Khuldabad	0.058	0.67	831	136	-1.22
Madha	0.163	0.59	627	98	-1.28
Majalgaon	0.553	2.33	821	124	-1.39
Mohol	0.183	0.56	659	98	-1.28
N.Solapur	0.350	0.94	720	98	-1.28
Nandgaon	0.011	0.62	595	135	-1.27
Paithan	0.206	4.94	707	136	-1.22
Parali	0.190	0.00	836	124	-1.39
Parner	0.129	1.19	534	95	-1.45
Sakri	0.031	0.80	656	109	-1.08
Sangamner	0.012	0.77	519	95	-1.45
Shirur	0.311	2.59	503	151	-1.57
Shirur	0.105	2.66	698	124	-1.39
Sillod	0.153	1.60	816	136	-1.22
Sindkheda	0.095	1.97	609	109	-1.08
Sinnar	0.151	0.82	636	135	-1.27
Soygaon	0.008	2.08	821	136	-1.22
Yeola	0.218	0.26	540	135	-1.27
Total	0.138	1.48	686	125	-1.28

Source: Authors, based on HarvestPlus survey data

percentage of maize area (14 percent) as compared with pearl millet area (6 percent) is covered by irrigation. Maize yields are considerably higher, and use of hybrid seed is 100 percent in maize production (Schroff and Kajale 2013).

Viewed from the perspective of the household farm, the relationship between maize and pearl millet is more complex. Like pearl millet, maize is a *kharif* crop planted in June or July, and harvested in October or November. However, maize has never been an integral part of the traditional Marathi diet. Thus, Schroff and Kajale (2013) report that 95 percent of maize produced is marketed, and prices fetched were an average of 6 percent higher than the minimum support price for maize. Of the mere 5 percent retained, they report that only 11 percent is for consumption on farm, and the remainder (89 percent) is destined for feed. In contrast, HarvestPlus survey (2010) estimates indicate that 84 percent of pearl millet is consumed on farm by the producing household. This means that maize is more likely to serve as a food crop complementary to, rather than as a substitute for, pearl millet, and as a cereal cash crop.

Agriculture in the State of Maharashtra is primarily rainfed, with the rainfall during *kharif* distributed unevenly from as high as 2000 mm in the coastal areas to 600 mm

Table 4. Sources of Pearl Millet Seed

Source of seed	Frequency	Percent	Category
Input provider	272	23.3	Commercial
Agri-service center	671	64.3	Commercial
Neighbor	75	6.38	Farmer
Family member	46	3.91	Farmer
Farmer in common cooperative	13	1.11	Farmer
Farmer in common organization	3	0.26	Farmer
Friend	10	0.85	Farmer
Total	**1,175**	**100**	

Source: Authors, based on HarvestPlus survey data

Table 5. Sources of Information About Pearl Millet Hybrids

Source of information	Frequency	Percent	Category
Friend	352	29.96	Social (internal)
Farmer who is a neighbor	423	36	Social (internal)
Relative/family outside the household	55	4.68	Social (internal)
Public-sector extension officer	56	4.77	Public (external)
Private-sector extension officer	74	6.3	Private (external)
Farmer in a common cooperative	15	1.28	Social (internal)
Farmer in a common organization	2	0.17	Social (internal)
Radio	1	0.09	Public (external)
Print media (newspaper/magazine)	1	0.09	Private (external)
TV	1	0.09	Public (external)
Agri-exhibitions	10	0.85	Private (external)
Agri-information center (Krishi Vigyan Kendra)	167	14.21	private (external)
Others	12	1.02	NA
None of the above	6	0.51	NA
Total	1,175	100	

Source: Authors, based on HarvestPlus survey data

per year in the interior areas. An estimated 17 percent of the geographical area in the Maharasthra is vulnerable to chronic droughts, and almost two-thirds of the area is classified as semi-arid (ibid.). Current annual rainfall, long-term average rainfall in the month of planting (June), the share of irrigated land in the block (*Taluk*), and the average area (ha) in irrigated land per farm are shown in Table 3, by block. Even within the sample, irrigated land shares of total area per block vary between almost zero and 0.55. Per farm, average areas irrigated range from zero to about 5 ha. Long-term annual rainfall (1950–2000) is 686 mm, although in Khed, the average is more than 1,100 mm. Long-term average precipitation in June is 125 mm. The value of the PDSI is also shown for June 2008. Though the value of this variable is difficult to interpret, it is significantly (negatively) correlated (p-value<0.01) with the decision to grow pearl millet in the survey data. The greater the value of the index in absolute terms, the higher the drought severity.

The highly competitive hybrid seed industry in Maharasthra, combined with the persistence of farmer-to-farmer transactions based on social relationships, creates a distinctive distribution for pearl millet seed. Although farmers obtained pearl millet seed from various sources, all can be grouped as either "commercial" or "social" sources. In the commercial category, we include input providers anywhere on the market supply chain (traders, companies, dealers, retailers). In the social category, we group other farmers who are neighbors, family members, fellow members of cooperatives or organizations, or friends. Commercial input providers dominate seed supply for pearl millet among farmers surveyed, accounting for 87.6 percent of cases. The fact that social sources (other farmers) represent as much as 12.4 percent is perhaps remarkable in a sector where hybrids are the major cultivar type (Table 4). Some of these could be saved seed rather than F1 hybrids, but not necessarily. The seed could be provided as a "gift" from one farmer to another for nominal fees or at a discount. Similarly, sources of information about pearl millet cultivars grown by farmers can be understood in terms of the descriptors "external" and "internal." Internal sources are social networks, while external sources include both commercially or privately and publicly provided information by organizations outside the social sphere or farmer community. External sources are the less important of the two categories, cited by farmers in only 28 percent of cases; internal sources are by far the most important providers of cultivar-related information (Table 5). In Sections 4 and 5, we discuss the conceptual basis and econometric approach used to investigate farmer decision making with respect to choice of pearl millet cultivars.

4. CONCEPTUAL BASIS

The decision making framework that underlies our econometric specification is a trait-based model of cultivar choice, which is derived within the theoretical framework of the agricultural household (Singh, Squire, and Strauss 1986). Fully developed by Hintze, Renkow, and Sain (2003) and Edmeades and Smale (2006), the trait-based approach also draws from Lancaster's (1966) model of characteristics in consumer theory and earlier applied research (e.g., Adesina and Zinnah 1993; Smale, Bellon, and Aguirre 2001). A second recent approach also draws from Lancaster's framework, linking it directly to a mixed logit econometric specification in order to treat heterogeneity in farmer preferences as well as substitution among traits (Useche, Barham, and Foltz 2012). Though suitable, the second approach is not feasible in our case, given that (1) not all farmers are offered the same cultivar set, and (2) traits are not measured quantitatively by cultivar in the survey data, but are evaluated according to a 1–5 Likert scale for both importance and performance.

To summarize the former approach, the agricultural household maximizes utility over the attributes of the home-produced goods it consumes, a purchased good, and leisure time. The home-produced good is pearl millet, and the household chooses among cultivars with differing consumption attributes ($\boldsymbol{\alpha}_c$—the taste, color, texture, storability, appearance, and aroma of unleavened bread (*roti*). Utility is maximized conditional on a vector of household characteristics that shape preferences ($\boldsymbol{\Phi}_h$) and market characteristics, including prices ($\boldsymbol{\Phi}_m$). In the non-separable case, when markets are missing or imperfect, household characteristics affect the costs of market transactions. Thus, the prices that guide household decision making are implicit and household-specific. The separable case, in which markets are perfect, is modeled as profit maximization. In the context of pearl millet production and consumption by smallholder farmers in the State of Maharashtra, we can envision a range of implicit prices and decision outcomes that are largely consistent with the non-separable case.

Cultivar choices are also constrained by production technology, which is defined in part by the agronomic traits of cultivars ($\boldsymbol{\alpha}_a$: yield, disease and pest resistance, maturity, drought tolerance, fertilizer and moisture response), and by availability of seed ($\hat{\mathbf{S}}$) and seed-related information ($\mathbf{I}_s$). Expenditure constraints play a limited role in choice among hybrids of pearl millet cultivars, given the low seeding rate and high benefit-cost ratios for hybrids cited above. In this semi-arid, drought-prone environment, application of mineral fertilizer to pearl millet is rare (although farmers apply manure and compost), and soil types, along with availability of irrigation, can have strong effects on farm productivity. Still, differences among hybrids with respect to these features may be slight and difficult to discern in the first few years of cultivation. Labor supply, included in the vector of household characteristics, is also a potential constraint, but again, is not likely to vary in major ways among hybrids. The production technology is conditioned on physical farm (Φ_f) characteristics, which are measured both at the farm and on a broader geographical scale.

Even in this rapidly changing seed industry, attributes of new cultivars are not known to farmers until they grow the cultivar or observe it grown in the fields of other farmers. Consistent with the survey findings noted above, with a history of viewing adoption of any new agricultural technology as a process that reflects farming learning under uncertainty and risk (Hiebert 1974), and with more recent paradigms of social learning (Foster and Rosenzweig 1995), we hypothesize that farmers learn about pearl millet cultivars largely through social connections. Household, market, and farm characteristics affect the way that farmers discover new cultivars by influencing the costs of assembling related information.

Seed-demand equations for pearl millet can be derived from the model and expressed in reduced form for household i as

$$S_i = S_i\,[\boldsymbol{\alpha}_c, \boldsymbol{\alpha}_a, \boldsymbol{\Phi}_h, \boldsymbol{\Phi}_m, \boldsymbol{\Phi}_f, \hat{S}(\boldsymbol{\Phi}_h, \boldsymbol{\Phi}_m, \boldsymbol{\Phi}_f), I_s(\boldsymbol{\Phi}_h, \boldsymbol{\Phi}_m, \boldsymbol{\Phi}_f)]. \quad (1)$$

Seed demand is positive, given that farmers choose to grow pearl millet. For any particular cultivar, cultivar group, or seed type, seed demand can be measured as a binary [0,1] variable or censored variable [observations clustered at zero, continuous above zero]. Equation (1), with these corollaries, is the basis for the empirical strategy described next.

5. EMPIRICAL APPROACH

To examine why farmers choose to grow a more or less popular cultivar of pearl millet, we first define "popular," and express equation (1) in a way that conforms to that definition, and then we explore econometric models that enable us to estimate equation (1). Finally, we define operational variables for the demand determinants in equation (1) based on data collected in the survey.

5.1. Defining Popularity

All of the cultivars named by farmers surveyed, with the exception of Mahabeej ICTP 8203 and those labeled *desi*

Table 6. Frequency Distribution of Cultivars Grown by Farmers, by Percentage of Pearl Millet Growers

Cultivar Name	Frequency	Percent
Mahyco 204	278	23.94
Pioneer 86M32	175	15.07
Nirmal 9	95	8.18
Mahyco 2210	88	7.58
Mahyco 167	74	6.37
Mahalaxmi 308	71	6.12
Mahabeej ICTP 8203	55	4.74
Nirmal 40	48	4.13
Ganga Kaveri 1044	43	3.7
Pioneer 86M52	29	2.5
Nirmal Tulja 1579	23	1.98
Mahalaxmi 504	21	1.81
Desi	20	1.72
Dhanya 7870	19	1.64
Mahalaxmi 267	15	1.29
Mahabeej Shraddha 8609	10	0.86
Bayer-Proagro 9330	9	0.78
Mahabeej 1001	8	0.69
Vijay 444	8	0.69
Ajit 27	7	0.6
Kaveri Boss 456	7	0.6

Bayer-Proagro 9333	7	0.6
Mahyco 163	6	0.52
Krushi Dhan Ratan 666	5	0.43
Mahodaya 318	5	0.43
Nirmal Sindhu 2475	3	0.26
Advanta seeds 931	2	0.17
Grade Seed 520	2	0.17
Jaikisan 208	2	0.17
Jaikisan 2301	2	0.17
Arun 308	2	0.17
Shahansha 32	2	0.17
Sidhi	2	0.17
Gayatri	1	0.09
Green Gold 27	1	0.09
Hypearl 51	1	0.09
Karadi	1	0.09
Mahabeej Saburi	1	0.09
Ankur 909	1	0.09
Mahyco 983	1	0.09
Pragati	1	0.09
Sankarit 7	1	0.09
Shanti 1035	1	0.09
Suverna 222	1	0.09
Arya 4	1	0.09
Western 46	1	0.09
Yashoda 30Y93	1	0.09
Zuari 2021	1	0.09
Zuari 2304	1	0.09
BK 560	1	0.09
Bayer-Proagro XL51	1	0.09
Total	**1,161**	**100**

Source: Authors, based on HarvestPlus survey data. Season is kharif 2009.

Note: Not all farmers reported names.

(farmers' varieties), are hybrids (Table 6). None of them, however, is reported in the list of notified varieties officially released in India as of March 31, 2011 (Annex 1). For this reason, no year of release or other data about them could be obtained. Some information was available on the Internet for major hybrids, but was not particularly informative.

For the purposes of our analysis, we define the popularity of pearl millet cultivars according to the distribution of percentages shown in Table 6. Cultivars grown by more than 7.48 percent of pearl millet growers are within the 90th percentile of the frequency distribution. These cultivars, which comprise our set of "major" hybrids, include Mahyco 204, Pioneer 86M32, Nirmal 9, and Mayco 2210. Given the skewness of the distribution (many hybrids cited only once), we define "minor" cultivars as all hybrids or varieties grown by 1.7 percent of farmers (the lowest value of the 75th percentile) or fewer, including *desi* varieties. (When we use the term cultivar, we are referring to either cultivated varieties or hybrids.)

For the purpose of identifying the determinants of the decision to grow a more popular versus a less popular cultivar (estimating equation 1), we measure seed demand for major and minor cultivar groups in terms of a binary variable [0,1], where 1 implies that the farmer grew one of the cultivars in either of the two groups. Cultivars that are neither major nor minor are coded zero.

5.2. Regression Strategy

Several hypotheses lead to the regression strategy we pursue. First, we hypothesize that the decision to grow cultivars in either of the major or minor groups may be correlated, so that the two discrete choice equations should be estimated in a bivariate, seemingly unrelated system of two equations.

Second, a priori, we cannot rule out the possibility that the decision to obtain seed or seed-related information from a particular source is endogenous to the discrete choice to grow a major or minor cultivar. In alignment with our conceptual basis, the same household and market characteristics that influence cultivar choice, whether observed or unobserved, may also affect the seed source and related information, since these can also be understood as "purchases" with associated transactions costs. Thus, we follow a recursive formulation, in which both a systematic and a seemingly unrelated interrelationship is tested. Seed source (commercial, social) and information source (external, internal) are thus included as dummy explanatory variables in the two cultivar choice regressions, and also as dependent variables in discrete choice equations. Combined, this constitutes a multivariate probit, recursive, seemingly unrelated system of equations.

The dependent variables in the regression system can be considered as latent variables for which only the dichotomous outcomes can be observed (Maddala 1983). In addition to a shared vector of exogenous variables, each cultivar equation includes the seed source variables as potentially endogenous regressors. Although Maddala (1983) highlighted a potential problem of identification, Wilde (2000) concluded that in contrast to linear simultaneous equations with only continuous endogenous variables, in recursive multiple equation probit models with endogenous dummy regressors, no exclusion restrictions for the exogenous variables are needed if there is sufficient variation in the data. That condition is ensured by the assumption that each equation contains at least one varying exogenous regressor—an assumption that is rather weak in economic applications. However, we also address the exclusion restriction by including the trait importance scores in the cultivar choice model, but not in the seed or information source variables.

The appropriateness of the multi- or bivariate model as compared with the separate probit models can be evaluated with a likelihood ratio test. The independent univariate models are nested within the multi-equation model, which represents the unconstrained regression. In our case, the Wald test indicates whether the error structures are related, as represented by the estimated correlation coefficient ρ-hat. Failure to reject the null hypothesis that ρ equals zero leads to separate estimation of the equations. The test of the regression coefficients on sources of seed or information (S, I_S) provides evidence of whether the recursive model is an appropriate representation of the data.

Third, we consider the possibility that unobserved, intrinsic characteristics of farm households that lead them to decide to grow pearl millet also affect cultivar choice. Thus, we begin by testing for selection bias in each cultivar choice equation with a Heckman probit model. In the selection equation, we draw on variables measured at a larger geographical scale of analysis in secondary databases, such as rainfall patterns and the extent of irrigated land, temperature and elevation, rural population densities, prices, and production patterns for alternative crops. These variables drive the decision to sow pearl millet, but are not likely to directly affect the choice between the decision to grow a more or less popular cultivar. Although we are not satisfied with the Heckman model as applied in this context, we present the single-equation probit model because it is of interest concerning the decision to grow pearl millet. Thus, our cultivar choice models should be understood as conditional on the decision to grow pearl millet.

5.3. Explanatory Variables

Explanatory variables are defined operationally to represent the conceptual variables shown in equation (1): cultivar traits, household characteristics, market characteristics, farm characteristics, seed source, and information source. As noted above, explanatory variables included in the seed source and seed information equations also include household, market, and farm characteristics, but not variety traits. Variables in the crop choice model include those measured at a different geographical scale that are hypothesized to influence the decision to grow pearl millet, and not variety traits.

Variable definitions are shown with means and standard deviations in Table 7, including both continuous and binary [0,1] variables. In the case of binary variables, the mean value is the proportion of observations with a value of 1. Thus, 55 percent of pearl millet farmers grew major cultivars, as compared with only 14 percent who grew minor cultivars.

In terms of household characteristics, about two-thirds of pearl millet growers are members of scheduled castes. The average household in the sample has more than two years of experience growing the pearl millet variety that they cultivated in the survey year, with a maximum of 55 and minimum of only the current season (not shown). The average per capita land area is 0.40 ha, ranging from nearly zero to as much as 4 ha. Similarly, on average, a household has a livestock wealth (measured in Tropical Livestock Units, or TLU) of 58,431 Rs. and a per capita income of 5,581 Rs.

Turning to market characteristics, the distance to the seed supplier, which is used as a proxy for market access, is on average 8 km. Eighty percent of seed sources are commercial vendors, as explained above in the contextual section. However, the majority of households (78 percent) acquire information about pearl millet cultivars from "internal" sources—that is, friends or neighbors within their social network or community. Some of these, of course, may also be traders or retailers.

Considering market prices, the mean seed-to-grain price ratio for pearl millet is only 0.76, which is extremely low for a hybrid crop. As discussed above, previous analyses suggest that the cost of seed has not constrained the adoption of pearl millet hybrids in India (Matuschke and Qaim 2008; Tripp and Pal 2000). Average seed-to-grain price ratios are considerably higher for commercial sources than for social sources, but lower for major than for minor hybrids. In terms of competing crops, product prices are much lower for pearl millet than for maize. The mean harvest price of maize was 824 Rs. per quintal in 2008, compared with 798 Rs. per quintal for pearl millet.

Farm characteristics include soils, irrigated area, and crop richness. The average household has lower light-soil and black-soil shares relative to medium-soil types, at 20 percent and 21 percent, respectively. On average, a household cultivated only slightly more than one crop in the preceding *rabi* season, with a range from 0 to 6. For purposes of comparison, the mean during the *kharif* season is 1.9, ranging to 7. We include only the *rabi* season because it precedes the survey season, and can thus be considered to be exogenous to current crop choices.

We have also included characteristics of the farming system and agro-ecology measured at a larger geographical scale, grouped under farm physical characteristics. These include the rural population of the *Taluk* (block), the average rainfall (1950–2000) in mm during the month of June, the average maximum temperature recorded over the

Table 7. Definitions of Explanatory Variables and Summary Statistics

Variable	Definition	Mean or percent	Std. dev.
Dependent variables			
- Grow major hybrid	Most popular 4 varieties (above 7.58% of pearl millet growers each)	54.9	
- Grow minor cultivar	Less popular varieties (less than 1.7% of pearl millet growers each)	13.8	
- Grow pearl millet	Grew pearl millet in *kharif* 2009	59.7	
Explanatory variables			
Household characteristics			
- Caste	1 = non-open caste (scheduled, less privileged); 0 = open caste	67.3	
- Literacy	Respondent literate = 1, 0 otherwise	75.9	
- Years growing cultivar	Number of years growing currently pearl millet variety	2.41	2.42
- Livestock value	Total value of livestock owned in rupees using Tropical Livestock Unit (TLU)	58,400	375,000
- Income per capita	Total farm and off-farm income during 12 months preceding survey, in Rs./household size	5,580	25,700
- Land per capita	Total land area operated (ha)/household size	0.396	0.385

Market characteristics			
- Distance to seed supplier	Distance to the seed supplier for the variety cultivated (km)	7.99	6.66
- Seed source	1 if the source is either input provider or agri-service center, 0 otherwise	88.5	
- Information source	1 if the source is external, 0 if it is from social networks	21.8	
- Seed-to-grain price ratio	Expense per kg on pearl millet seed/average district wholesale pearl millet price during harvest (Sept.–Oct. 2008)	0.77	1.59
- Maize price	District whole maize price during harvest (Sept.–Oct. 2008)	824.0	45.1
Farm characteristics			
- Light soils share	Ratio of area of light soil to the total cultivated land	0.197	0.393
- Black soils share	Ratio of area of heavy soil (black soil) to the total cultivated land	0.213	0.399
- Irrigated area	Size of plot that uses irrigation	1.48	2.97
- Crop richness (*rabi*)	Number of different crops cultivated by a household in *rabi* 2008	1.110	0.945
Block characteristics			
- Rural population	Rural population of the *Taluk*/block	161	66.7
- June rainfall	Long-term monthly rainfall averages in mm—June	125.0	18.8
- PDSI	Palmer Drought Severity Index in June (by *Taluk*/block; see text)	-1.28	0.1
- Maximum temperature	Average of maximum temperature of 12 months of the *Taluk*/block (in Celsius)	32.30	1.03
- Elevation	Elevation of the *Taluk*/block (in meters)	560	126
- Extent of irrigated land	Ratio of irrigated land area to total land area (ha)	0.138	0.112
- Cotton area in block	Total area cultivated to cotton by block (ha)	35.6	44.7
Cultivar traits			
- Production	Ratio of importance of production in variety choice: total ratings/total possible	0.703	0.115
- Market/processing	Ratio of importance of marketing in variety choice: total ratings/total possible	0.703	0.145
- Consumption	Ratio of importance of consumption: total ratings/total possible	0.793	0.120
- Fodder, fuel, construction	Ratio of importance of fodder yield: total ratings/total possible	0.628	0.207

Source: Authors, based on HarvestPlus survey data. Percentage reported for 0–1 variables; mean reported for continuous variables.

12-month period in the harvest year, elevation of the block, extent of irrigated land, and area of cotton cultivation in the block. The average long-term rainfall in June, which is the pre-*kharif* season, is registered at 125.19 mm, whereas the average maximum temperature of 12 months of the *Taluk*/block average is 32.26 degrees Celsius. The average elevation is 560.09 meters in Maharashtra, while the ratio of irrigated land area to total land area of the *Taluk*/block is 0.14 ha. The mean total area cultivated to cotton by a *Taluk*/block is 35.58 ha.

Farmers surveyed were asked to rate the performance of their cultivars on a Likert scale (1–5) according to 12 production traits; 5 marketing and processing traits; 6 consumption traits; 4 fodder, fuel, and construction traits; and 6 traits related to alcoholic beverages produced with pearl millet. However, traits were added within categories, as reported by farmers, in an open-ended fashion, during the course of the survey. To control for this process and standardize the PDSI, the scores were developed as ratios of totals reported to the ratio of possible traits at the time of the interview. Even when this is taken into consideration, the number of observations for the beer category was too few to be considered reliable, and this group of traits was dropped. The full list of traits is shown in Annex 2.

6. RESULTS

6.1. Econometric Results

Initial regressions testing for the statistical significance of selection effects in the decision to grow pearl millet cultivars in the major or minor group were inconclusive. Results of Heckman probit models estimated by maximum likelihood methods are provided in Annex 3. The likelihood ratio test on the correlation coefficient (ρ) leads us to reject the hypothesis of no unobserved selection effects in the case of the minor group at a significance level of less than 1 percent; we fail to reject the null hypothesis of independence in the case of major hybrids at the 5 percent level of significance, and reject it at the 10 percent level. One way to interpret these results is that underlying unobserved factors affect both the decision to grow pearl millet and the decision to grow minor hybrids or *desi* varieties, but these are not so distinguishable in the case of major hybrids. However, the meaning of these findings for analysis of cultivar choice is not evident. For example, in cases where the related equation is a variable measuring effects (impacts) on such outcomes as market participation or household well-being, we know that a positive sign would suggest that we have inflated our estimates of effects, unless we have controlled for selection bias. In contrast, the sign on ρ is negative in the case of the minor group,

Table 8. Factors Influencing the Decision to Grow Pearl Millet in Maharashtra

Factors	dy/dx	Delta-method std. err.	Z	P>z
Seed-to-grain price	-0.013	0.005770	-2.19	0.028
Maize price	0.000190	0.000353	0.54	0.591
Population	-.000519	.0001935	-2.68	0.007
June rainfall	-0.0025232	0.0007294	-3.46	0.001
June drought severity	-0.297	0.139	-2.13	0.033
Maximum temperature	0.120	0.031	3.87	0.000
Elevation (thousand m)	0.7352	0.2359	3.12	0.002
Extent of irrigated land	-2390	1245	-1.92	0.055
Caste	-0.036	0.025	-1.44	0.151
Livestock value (million Rs)	0.317	0.106	2.99	0.003
Land per capita	0.0646	0.0327	1.98	0.048
Income per capita (million Rs)	-1.55	0.895	-1.73	0.083
Cotton area in block (thousand ha)	-0.0653	0.433	-0.15	0.880
Likelihood ratio test chi2(13) = 84.81;	p-value = 0.0000.			
Log likelihood value = –1185.8209.				

Source: Authors, based on HarvestPlus survey data

and positive for the major group. We argue that, given this empirical situation, it makes more sense to consider our analyses of cultivar choice as conditioned on the decision to grow pearl millet.

Nonetheless, in and of itself, the probit model provides some useful insights concerning the factors that influence the decision to grow pearl millet in Maharashtra (Table 8). As predicted by economic principles in the case of profit maximizing, the decision to grow pearl millet is negatively related to the seed-to-grain price ratio. This finding attests to the commercial orientation of the average pearl millet grower in the State of Maharasthra. The maize price, however, is not of statistical importance—perhaps because, as hypothesized, maize may play more of a complementary role, rather than a competitive role, , as much as it does a competitive role at the scale of farm household decision-making. Nor is the total area planted to cotton at the block level (or the general orientation toward more cotton in the vicinity of the farmer) a significant determinant. The more densely populated the locality, the less likely it is that farmers will grow pearl millet. Higher long-term rainfall in June is negatively associated with planting pearl millet, which makes sense, given cropping alternatives. The more negative the PDSI (the higher its absolute value), the more likely the farmer is to grow pearl millet. However, the range of this variable in the data does not indicate the presence of severe drought on a world scale—the worst values are around –1.5, which is better than moderate (–2) and far from severe (–3). Higher temperatures also bear a positive relationship with the decision to grow pearl

Table 9. Multivariate, Recursive Probit model explaining choice of pearl millet cultivars and seed source in Maharasthra, India

		Robust			Robust	
	Coef.	**Std. err.**	**P>z**	**Coef.**	**Std. err.**	**P>z**
	Grow major hybrid			*Grow minor cultivar*		
Caste	0.284	0.108	0.008	-0.281	0.124	0.023
Literacy	-0.162	0.125	0.194	-0.0229	0.138	0.869
Light soils share	0.0239	0.133	0.858	0.108	0.141	0.444
Black soils share	0.451	0.137	0.001	-0.205	0.164	0.211
Irrigated area	-0.041	0.0164	0.014	0.0571	0.0184	0.002
Crop richness, rabi	0.125	0.058	0.032	-0.107	0.067	0.114
Livestock value (million Rs.)	0.159	0.144	0.270	-0.236	0.146	0.107
Income per capita Rs.)	-.0000227	7.27e-06	0.002	7.56e-06	6.50e-06	0.245
Distance to seed supplier	0.00965	0.00772	0.211	-0.000986	0.00895	0.912
Years growing	0.0436	0.0165	0.008	-0.139	0.0450	0.002
Seed source	0.766	0.36	0.033	-0.0947	0.379	0.803
Production	-0.332	0.471	0.481	-0.785	0.547	0.151
Market/processing	0.201	0.442	0.649	0.380	0.530	0.474
Consumption	-0.818	0.461	0.076	1.71	0.596	0.004
Fodder, fuel, construction	-0.384	0.267	0.150	-0.262	0.316	0.406

Likelihood-ratio test of rho = 0: chi 2(1) = 172.05; p-value = 0.000.
Wald chi2(30) = 90.97.
Log likelihood equations = –749.7; p-value = 0.0000.

Source: Authors, based on HarvestPlus survey data

millet in any given year. Among household characteristics, livestock wealth and land per family member contribute to the likelihood that farmers will grow pearl millet. Pearl millet is an extensive crop, and the fodder is of potential importance for animal feed. On the other hand, higher income per capita decreases the chances a household will grow pearl millet, as expected, given the literature reviewed above. Caste has no significance.

Diagnostic tests ($\rho_{ij} = 0$ for each *ij* combination, where *ij* refer to a pair of regressions) from initial multivariate regressions lead us to reject the hypothesis that major and minor cultivar choice equations are independent. We also reject the hypothesis that the seed source and information source equations are independent of cultivar choice equations. We find that seed source is a significant determinant in the choice of minor cultivars, but information source is significant in neither. Results suggest that differentiating information sources by external or internal origin is unimportant in cultivar choice, either because the seed system is so dynamic and competitive or because the transactions costs incurred when farmers seek information about cultivars are not appreciable. The diagnostic tests are shown in Annex 4.

Given these test results, we estimate the multivariate, seemingly unrelated probit regressions of cultivar choice, with seed source treated also treated as a recursive variable. Regression coefficients, standard errors, and p-values are shown for each model in Table 9. STATA 13 does not estimate marginal effects for multivariate probit.

Comparing across cultivar choice equations, we find that membership in a scheduled caste, which tends to include more disadvantaged people, is positively associated with growing a major hybrid, but negatively influences the probability of a farmer growing a minor cultivar. One interpretation of this finding is that scheduled castes are as oriented to growing popular hybrids as any other caste, despite their lower social status, though they are less likely to experiment with recently released hybrids or less common cultivars. Literacy does not appear to be significant in explaining a farmer's choice to grow major hybrids and minor cultivars of pearl millet relative to those in the intermediate group, but literacy is strongly (and negatively) associated with membership in a scheduled caste. Opposite signs on literacy and caste coefficients are thus explicable. Similarly, lower income per capita is strongly related to growing a major hybrid. Wealth (livestock value) bears no significant relationship to choice in either cultivar group.

Commercial seed source is positive in the decision to grow a major hybrid, but negative in the choice of a minor cultivar—perhaps reflecting that many of the minor cultivars are *desi* varieties, or those bred by the public sector. Years growing the cultivar influence the choice of either type positively, which suggests some "habit" in growing pearl millet. Distance to the seed supplier is of no importance in either equation.

The share of farmland in black soils is positively related to growing major cultivars of pearl millet, but does not appear significant in the equation explaining the choice to grow minor cultivars. The size of irrigated area is a negative factor in the decision to grow a major hybrid, but positive in the decision to grow a minor cultivar. In terms of bivariate statistics, more extensive irrigated area is associated with growing more maize and cotton. On the other hand, crop richness in the preceding *rabi* season is positively, though weakly (at the 10 percent significance level) related to choosing to grow a major hybrid of pearl millet in the *kharif* season.

Only the importance of consumption traits appears to influence the likelihood of growing a major hybrid—and has a negative effect. On the other hand, the results suggest that farmers who ascribe importance to consumption traits are more likely to grow minor cultivars of pearl millet, as are those less concerned about production traits.

Acquiring a pearl millet cultivar from a commercial seed source is no less likely among scheduled castes than among other castes, but it is significantly more likely for literate farmers and less likely for farmers with lower per capita income (Table 9). The closer the source, the less likely it is to be private. The finding that the number of years growing a cultivar is also positively related to a commercial seed source may suggest some "loyalty" to seed supplied by private companies or services.

7. CONCLUSIONS

In this paper, we have sought to identify the factors that determine whether farmers choose to grow the most popular and least popular cultivars of pearl millet. A trait-based model of the household farm has served as the conceptual basis for our econometric approach, in which we have estimated multivariate, seemingly unrelated probit models to test for both systematic and unobserved correlations among cultivar choices, seed, and information sources. We have also tested and controlled for potential selection effects related to the decision to grow pearl millet in cultivar choice. We have selected Maharashtra as the state of focus, given 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 for crop development and delivery strategies by HarvestPlus and its partners, the State of Maharashtra and Government of India, to ensure maximum adoption and consumption of soon to-be-released, high-iron varieties of pearl millet. These varieties are likely to be conventionally bred, biofortified hybrids.

Analysis of survey data suggests that, as predicted by the contextual literature, the factors that raise the likelihood that smallholder farmers in Maharashtra choose to grow pearl millet include a drier long-term rainfall in the locality, higher temperatures, a greater incidence of drought, and less extent of irrigated land. Pearl millet growers are indeed more likely to have livestock but also lower annual income. Thus, it continues to be the case that improving pearl millet de facto targets poorer farm families in more challenging farming environments.

Caste does not appear to play a role in the decision to grow pearl millet, though the data suggest that it does when choosing cultivars. Growing popular hybrids is more likely among the scheduled castes, which tend to include less privileged groups, though growing minor cultivars is less likely. While numerous underlying factors may explain this pattern, it has two possible interpretations. One is that, clearly, an optimal choice for developers would be an already popular hybrid. Another is that any popular new hybrid (high-iron or not) tends to be adopted by, or to "reach," less privileged socio-economic groups in Maharashtra. This is an encouraging interpretation, and is not surprising, given previous evidence that seed price is not a constraint to using hybrids in this state. At the same time, controlling for caste and other factors, the preliminary crop choice equation confirms a negative response to the seed-to-grain price ratio overall, consistent with the economic principle that other crops with purchased seed (such as maize) become relatively more attractive if the input-to-output ratio rises for pearl millet, with all other factors remaining the same. Thus, to support the adoption potential of high-iron pearl millet hybrids, seed prices should be comparable to those of other currently popular hybrid seeds.

The relative importance farmers assign to categories of variety affects their decision to grow or not to grow major pearl millet hybrids. However, farmers who rate consumption traits as highly important are less likely to grow major hybrids. At the same time, they are more likely to grow minor cultivars. Further, farmers who rate production traits as highly important do not tend to grow minor cultivars. These findings are consistent with the broad empirical literature indicating that smallholder farmers often continue to grow local varieties or lower-yielding varieties on a very small scale to meet consumption preferences. To ensure that farmers prefer high-iron pearl millet varieties, both for their consumption/processing and production characteristics, consumer acceptance studies should be implemented alongside studies of participatory variety selection (e.g., Banerji et al. 2015). Only when high-iron hybrids have both the production and the consumption attributes sought by farmers will their adoption and consumption potential be attained. In turn, attaining adoption potential is a prerequisite for nutritional impact.

Finally, the seed source results offer a few simple messages that are relevant for delivery and promotion/marketing strategies. While use of major hybrids is positively associated with membership in the scheduled castes, these farmers are not any less likely to obtain their seed from commercial sources. In the competitive seed industry of Maharashtra, where commercial agrodealers are by far the dominant means of acquiring pearl millet seed, only literacy (positively), income (negatively), and distance to seed supplier (negatively) explain whether a farmer obtains seed from commercial or social networks. Caste has no apparent influence in and of itself, nor is income an impediment to commercial seed purchase. Thus, to reinforce a breeding strategy that addresses consumption traits, delivery approaches focused on commercial marketing make sense in order to reach not only advantaged but also disadvantaged farmers. In developing high-iron varieties, one strategy for HarvestPlus would be to partner with seed companies that supply currently popular hybrids.

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ANNEX

Annex 1. List of All Pearl Millet Varieties Officially Released ın India (notified varieties)

Group name\crop name\variety name	Year of release	Notification date	Notification number	State of release
NANDI-61(MH-1548)		8/31/2010	S.O. 2137(E)	
NANDI-65(MH-1549)		8/31/2010	S.O. 2137(E)	
RHRBH-9808		8/31/2010	S.O. 2137(E)	
BAIF BAJRA-1		1/2010	S.O. 211(E)	
HHB-216 (MH-1421)		1/29/2010	S.O. 211(E)	
HHB-223 (MH-1468)		1/29/2010	S.O. 211(E)	
NANDI-64 (MSH-199) (NMH-69)		1/29/2010	S.O. 211(E)	
NAPIER GRASS CULTURE-21		1/29/2010	S.O. 211(E)	
NAPIER GRASS CULTURE-4		1/29/2010	S.O. 211(E)	
AVIKA BAJRA CHARI (AVKS-19)		8/27/2009	2187(E)	
JKBH-676 (MH-1299)		8/27/2009	S.O. 2187(E)	
RHB-154 (MH-1340)		8/27/2009	S.O. 2187(E)	
GK 1051 (MH 1385)		2/11/2009	S.O. 454(E)	Central
PHB-2168		5/8/2008	S.O. 1108(E)	Central
GHB-744 (MH-1272)		1/2008	S.O. 72(E)	Central
GHB-757 (MH1328)		1/10/2008	S.O. 72(E)	Central
GHB732 (MH-1307)		1/10/2008	S.O. 72(E)	Central
HHB-197 (MH-1302)		1/10/2008	S.O. 72(E)	Central
NANDI-52 (MH-1078) (NMH-45)		1/10/2008	S.O. 72(E)	Central
PROAGRO 9555 (MSH 16) (PB 727)		1/10/2008	S.O. 72(E)	Central
B-2301 (MH 1192) (B 2301)		10/5/2007	1703(E)	Central
NANDI-62(MH 1274) (NMH 68)		10/5/2007	1703(E)	Central
FBC 16		7/20/2007	1178(E)	Central
JBV-4 (MP-403)		7/20/2007	1178(E)	Central
PCB 164		7/20/2007	1178(E)	Central
GHB-719 (MH-1236)		2/6/2007	122(E)	Central
HHB-67 IMPROVED		11/5/2005	1566(E)	Central
HHB-67 IMPROVED (843 -22-B)		11/5/2005	1566(E)	Central
HHB-67 IMPROVED (H-77-833-2R)		11/5/2005	1566(E)	Central
HHB-67 IMPROVED (MS 843 A-22 A)		11/5/2005	1566(E)	Central
COCU-9		8/25/2005	1177(E)	Central
GHB-538 (MH-1049)		8/25/2005	1177(E)	Central
PARBHANI SAMPADA (PPC-6)		2/2/2005	122(E)	Central
HHB-117		5/31/2004	642(E)	Central
GHB-577		2/4/2004	161(E)	Central
GHB-526 (MSH-105)		3/12/2003	283(E)	Central
GHB-558 (MH-946)		2/12/2003	283(E)	Central
HHB-146 (MH-960)		2/12/2003	283(E)	
HC-20 (HMP 9102)	2001	9/4/2002	937(E)	

AIMP-92901 (SAMRUDHI-MP-282)	2000	11/15/2001	1134(E)	Maharashtra
COH (CU) 8	2001	11/15/2001	1134(E)	Tamilnadu
NANDI-35 (MH-889)		11/15/2001	1134(E)	Central
PROAGRO 9445 (MH 882, PB 112)		11/15/2001	1134(E)	Central
PUSA COMPOSITE-383 (MP-383)		11/15/2001	1134(E)	Central
RHB-121 (MH-892)		11/15/2001	1134(E)	Central
7688 (MH 795)		2/2/2001	92(E)	Central
GICKV-96752 (MP363)		2/2/2001	92(E)	Central
PROAGRO 9443 (MH-846)		2/2/2001	92(E)	Central
RHB-90 (MH-463)	1999	9/13/2000	821(E)	Rajasthan
HARYANA COMPOSITE-10	1999	4/3/2000	340(E)	
HHB-94	1999	4/3/2000	340(E)	
MLBH-505 (MH-793, MLBH-44)		10/26/1999	1050(E)	Central
NANDI-32 (MH-773)		10/26/1999	1050(E)	Central
PUSA COMPOSITE-334 (MP-334)		10/26/1999	1050(E)	Central
PUSA-415 (MP-739)		10/26/1999	1050(E)	Central
JBV-2 (GKKV-93191)		6/8/1999	425(E)	Central
NANDI-8 (MH-741)		6/8/1999	425(E)	Central
PUSA-605 (MH-564)		6/8/1999	425(E)	Central
7686 (MH-643, XM-631)		5/15/1998	401(E)	Central
GK-1004 (MH-662)		5/15/1998	401(E)	Central
PAC-903 (ICI-903, MH-552)		5/15/1998	401(E)	Central
PROAGRO NO-1 (FMH-3)		05/15/1998	401(E)	Central
ANANTA (APS-1)	1996	9/17/1997	662(E)	Andhra Pradesh
GHB-316 (MH-670)		9/17/1997	662(E)	Central
JKBH-26 (MH-595)		9/17/1997	662(E)	Central
X-7	1997	9/9/1997	647(E)	
CZ-1C-923 (MP-258)		5/1/1997	360(E)	Central
GHB-183	1993	5/1/1997	360(E)	
MLBH-285 (MH-518)		5/1/1997	360(E)	Central
NANDI-30 (MH-515)		5/1/1997	360(E)	Central
PUSA BAJRA-266 (MP-266)		5/1/1997	360(E)	Central
RBH-30	1991	5/1/1997	360(E)	Rajasthan
SABURI (MH-483, RHRBH-8924)	1994	5/1/1997	360(E)	
X-6 (MH-140)	1992	5/1/1997	360(E)	Tamilnadu
MLBH-267 (MH-425)		1/1/1996	1(E)	Central
PUSA-444 (MH-444)		5/4/1995	408(E)	Central
RHB-58 (MH-320)		5/4/1995	408(E)	Central
AHB-251 (MH-258, DEOGIR)		9/2/1994	636(E)	Central
GUJARAT HYBRID BAJRA-15		9/2/1994	636(E)	Central
GUJRAT HYBRID BAJRA-235		9/2/1994	636(E)	Central
RHRBH-8609 (SHRADDHA)		9/2/1994	636(E)	Central
CO-8		8/17/1993	615(E)	Central
HHB-68 (MH-306)		8/17/1993	615(E)	Central

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

AIMP-92901 (SAMRUDHI-MP-282)	2000	11/15/2001	1134(E)	Maharashtra
COH (CU) 8	2001	11/15/2001	1134(E)	Tamilnadu
NANDI-35 (MH-889)		11/15/2001	1134(E)	Central
PROAGRO 9445 (MH 882, PB 112)		11/15/2001	1134(E)	Central
PUSA COMPOSITE-383 (MP-383)		11/15/2001	1134(E)	Central
RHB-121 (MH-892)		11/15/2001	1134(E)	Central
7688 (MH 795)		2/2/2001	92(E)	Central
GICKV-96752 (MP363)		2/2/2001	92(E)	Central
PROAGRO 9443 (MH-846)		2/2/2001	92(E)	Central
RHB-90 (MH-463)	1999	9/13/2000	821(E)	Rajasthan
HARYANA COMPOSITE-10	1999	4/3/2000	340(E)	
HHB-94	1999	4/3/2000	340(E)	
MLBH-505 (MH-793, MLBH-44)		10/26/1999	1050(E)	Central
NANDI-32 (MH-773)		10/26/1999	1050(E)	Central
PUSA COMPOSITE-334 (MP-334)		10/26/1999	1050(E)	Central
PUSA-415 (MP-739)		10/26/1999	1050(E)	Central
JBV-2 (GKKV-93191)		6/8/1999	425(E)	Central
NANDI-8 (MH-741)		6/8/1999	425(E)	Central
PUSA-605 (MH-564)		6/8/1999	425(E)	Central
7686 (MH-643, XM-631)		5/15/1998	401(E)	Central
GK-1004 (MH-662)		5/15/1998	401(E)	Central
PAC-903 (ICI-903, MH-552)		5/15/1998	401(E)	Central
PROAGRO NO-1 (FMH-3)		05/15/1998	401(E)	Central
ANANTA (APS-1)	1996	9/17/1997	662(E)	Andhra Pradesh
GHB-316 (MH-670)		9/17/1997	662(E)	Central
JKBH-26 (MH-595)		9/17/1997	662(E)	Central
X-7	1997	9/9/1997	647(E)	
CZ-1C-923 (MP-258)		5/1/1997	360(E)	Central
GHB-183	1993	5/1/1997	360(E)	
MLBH-285 (MH-518)		5/1/1997	360(E)	Central
NANDI-30 (MH-515)		5/1/1997	360(E)	Central
PUSA BAJRA-266 (MP-266)		5/1/1997	360(E)	Central
RBH-30	1991	5/1/1997	360(E)	Rajasthan
SABURI (MH-483, RHRBH-8924)	1994	5/1/1997	360(E)	
X-6 (MH-140)	1992	5/1/1997	360(E)	Tamilnadu
MLBH-267 (MH-425)		1/1/1996	1(E)	Central
PUSA-444 (MH-444)		5/4/1995	408(E)	Central
RHB-58 (MH-320)		5/4/1995	408(E)	Central
AHB-251 (MH-258, DEOGIR)		9/2/1994	636(E)	Central
GUJARAT HYBRID BAJRA-15		9/2/1994	636(E)	Central
GUJRAT HYBRID BAJRA-235		9/2/1994	636(E)	Central
RHRBH-8609 (SHRADDHA)		9/2/1994	636(E)	Central
CO-8		8/17/1993	615(E)	Central
HHB-68 (MH-306)		8/17/1993	615(E)	Central

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

AIMP-92901 (SAMRUDHI-MP-282)	2000	11/15/2001	1134(E)	Maharashtra
COH (CU) 8	2001	11/15/2001	1134(E)	Tamilnadu
NANDI-35 (MH-889)		11/15/2001	1134(E)	Central
PROAGRO 9445 (MH 882, PB 112)		11/15/2001	1134(E)	Central
PUSA COMPOSITE-383 (MP-383)		11/15/2001	1134(E)	Central
RHB-121 (MH-892)		11/15/2001	1134(E)	Central
7688 (MH 795)		2/2/2001	92(E)	Central
GICKV-96752 (MP363)		2/2/2001	92(E)	Central
PROAGRO 9443 (MH-846)		2/2/2001	92(E)	Central
RHB-90 (MH-463)	1999	9/13/2000	821(E)	Rajasthan
HARYANA COMPOSITE-10	1999	4/3/2000	340(E)	
HHB-94	1999	4/3/2000	340(E)	
MLBH-505 (MH-793, MLBH-44)		10/26/1999	1050(E)	Central
NANDI-32 (MH-773)		10/26/1999	1050(E)	Central
PUSA COMPOSITE-334 (MP-334)		10/26/1999	1050(E)	Central
PUSA-415 (MP-739)		10/26/1999	1050(E)	Central
JBV-2 (GKKV-93191)		6/8/1999	425(E)	Central
NANDI-8 (MH-741)		6/8/1999	425(E)	Central
PUSA-605 (MH-564)		6/8/1999	425(E)	Central
7686 (MH-643, XM-631)		5/15/1998	401(E)	Central
GK-1004 (MH-662)		5/15/1998	401(E)	Central
PAC-903 (ICI-903, MH-552)		5/15/1998	401(E)	Central
PROAGRO NO-1 (FMH-3)		05/15/1998	401(E)	Central
ANANTA (APS-1)	1996	9/17/1997	662(E)	Andhra Pradesh
GHB-316 (MH-670)		9/17/1997	662(E)	Central
JKBH-26 (MH-595)		9/17/1997	662(E)	Central
X-7	1997	9/9/1997	647(E)	
CZ-1C-923 (MP-258)		5/1/1997	360(E)	Central
GHB-183	1993	5/1/1997	360(E)	
MLBH-285 (MH-518)		5/1/1997	360(E)	Central
NANDI-30 (MH-515)		5/1/1997	360(E)	Central
PUSA BAJRA-266 (MP-266)		5/1/1997	360(E)	Central
RBH-30	1991	5/1/1997	360(E)	Rajasthan
SABURI (MH-483, RHRBH-8924)	1994	5/1/1997	360(E)	
X-6 (MH-140)	1992	5/1/1997	360(E)	Tamilnadu
MLBH-267 (MH-425)		1/1/1996	1(E)	Central
PUSA-444 (MH-444)		5/4/1995	408(E)	Central
RHB-58 (MH-320)		5/4/1995	408(E)	Central
AHB-251 (MH-258, DEOGIR)		9/2/1994	636(E)	Central
GUJARAT HYBRID BAJRA-15		9/2/1994	636(E)	Central
GUJRAT HYBRID BAJRA-235		9/2/1994	636(E)	Central
RHRBH-8609 (SHRADDHA)		9/2/1994	636(E)	Central
CO-8		8/17/1993	615(E)	Central
HHB-68 (MH-306)		8/17/1993	615(E)	Central

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

ICMH-356		8/17/1993	615(E)	Central
ICMV-221		8/17/1993	615(E)	Central
MH-322 (PUSA-332)		08/17/1993	615(E)	Central
RAJ-171		11/4/1992	814(E)	Central
EKNATH-301 (MH-333/NBH-9)		11/22/1991	793(E)	Central
MLBH-104 (MH-351)		11/22/1991	793(E)	Central
ICMV-155		8/16/1991	527(E)	Central
VBH-4		8/17/1990	639(E)	Central
HHB-67		5/15/1990	386(E)	Central
HHB-67 (843-22-B)		5/15/1990	386(E)	
HHB-67 (H-77-833-2-202 R)		5/15/1990	386(E)	
HHB-67 (MS 843 A-22 A)		5/15/1990	386(E)	
RAJ BAJRA CHARI-2		5/15/1990	386(E)	Central
MBH-136		4/13/1989	280(E)	Central
PUSA SAFED		4/13/1989	280(E)	Central
HHB-60		12/1/1988	1135(E)	Central
MP-124 (ICTP-8203)		12/1/1988	1135(E)	Central
ICMH-423		1/1/1988	10(E)	Central
PUSA-23		9/18/1987	834(E)	Central
GHB-30		3/6/1987	165(E)	Central
HHB-50		3/6/1987	165(E)	Central
HHB-50 H-90/4-5		3/6/1987	165(E)	
HHB-50 MS-81A		3/6/1987	165(E)	
HHB-50 MS-81B		3/6/1987	165(E)	
MBH-130		3/6/1987	165(E)	Central
CO-7		11/26/1986	867(E)	Central
MH-179 (ICM-451)		05/1986	258(E)	Central
MH-180 (ICMH-501)		5/14/1986	258(E)	Central
MH-182		5/14/1986	258(E)	Central
PCB-15	1985	5/14/1986	258(E)	Punjab
SANGAM (RHR-1)		5/14/1986	258(E)	Central
ICMS-7703	1985	11/18/1985	832(E)	Central
PHB-47	1983	11/18/1985	832(E)	Punjab
RCB-2	1984	11/18/1985	832(E)	Rajasthan
HHB-45	1984	7/24/1985	540(E)	Haryana
GIANT BAJRA	1984	4/9/1985	295(E)	Maharashtra
HC-4	1985	4/9/1985	295(E)	Central
MBH-118	1985	4/9/1985	295(E)	Central
X-5 (UCH-9)	1983	4/9/1985	295(E)	Tamilnadu
GHB-27	1981	7/8/1983	499(E)	Gujarat
CO.6	1976	1/3/1983	2(E)	Tamilnadu
MHB-110		1/3/1983	2(E)	Central
PUSA-46	1982	1/3/1983	2(E)	Central
PUSA-763 (BD-763)	1982	5/29/1982	371(E)	Central

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

ICMH-356		8/17/1993	615(E)	Central
ICMV-221		8/17/1993	615(E)	Central
MH-322 (PUSA-332)		08/17/1993	615(E)	Central
RAJ-171		11/4/1992	814(E)	Central
EKNATH-301 (MH-333/NBH-9)		11/22/1991	793(E)	Central
MLBH-104 (MH-351)		11/22/1991	793(E)	Central
ICMV-155		8/16/1991	527(E)	Central
VBH-4		8/17/1990	639(E)	Central
HHB-67		5/15/1990	386(E)	Central
HHB-67 (843-22-B)		5/15/1990	386(E)	
HHB-67 (H-77-833-2-202 R)		5/15/1990	386(E)	
HHB-67 (MS 843 A-22 A)		5/15/1990	386(E)	
RAJ BAJRA CHARI-2		5/15/1990	386(E)	Central
MBH-136		4/13/1989	280(E)	Central
PUSA SAFED		4/13/1989	280(E)	Central
HHB-60		12/1/1988	1135(E)	Central
MP-124 (ICTP-8203)		12/1/1988	1135(E)	Central
ICMH-423		1/1/1988	10(E)	Central
PUSA-23		9/18/1987	834(E)	Central
GHB-30		3/6/1987	165(E)	Central
HHB-50		3/6/1987	165(E)	Central
HHB-50 H-90/4-5		3/6/1987	165(E)	
HHB-50 MS-81A		3/6/1987	165(E)	
HHB-50 MS-81B		3/6/1987	165(E)	
MBH-130		3/6/1987	165(E)	Central
CO-7		11/26/1986	867(E)	Central
MH-179 (ICM-451)		05/1986	258(E)	Central
MH-180 (ICMH-501)		5/14/1986	258(E)	Central
MH-182		5/14/1986	258(E)	Central
PCB-15	1985	5/14/1986	258(E)	Punjab
SANGAM (RHR-1)		5/14/1986	258(E)	Central
ICMS-7703	1985	11/18/1985	832(E)	Central
PHB-47	1983	11/18/1985	832(E)	Punjab
RCB-2	1984	11/18/1985	832(E)	Rajasthan
HHB-45	1984	7/24/1985	540(E)	Haryana
GIANT BAJRA	1984	4/9/1985	295(E)	Maharashtra
HC-4	1985	4/9/1985	295(E)	Central
MBH-118	1985	4/9/1985	295(E)	Central
X-5 (UCH-9)	1983	4/9/1985	295(E)	Tamilnadu
GHB-27	1981	7/8/1983	499(E)	Gujarat
CO.6	1976	1/3/1983	2(E)	Tamilnadu
MHB-110		1/3/1983	2(E)	Central
PUSA-46	1982	1/3/1983	2(E)	Central
PUSA-763 (BD-763)	1982	5/29/1982	371(E)	Central

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

WCC-75	1982	5/29/1982	371(E)	Central
KBH-1	1980	1/14/1982	19(E)	Tamilnadu
PSB-8	1980	1/14/1982	19(E)	Punjab
X-4	1980	1/14/1982	19(E)	Tamilnadu
BD-111	1979	02/19/1980	470	Central
BJ-104		2/19/1980	470(E)	
BK-560		2/19/1980	470(E)	
BALAJI	1976	12/19/1978	13	Andhra Pradesh
BJ-104 (KM-1)	1979	12/19/1978	13	Central
BK-560 (KM-2)	1985	12/19/1978	13	Central
CJ-104	1975	12/19/1978	13	Gujarat
HS-1 (SYNTHETIC)	1978	12/19/1978	13	Haryana
MAINUPUR		12/19/1978	13	Uttar Pradesh
MBH-110	1982	12/19/1978	13	Central
MSH-104		12/19/1978	13	Central
NAGARJUNA	1976	12/19/1978	13	Andhra Pradesh
RAJKO		12/19/1978	13	Central
VISAKHA	1976	12/19/1978	13	Andhra Pradesh
CS-3541		2/2/1976	786	Central
CSV-3 (370)		2/2/1976	786	Central
NHB-5	1975	2/2/1976	786	Central
PHB-10	1975	2/2/1976	786	Central
PHB-14	1975	2/2/1976	786	Central
VIJAY	1972	8/21/1975	440(E)	Andhra Pradesh
VIJAYA		6/21/1975	440	Central
A-1/3	1942	6/30/1973	361(E)	Punjab
S-530	1965	6/30/1973	361(E)	Punjab
T-55	1952	6/30/1973	361(E)	Punjab
HYBRID BAJRA NO.1	1965	9/24/1969	4045	Central
HYBRID BAJRA NO.2	1966	9/24/1969	4045	Central
HYBRID BAJRA NO.3	1968	9/24/1969	4045	Central
HYBRID BAJRA NO.4	1968	9/24/1969	4045	Central
AVSARI	1934			Maharashtra
BABAPURI				Gujarat
BD-111 D-111R				
BD-111 MS-5141A				
BD-111 MS-5141B				
BD-763 D-763R				
BD-763 MS-8141A				
BJ-104 J-104R				
BJ-104 MS-5141A				
BJ-104 MS-5141B				
BK-560 K-560-230R				
BK-560 MS-5141A				

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

WCC-75	1982	5/29/1982	371(E)	Central
KBH-1	1980	1/14/1982	19(E)	Tamilnadu
PSB-8	1980	1/14/1982	19(E)	Punjab
X-4	1980	1/14/1982	19(E)	Tamilnadu
BD-111	1979	02/19/1980	470	Central
BJ-104		2/19/1980	470(E)	
BK-560		2/19/1980	470(E)	
BALAJI	1976	12/19/1978	13	Andhra Pradesh
BJ-104 (KM-1)	1979	12/19/1978	13	Central
BK-560 (KM-2)	1985	12/19/1978	13	Central
CJ-104	1975	12/19/1978	13	Gujarat
HS-1 (SYNTHETIC)	1978	12/19/1978	13	Haryana
MAINUPUR		12/19/1978	13	Uttar Pradesh
MBH-110	1982	12/19/1978	13	Central
MSH-104		12/19/1978	13	Central
NAGARJUNA	1976	12/19/1978	13	Andhra Pradesh
RAJKO		12/19/1978	13	Central
VISAKHA	1976	12/19/1978	13	Andhra Pradesh
CS-3541		2/2/1976	786	Central
CSV-3 (370)		2/2/1976	786	Central
NHB-5	1975	2/2/1976	786	Central
PHB-10	1975	2/2/1976	786	Central
PHB-14	1975	2/2/1976	786	Central
VIJAY	1972	8/21/1975	440(E)	Andhra Pradesh
VIJAYA		6/21/1975	440	Central
A-1/3	1942	6/30/1973	361(E)	Punjab
S-530	1965	6/30/1973	361(E)	Punjab
T-55	1952	6/30/1973	361(E)	Punjab
HYBRID BAJRA NO.1	1965	9/24/1969	4045	Central
HYBRID BAJRA NO.2	1966	9/24/1969	4045	Central
HYBRID BAJRA NO.3	1968	9/24/1969	4045	Central
HYBRID BAJRA NO.4	1968	9/24/1969	4045	Central
AVSARI	1934			Maharashtra
BABAPURI				Gujarat
BD-111 D-111R				
BD-111 MS-5141A				
BD-111 MS-5141B				
BD-763 D-763R				
BD-763 MS-8141A				
BJ-104 J-104R				
BJ-104 MS-5141A				
BJ-104 MS-5141B				
BK-560 K-560-230R				
BK-560 MS-5141A				

Annex 1 (cont'd). List of All Pearl Millet Varieties Officially Released In India (notified varieties)

BK-560 MS-5141B		
CJ-104 J-104R		
CJ-104 MS-5040A		
CJ-104 MS-5040B		
G-61/21		Punjab
GHB-1399	1975	Gujarat
GHB-32 (MH-29)		Gujarat
GHB-732 (MH 1307) A-LINE		
GHB-732 (MH 1307) B-LINE		
GHB-732 (MH 1307) R-LINE		
HB-5	1972	Central
HHB-197 (MH 1302) A-LINE		
HHB-197 (MH 1302) B-LINE		
HHB-197 (MH 1302) R-LINE		
HHB-60 H-77/833-2R		
HHB-60 MS-81A		
HHB-60 MS-81B		
HHB-67 H-77/833-2R		
HHB-67 MS-843A		
HHB-67 MS-843B		
HHB-68 H-77/833-2R		
HHB-68 MS-842A		
HHB-68 MS-842B		
HHB-94 G-73-107R		
HHB-94 MS-89111A		
HHB-94 MS-89111B		
JARKHARANA	1950	Jharkand
K-2	1977	Tamilnadu
K-3	1977	Tamilnadu
KOPARGAON LOCAL	1934	Maharashtra
MH-143 ICMP-423R		
MH-143 MS-841A		
MH-143 MS-841B		
MH-169 (PUSA-23) D-23R		
MH-169 (PUSA-23) MS-841A		
MH-169 (PUSA-23) MS-841B		
MH-180 ICMP-501		
MH-180 MS-834A		
MH-180 MS-834B		
MH-182 MS-732A		
MH-182 MS-732B		
MH-182 PNBMR		
MH-320 (RHB) MS-81A		
MH-320 (RHB) MS-81B		

MH-320 (RHB) RHB-20K86R		
MP 406 (CZP 9802)		Central
MS-179 ICP-451R		
MS-179 MS-81A		
MS-179 MS-81B		
N-28-15-1	1934	Maharashtra
N-28-15-2		Gujarat
N.207	1938	Gujarat
NEW VIJAY	1975	Andhra Pradesh
NHB-3	1975	Gujarat
PUSA MOTI	1969	Central
PUSA-322 (MH-322) MS-841A		
PUSA-322 (MH-322) MS-841B		
PUSA-322 (MH-322) PPMI-301-13R		
PUSA-444 (MH-444) PPMI-301-13		
PUSA-605 MS-841A		
PUSA-605 MS-841B		
PUSA-605 PPMI-69R		
RHR-1 (MP-31)	1985	Central
RSJ	1956	Rajasthan
RSK	1956	Rajasthan
SHARDHA RHR-BH-138R		
SHARDHA RHR-BH-1A		
SHARDHA RHR-BH-1B		

Source: List of notified varieties as of March 31, 2011.

Annex 2. List of Traits Included in the HarvestPlus Survey, by Category

Production traits
- Earliness in maturity
- Grain yield
- Grain mass
- Panicle length
- Resistance to downy mildew
- Resistance to smut
- Resistance to rust
- Labor input requirement
- Irrigation/water requirement
- Chemical fertilizer requirement
- Draught tolerance
- Compost/manure requirement
Marketing and processing traits
- Cost (labor, energy etc.) of processing
- Price it fetches
- Reliability of buyers/demand
- Ease of processing
- Ease of transportation
Consumption traits—unleavened bread (roti) quality
- Taste
- Color
- Overnight/long time keeping
- Texture
- Appearance
- Aroma
Fodder, fuel, and construction
- Dry fodder yield
- Green fodder yield
- Building material quality
- Fuel quality
Consumption traits—beer/alcoholic beverage quality
- Taste
- Color
- Overnight/long time keeping
- Texture
- Appearance
- Aroma

Source: " Farmers' Choice of Pearl Millet (Bajra) Varieties in Maharashtra"—India survey questionnaire.

Annex 3. Results of Test For Selection Effect (Heckman probit)

	Coef.	Std. Err.	P>z	Coef.	Std. Err.	P>z
Grow major hybrid				*Grow minor cultivar*		
Caste	0.182	0.114	0.109	-0.152	0.118	0.196
Light soils share	-0.0524	0.119	0.661	0.2616	0.121	0.031
Black soils share	0.378	0.127	0.003	-0.034	0.123	0.783
Irrigated area	-0.046	0.020	0.020	0.036	0.017	0.039
Crop richness	0.0917	0.0554	0.098	-0.0136	0.0574	0.813
Livestock value	2.97E-07	1.54E-07	0.055	-2.73E-07	1.50E-07	0.068
Income per capita	-2.3E-05	6.66E-06	0.001	9.29E-06	4.68E-06	0.047
Land per capita	2.04E-01	1.39E-01	0.143	-1.06E-01	1.37E-01	0.441
Distance to seed supplier	2.69E-03	7.21E-03	0.709	2.06E-03	6.93E-03	0.766
Years growing	0.0282	0.0172	0.101	-0.1135	0.0484	0.019
Seed source	0.259	0.134	0.054	-0.313	0.141	0.027
Production	0.0374	0.433	0.931	-1.2303	0.461	0.008
Market/processing	0.276	0.397	0.488	0.201	0.440	0.648
Consumption	-0.674	0.453	0.137	0.919	0.544	0.091
Fodder, fuel, construction	-0.301	0.245	0.219	-0.087	0.276	0.751
Constant	-0.299	0.451	0.508	0.305	0.415	0.462
Grow pearl millet				*Grow pearl millet*		
Seed-to grain-price	-0.183	0.056261	0.001	-0.143	0.052258	0.006
Maize price	-0.002953	0.001372	0.031	-0.004653	0.001188	0.000
Population density	-748431	374346	0.046	-558763	370139	0.131
June rainfall	-0.01472	0.002305	0.000	-0.01194	0.002255	0.000
June drought severity	-0.770	0.463	0.096	-1.354	0.444	0.002
Maximum temperature	0.074	0.025	0.003	0.086	0.024	0.000
Elevation	0.001473	0.000527	0.005	0.001203	0.00049	0.014
Extent of irrigated land	3228	3291	0.327	3459	3137	0.270
Caste	-0.059	0.081	0.468	-0.079	0.081	0.327
Livestock value	1.15E-06	3.14E-07	0.000	9.46E-07	3.07E-07	0.002
Income per capita	0.2881	0.0983	0.003	0.2485	0.0982	0.011
Land per capita	-6E-06	3.55E-06	0.093	-3.9E-06	3.33E-06	0.239
Cotton area in block	0.005076	0.001438	0.000	0.005867	0.001304	0.000
Wald chi2(15) = 34.91. Log likelihood = –1352.881; p-value = 0.0025.				Wald chi2(15) = 34.08. Log likelihood = –1358.271; p-value = 0.0033.		

Major: LR test of indep. eqns. (rho = 0): chi2(1) = 3.15. Prob > chi2 = 0.0759.

Minor: LR test of indep. eqns. (rho = 0): chi2(1) = 11.05. Prob > chi2 = 0.0009.

Note: Coefficients reported here are not marginal effects.

Annex 4. Diagnostic Statistics For Recursive, Multivariate Probit Regression of Cultivar Choice and Information Source

	Coeff.	St. Err.	P>z
Rho, major-minor cultivar choice	-0.831	0.044	0.000
Rho, major cultivar—information source	-0.214	0.163	0.188
Rho, minor cultivar—information source	0.122	0.157	0.436
Information source as regressor in major cultivar choice	0.337	0.289	0.245
Information source as regressor in minor cultivar choice	-0.279	0.268	0.298
Rho, major-minor cultivar choice	0.401	0.380	0.292
Rho, major cultivar—seed source	0.021	0.173	0.905
Rho, minor cultivar—seed source	-0.574	0.147	0.000
Seed source as regressor in major cultivar choice	-0.006	0.203	0.976
Seed source as regressor in minor cultivar choice	-0.556	0.312	0.075

Source: Authors, based on HarvestPlus survey data