14 Analysing Scientific Strength and Varietal Generation, Adoption and Turnover in Peninsular India: The Case of Sorghum, Pearl Millet, Chickpea, Pigeonpea and Groundnut

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Introduction

The importance of crop genetic improvement research is demonstrated by the Green Revolution, which led to a rapid increase in food production in Asia. Those productivity gains contributed to a reduction in poverty directly through increased farm-household income and indirectly through a long-term decline in the prices of food grains, which account for a large share of poor consumers' expenditure. The success of crop genetic improvement research that led to the development of improved varieties of food crops is well documented (Evenson and Gollin, 2003; Bantilan *et al*., 2013).

Despite the rapid progress made in the past, poverty is still concentrated in South Asia with around 571 million or one-third of the world's poor, estimated at about 1.29 billion in 2011 (World Bank, 2012). Substantial scope exists for further reducing poverty through crop genetic improvement by increasing or stabilizing the yield of major food crops, particularly the dryland crops in South Asia. Modern varietal change by itself may not lift large numbers of people out of poverty, but greater dynamism in this area can go a long way toward moving poor people closer to that threshold. Moreover, modern varietal change can set the stage for the adoption of improved crop management practices, thereby making it possible for farmers to reduce the cost of production substantially.

Modern varietal change is addressed in this chapter for the five dryland crops in the mandate of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT): sorghum, pearl millet, chickpea, pigeonpea and groundnut. These results from peninsular India are complementary to those presented for sorghum, pearl millet, groundnut and pigeonpea in Chapter 7 and for chickpea in Chapter 12 for sub-Saharan Africa. Indeed, this work, like that described for rice in Chapter 13, was undertaken to establish a benchmark for evaluating the performance of genetic improvement in sub-Saharan Africa. However, our principal objective is to assess the effectiveness of crop improvement in India beginning in the mid-1960s when the first short-statured, high-yielding, early-maturing,

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photoperiod-insensitive sorghum and pearl millet hybrids were released for cultivation. Like the other earlier chapters in this volume, this assessment is carried out from the perspectives of inputs (scientific capacity of national programmes), outputs (released varieties and hybrids) and outcomes (aggregate and cultivar-specific adoption and the velocity of varietal turnover). In conducting this evaluation, we also update the findings for India in the 1998 Initiative for sorghum (Deb and Bantilan, 2003), pearl millet (Bantilan and Deb, 2003) and groundnut (Bantilan *et al.*, 2003).

One of the unique areas and strengths of this paper is the reporting and analysis of variety-specific levels of adoption in 2010 for each of the five crops in their major-producing states. These estimates were generated via structured expert elicitation. Their validation from the perspectives of community focus groups and household surveys is described later in the chapter after the main analytical section on the evaluation of scientific capacity, varietal output, varietal adoption and the velocity of varietal turnover. Substantive and methodological implications are discussed in a concluding section where the main results are summarized. Before results are presented and discussed, we briefly describe state coverage, institutional linkages and methods of data collection followed by crop-specific background information that provides context for the assessment of the key aspects of genetic improvement during the past 50 years.

Crops coverage, institutional linkages and methods of data collection

Coverage is at the all-India level for the databases on scientific capacity and varietal release. For the adoption database, five to six of the largest-producing states were selected for each crop based on 2007–2009 cropped area (Table 14.1). These states accounted for about 90% of cultivated area in each crop in India during 2007 to 2009.

Institutional linkages

ICRISAT has implemented this research on the performance of genetic improvement for its mandated crops in close collaboration with the Indian Council of Agricultural Research (ICAR), New Delhi, and crop-specific AICRPs (All-India Coordinated Research Projects). Stakeholders from the State Agricultural Universities (SAUs) were involved in the elicitation process. Representatives of ICRISAT's Hybrid Parents Research Consortium (HPRC) and scientists from other major private companies also contributed. Crop-specific research collaborations among major stakeholders are summarized in Table 14.2.

Methods of data collection

Information on cultivar releases was compiled from the Central Varietal Release Committee (CVRC) and State Varietal Release Committee (SVRC) and from compiled annual reports published by Seed Division, Government of India. Similarly, information was also validated with the crop-specific Directorates or respective AICRP publications and databases.

The ICRISAT research team officially took part in the crop-specific AICRP Annual Meetings and explained the research and collected feedback from each centre. All the scientists (around 150 per crop) who work on crop improvement in India attend these planning meetings that are organized annually crop

Table 14.1. States covered by crop.

Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
Maharashtra (54)	Rajasthan (56)	Madhya Pradesh (34)	Maharashtra (31)	Gujarat (30)
Karnataka (18)	Maharashtra (12)	Maharashtra (16)	Karnataka (18)	Andhra Pradesh (29)
Rajasthan (8)	Gujarat (9)	Rajasthan (16)	Andhra Pradesh (13)	Karnataka (14)
Madhya Pradesh (6)	Uttar Pradesh (9)	Uttar Pradesh (7)	Uttar Pradesh (10)	Tamil Nadu (8)
Andhra Pradesh (4)	Haryana (7)	Karnataka (9)	Madhya Pradesh (9)	Maharashtra (6)
–	–	Andhra Pradesh (8)	Gujarat (8)	Rajasthan (5)

Note: Percentage shares of area cultivated in 2007–2009 are given in parentheses.

Table 14.2. Institutional partnerships by crop.

Crop	NARS, including ICAR collaborations with:			Others
Sorghum	DSR, Hyderabad	AICSIP	SAUs	HPRC
Pearl millet	–	AICPMIP	SAUs	HPRC
Pigeonpea	IIPR, Kanpur	AICRP on Pigeonpea	SAUs	HPRC
Chickpea	IIPR, Kanpur	AICRP on Chickpea	SAUs	–
Groundnut	DGR, Junagadh	AICRP on Groundnut	SAUs	–

AICSIP: All-India Coordinated Sorghum Improvement Project; AICPMIP: All-India Coordinated Pearl Millet Improvement Project; DGR: Directorate of Groundnut Research, Junagadh, Gujarat; DSR: Directorate of Sorghum Research, Rajendranagar, Hyderabad; HPRC: Hybrid Parents Research Consortium, ICRISAT; ICAR: Indian Council of Agricultural Research; IIPR: Indian Institute of Pulse Research, Kanpur; NARS: National agricultural research system; SAUs: State Agricultural Universities.

by crop. Participation in these meetings was a cost-effective means to elicit information on the adoption of improved varieties for each state listed in Table 14.1.

ICRISAT conducted the expert elicitations on cultivar adoption in two rounds. Experts in the first round were canvassed from scientists of the respective AICRP centre located in that state. In general, each expert elicitation was attended by a minimum of four to five scientists based at that centre. The elicitation group was represented by scientists with diverse backgrounds (breeding, plant protection, agronomy, extension, seed science, etc.). On the basis of knowledge and skills in the group, estimates were elicited at either the regional or state level. After obtaining these preliminary adoption estimates from each state during the first round, a second round of elicitations was carried out with state/national-level experts in separate crop-wise workshops.

Additional secondary sources of information were also gathered from the State Department of Agriculture, State Seed Development Corporation (SSDC) and State Seed Certification Agency (SSCA) for the same period. A 'varietal identification protocol' was also developed for increasing the accuracy in the identification of improved cultivars at the farm-level. The protocol was extensively used in the conduct of the adoption validation surveys that are described later in this chapter.

The Five Dryland Crops

The five dryland crops are made up of two cereals, sorghum and pearl millet, two pulses, chickpea and pigeonpea, and one oilseed, groundnut. In India, they have several things in common. With the exception of chickpea, the dryland crops are planted at the onset of the south-west monsoon in the rainy or kharif season. (Rabi or post-rainy season sorghum and irrigated summer groundnut and pearl millet are other important seasonal cropping systems in regionally compact areas of peninsular India.) They share a low historical level of productivity that ranged from about 400 kg per hectare for pearl millet to 800 kg per hectare for pigeonpea at the start of the Green Revolution in the mid-1960s. With the exception of groundnut, where China has eclipsed India as the largest global producer, more area is sown to these crops in India than in any other country. Major diseases and insect pests influence productivity in these dryland crops. Most of the diseases can be managed with resistant cultivars in all five crops. In contrast to rice and wheat, none of these crops has received sustained direct policy protection since independence. Lastly, although irrigation has steadily expanded in peninsular India over the past 50 years, these crops have not benefited substantially from this expansion. Their rainfed character has not changed. Additionally, empirical evidence suggests that the quality of their production environment has declined with regional shifts in production over time. The trend towards a lower quality production environment may not apply equally to all five crops but it is a recurring theme in this chapter.

Sorghum

In the past, sorghum was even more important in India than it is now. Shortly after independence in the early 1950s, sorghum ranked as the second most extensively grown cereal in the country after rice. Nowadays, more area is sown to wheat, pearl millet and maize than to sorghum.

Sorghum is grown in both rainy (2.6 million hectares) and post-rainy (3.5 million hectares) seasons. An estimated 2 million ha is also sown to forage sorghum cultivated in the summer season. Over half of rainy-season sorghum is cultivated as an intercrop with pulses and oilseeds. In contrast, 90% of the post-rainy sorghum is produced as a sole crop on black soil on residual moisture in fields that are fallowed during the monsoon from June to October.

Sorghum is produced for a variety of uses but it is mainly consumed as food, feed, fodder and forage. The end uses have evolved over time. Food and fodder have decreased in importance. Feed and forage have increased in importance. With increasing urbanization, the demand for sorghum as a food grain has sharply declined. The widespread replacement of bullocks with tractors has also reduced the demand for sorghum residue, stalks and leaves, as stover.

The rising demand for sorghum for animal feed and forage has not compensated for the declining demand for sorghum as a food grain and as stover. As a result, sorghum area has declined since it peaked at 18 million hectares in the late 1960s. Its seasonal composition in relative importance has also changed over time. In the 1960s, rainy-season sorghum accounted for about two-thirds of cultivated area. Today, the share of rainy-season sorghum in total harvested area has shrunk to about 40%. The post-rainy season is the dominant source of area and production.

Production reached its maximum in the late 1980s and early 1990s when it approached 13 million tonnes. Since their generation and release in the early to mid-1960s with help from the Rockefeller Foundation and the CSH (Coordinated Sorghum Hybrids) public sector, and later the private sector, improved cultivars have fuelled positive productivity gains in the rainy season in India. For example, in the dominant producing state of Maharashtra, yield growth was 1.87% between 1970 and 2009. Thus, productivity gains from rainy-season production partially offset the declining trend in area. However, productivity growth was overwhelmed by the strong decline in area that has accelerated since the early 1990s. Productivity growth in the post-rainy season has been negligible during the past 50 years because technological change, for all intents and purposes, has not taken place, i.e. adoption of improved cultivars and intensification of management practices is limited.

Pearl millet

In India, pearl millet is the third most important cereal after rice and wheat. It is predominantly grown as a grain crop but is also valued for its stover and fodder. Pearl millet production in India was characterized by subsistence cultivation during the 1970s with a small marketable surplus. But in recent years, its uses are expanding from food to animal feed, potable alcohol, processed food, etc.

In spite of systematic pearl millet research in India since the 1960s, area under cultivation witnessed a continuous reduction from 12.23 to 9.61 million hectares between 1966 and 2010. The reduction was attributed to frequent outbreaks of downy mildew disease, changing food consumption habits, lower remuneration in pearl millet cultivation compared to other commercial crops and weak demand for grain, resulting in farmers moved away from pearl millet cultivation to other commercial crops. Despite the decline in acreage, production has more than doubled from 4.5 to 10.36 million tonnes in the same period. This was made possible through the adoption of short-duration hybrids and their response to fertilizer. Sustained growth of production is a typical Green Revolution success story in the atypical circumstances of rainfed agriculture in the arid and dry semi-arid tropics (Pray and Nagarajan, 2009).

Aridity in pearl millet production is also increasing as the crop has shifted to dryer environments. In districts where pearl millet was produced in the mid-1960s, mean annual average rainfall was about 900 mm (Walker, 2009). In districts where the crop was cultivated in 2008, mean annual average rainfall was only 600 mm. This shift to aridity was especially noted in Rajasthan where pearl millet is traditionally cultivated. It has lost ground to other crops in the wetter eastern and central part of the state and has maintained its share of area in arid Western Rajasthan.

Chickpea

India is the largest chickpea producer as well as consumer in the world. India mainly produces small-seeded desi chickpea although bold-seeded kabuli chickpea, mainly grown in the Middle East, is gradually gaining in popularity. The demand for chickpea is strong and it is characterized by an array of end uses.

Chickpea was one of the main casualties of the expansion of wheat area during the Green Revolution in the 1960s and 1970. Wheat and chickpea compete for land in the post-rainy season in North India. Since the mid-1960s, chickpea area in North and North-eastern India has declined steadily from 4.5 million hectares to around 0.5 million hectares. Conversely, chickpea has increased by over 3.0 million hectares in the central and southern states.

In 2010 and 2011, the area under chickpea was estimated to be around 9.18 million hectares and harvested produce about 8.22 million tonnes with estimated yield approaching 900 kg per hectare. More than 70% of chickpea is grown in the post-rainy season as a rainfed crop; the remaining area is cultivated under irrigated conditions. During the last five decades (1960–2010), chickpea area has registered a slightly negative annual growth rate of –0.4% (acreage declined from 9.28 to 9.18 million hectares), whereas production has increased from 6.25 to 8.22 million tonnes with an average annual growth rate of 0.42%. Despite the decline in acreage, production has increased and this increase is attributed to the introduction of high-yielding and disease-resistant varieties.

Pigeonpea

Pigeonpea is a very plastic crop from the perspective of the length of its growing season. It is characterized by four common durations: early or extra early of about 110–120 days, medium duration of about 180 days, long duration of 240 to 270 days, and it also grows as a perennial. Long duration pigeonpea in North India, especially in Uttar Pradesh, was common in the 1950s and 1960s but, with the advent of the Green Revolution in rice and wheat, long-duration pigeonpea was replaced by more profitable sequential cropping systems. Nowadays, medium-duration pigeonpea is the dominant maturity group; it is usually produced as an intercrop with cotton and other cash crops in Central and South India. Pigeonpea is also cultivated on field bunds or as a backyard crop where it does not receive much if any purchased inputs.

Aside from its plasticity, pigeonpea is technologically interesting because it is one of the first grain legumes to benefit from marked productivity gains from in-breeding and subsequent hybridization. After many years of research, commercial hybrids from ICRISAT parental materials have been released and are now available in India.

In contrast to its diverse and novel traits in production, pigeonpea, unlike chickpea, does not have diverse end uses; it is consumed in India almost entirely as dhal.

During 2010–2011, pigeonpea was cultivated on about 4.42 million hectares with 2.89 million tonnes of production, representing 16% of the national pulse acreage and 15% of production. National average pigeonpea yield is hovering in the range of 650–800 kg per hectare; this has remained more or less stagnant from 1960 to 2010 despite extensive research efforts. This sluggish growth in productivity can be attributed to slow uptake of improved cultivars and production technologies and to the shift in crop area from more favourable to marginal environments.

Groundnut

In terms of consumption, groundnut is the fifth most important oilseed in India after oil palm, soybean, rapeseed and mustard. Groundnut is produced in arid and semi-arid regions characterized by low and erratic rainfall, poor irrigation, frequent droughts and sandy soils. It is largely grown in India in the kharif season under rainfed conditions. Only about 20% of the total groundnut area in India is irrigated, mainly in the summer season. Groundnut is cultivated on 5.85 million hectares, which is about one-fifth of the total area under oilseeds. Groundnut seed production contributes around 25% of total oilseed production, which was 8.26 million tonnes during 2010–2011. Between 1981 and 2010, groundnut production registered a positive but meager annual growth rate of 0.1%. However, the rate of growth was higher (2.2%) during

1981–1995, but decelerated by –0.3% afterwards when the level of protection against Malaysian palm oil was diminished and imports increased. With declining profitability, the sown area began trending downwards in the early 1990s. Declining area has been accompanied by markedly increasing variability in production and yield over time. Since the early 1990s, national average yield has fluctuated between 700 and 1450 kg per hectare.

Key Aspects of the Performance of Food-Crop Genetic Improvement

Scientific strength in dryland crop improvement programmes, modern varietal output, and perceived adoption of improved varieties and hybrids are the main themes described in this section.

Scientific capacity in dryland crop improvement

Scientific capacity for improvement of the five dryland crops focuses on the public sector. The private sector is very active in breeding pearl millet and to a lesser extent in sorghum hybrids. Information is presented on the number of full-time equivalent (FTE) scientists in companies developing pearl millet hybrids but comparable data were not available for sorghum where the public sector is still the dominant institutional player in agricultural research. Private-sector participation in grain legume research is limited in India.

Multiple institutes contribute to public-sector research on dryland crops in India. The human resources data presented here refer to those institutes listed in the second and third column of Table 14.2. The descriptive analysis in this subsection is conducted at the all-India level.

Comparing FTE scientists across crops by discipline

Parity across the five dryland crops in research investment and in varietal output is one of the principal findings of this chapter. Four of the five crops are characterized by a level of total capacity in the very narrow range of 84–86 FTE scientists (Table 14.3). Among the crops in this interval – sorghum, chickpea, pigeonpea and groundnut – the total number of scientists does differ and ranges from 103 in sorghum to 134 in chickpea. But lower FTE scientist conversion rates in the two pulse crops result in the same level of FTE scientists as that found in sorghum and groundnut. The mean conversion rate across the five crops was 72%. The 28% difference is devoted to other purposes such as working on other crops, teaching, guiding students, conducting training programmes and extension.

Pearl millet is the outlier in Table 14.3 with a total FTE complement of slightly over 50 scientists. Historically, sorghum has been a significantly stronger crop improvement programme than pearl millet; therefore, a relatively low estimate for pearl millet improvement was expected. Moreover, private-sector investment in pearl millet research is equivalent to 28 FTE scientists. Therefore, the total investment for pearl millet approaches the amount of scientific input in public-sector sorghum improvement.

Another indication of parity is the degree to which the five crop improvement programmes are concentrated in four core disciplines: plant breeding, agronomy, pathology and entomology. Collectively, these disciplines account for about 83% of scientific resources, ranging from 77% in sorghum to 91% in pearl millet. The other 16 disciplinary categories in Table 14.3 are only sparsely represented in these public-sector crop improvement programmes. With only a 4% share, physiology leads this group of minor disciplines that support dryland crop improvement.

Sorghum exhibits the most diversification in its disciplinary portfolio, featuring an investment in social science, postharvest research, biochemistry, genetic resources and genetics that exceeds that of the other programmes. Implicitly, this higher level of diversification partially responds to demand constraints that have led to falling production, a trend unique to sorghum among the five dryland crops.

Although similar in their disciplinary composition, it is easy to identify crop-wise differences attributed largely to biotic constraints in investments in pathology and entomology. Insect pests figure prominently as yield reducers in the dryland crops except in pearl millet, which is associated with less investment in entomology than the other four crops. In pigeonpea, pod borer consistently causes more economic damage than any single insect pest in these dryland crops. In sorghum, infestations of shoot flies, stem borers

Table 14.3. Full-time equivalent (FTE) scientists by discipline by crop for 2010.

Discipline	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
Agricultural engineering	0	0	0.6	0.6	0
Agronomy	10.7	9.55	13.8	13.8	12
Biotechnology	2.5	0	1.5	1.6	1.6
Biochemistry	2.5	0.75	0.3	0.3	0
Computer application	0.8	0	0.3	0.3	0
Ecobotany	0.8	0.85	0	0	0
Entomology	13.9	2.55	10.8	14.1	12
Genetic resources	1.6	0	0.3	0.8	0
Genetics/cyotgenetics	2.5	0	0	0	1.6
Microbiology	0	0	4.6	3.8	1.6
Nematology	0	0	0.6	1.5	0.8
Pathology	10.7	8.55	17.2	12.4	11.2
Physiology	3.3	1.45	2.8	2.1	6.4
Plant breeding	30.3	25.7	29.2	32	32
Postharvest technology	0.8	0	0	0	0
Seed technology	0.8	0	0	0	1.6
Social science	3.3	0	0	0	0.8
Soil science	0	0	0.3	0.3	1.6
Statistics	0	0.75	1.4	0.3	0.8
Others	0	0.65	1.5	1.5	0
Total FTE	84.5	50.8	85.2	85.4	84
Total scientists	103	76	134	130	105
Proportion FTE/total	0.82	0.67	0.64	0.66	0.80

and head bugs can result in substantial production losses. Higher allocations to entomology in both pigeonpea and sorghum are attributed to the importance of these pests. Likewise, more investment in pathology is associated with the incidence and importance of well-identified diseases that can induce catastrophic losses in production. Chickpea periodically suffers from *Ascochyta* blight, whereas ergot and downy mildew are common diseases in pearl millet.

Comparing total FTE scientists in national and international programmes by discipline

A total of about 390 FTE scientists work in the five public-sector crop improvement programmes either at the national or state level. In 2010, 44 FTE scientists worked on the five dryland crops in ICRISAT at its Headquarters in Patancheru, India. A comparison of the relative emphasis in disciplinary allocation points to the complementarities in scientific capacity between national and international agencies, even in a very large country like India (Table 14.4). National crop improvement institutes focus on applied and adaptive research; international commodity centres allocate more resources to upstream research that is less likely to be associated with a payoff in the immediate to near future. In accordance with this conventional wisdom of institutional comparative advantage, about one FTE ICRISAT scientist in six works in biotechnology, mainly in areas related to molecular biology and marker-assisted selection. A comparable ratio for national programmes is less than one scientist in 50. Proportionally, plant breeding, social science, statistics and genetic resources command significantly more resources at ICRISAT than in the Indian National Improvement Programmes on dryland crops. ICRISAT allocated no resources to agronomy in 2010–2011. This is in line with the thinking that crop management entails a high level of location specificity that is best addressed by state and national crop improvement programmes.

Since its establishment in the early 1970s, ICRISAT has allocated some programmatic resources to biotechnology-related areas but the moderately high level of investment mirrored in Table 14.4 is relatively recent, reflecting an emphasis that gained momentum in the 2000s. Earlier – in the 1970s, 1980s and on into the

Table 14.4. Comparing relative scientific capacity in Indian national and state programmes in ICRISAT for dryland crops by discipline in 2010.

	NARS	ICRISAT	Difference
Discipline	Share of FTE scientists (%)		
Biotechnology	1.7	15.9	14.2
Plant breeding	39.3	46.6	7.3
Social science	1.0	5.7	4.7
Statistics	0.9	4.5	3.7
Genetic resources	0.6	3.4	2.8
Physiology	4.0	5.7	1.7
Genetics/cytogenetics	1.0	2.3	1.3
Postharvest technology	0.2	1.1	0.9
Seed technology	0.6	1.1	0.6
Microbiology	2.4	2.3	–0.1
Agricultural engineering	0.3	0.0	–0.3
Computer application	0.3	0.0	–0.3
Soil science	0.5	0.0	–0.5
Ecobotany	0.5	0.0	–0.5
Nematology	0.7	0.0	–0.7
Others	1.0	0.0	–1.0
Biochemistry	1.0	0.0	–1.0
Entomology	13.0	5.7	–7.3
Pathology	15.5	5.7	–9.8
Agronomy	15.6	0.0	–15.6
Total	389.9	44.0	0.0

1990s – ICRISAT's research resource allocation resembled more closely that of the Indian national programmes than it does now because pathology and entomology, and to a lesser extent physiology, figured prominently in the pattern of investment in those early decades. An increasing emphasis on biotechnology was accompanied by de-emphasizing pathology, entomology and physiology as total resources contracted in the mid-1990s to early 2000s. In contrast, it is likely that the disciplinary allocation of the Indian national programmes has stayed relatively constant over time.

Comparing the educational level of FTE scientists across crops

About nine of every ten FTE scientists working on dryland genetic improvement have PhDs. This ratio is maintained across the five crops (Table 14.5). Unlike those in sub-Saharan Africa, all scientists in the Indian programmes have graduate training at least to the level of an MSc. BSc holders are viewed strictly as non-scientific, research-support staff.

With the exception of pearl millet, the numbers in Table 14.5 are synonymous with a scientific strength of more than 75 PhDs per crop. This level of educational expertise is a far cry from the very low numbers, which were quantified and discussed in Chapter 7, of PhD scientists working on sorghum, pearl millet and groundnut in West Africa.

Comparing research intensities across crops

Research intensities are compared via production and value of production critieria in Table 14.6. By either criterion, high research intensities were estimated for sorghum vis-à-vis pearl millet and for pigeonpea relative to chickpea and groundnut. As the results in Table 14.6 make abundantly clear, these differences in research intensities are driven primarily by disparities in production and value of production. They have little to do with direct investment in scientific human resources that is, for all intents and purposes, equal for four of the five crops.

Table 14.5. Educational level (%) of FTE scientists by crop.

Educational level	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
PhD	93	89	91	93	92
MSc	7	11	9	7	8

Table 14.6. Estimated research intensities by crop from 2008–2009 to 2010–2011.

Estimated research intensity	Sorghum	Pearl millet	Chickpea	Pigeonpea	Groundnut
Production (FTE scientists per million tonnes)	11.6	4.6	12.6	32.8	12.1
Value of production (FTE scientists per US$100 million)[a]	8.2	3.6	3.0	7.4	3.6

[a]Prices per tonne used in calculation value of production were US$142 per tonne of sorghum, 126 for pearl millet, 416 for chickpea, 441 for pigeonpea and 337 for groundnut. These are in 2004–2006 prices and were taken from the FAOSTAT value of crop production for India.

Sorghum's high research intensity compares favourably with maize in East and Southern Africa where the private sector is very active in agricultural research (Chapter 11, this volume). Although the complex Indian Agricultural Research System is often assessed as reasonably efficient, the level of investment from the perspective of production often places India in the lower echelon of developing countries ranking behind China and developing countries in general (Pal and Byerlee, 2003). The estimate of 11.6 FTE scientists per million tonnes of production therefore seems high and atypical of the Indian context for the production of a cereal as extensively grown as sorghum. The high research intensity is partially attributed to the steeply declining area of rainy-season sorghum that has resulted in a downward trend in sorghum production. Although kharif sorghum has benefited substantially from technological change, soybean has replaced it and several other dryland crops during the monsoon season, especially in rainfall-assured zones.

Assuming that the level of FTE scientists has not changed that much over time – and this appears to be a reasonable supposition – past research intensities for sorghum were significantly lower than they are now. For example, for levels of production prevailing in the late 1960s, the estimated research intensity drops to 6.5, roughly half the estimate in Table 14.6.

In analysing the data on scientific capacity, two anomalies stand out. Both point to slowness on the part of national agricultural research in India to adjust to substantial regional shifts in the production of pulse crops. Over time, Uttar Pradesh has lost about three-quarters of its pigeonpea growing area and has dropped to fourth in state-wise importance. Yet, from the perspective of research resource allocation in terms of scientists that can be assigned to specific states, about 45% of FTE scientists are located in Uttar Pradesh. The fact that nodal research agencies are still located in Uttar Pradesh is a major explanation of why research resource allocation is incongruent with shares of production. Pigeonpea cropping systems differ markedly, however, between the North where the late-maturing pigeonpea is losing ground and Central and South India where medium-duration pigeonpea reigns as the dominant pigeonpea cropping system.

The same remarks about congruence of resource allocation and production shares apply to chickpea. Of a total of 24 research centres, only three serve the south zone, which has been one of the primary beneficiaries in the shift of production area from the north. The south zone is extensive and also includes large parts of East India.

Varietal Output

Parity in scientific capacity also applies to varietal output. The incidence and pattern of released varieties over time is broadly similar across the five dryland crops (Fig. 14.1). A total of 1013 varieties were released from the beginning of the 20th century to 2010. The number of releases ranges from a low of 159 in pigeonpea to a high of 253 in sorghum. Pearl millet, chickpea and groundnut are characterized by total releases in the narrow interval of 190 to 210. Each improvement programme also displayed a remarkable record of stability of releases over time. Since the 1970s, each programme has released at least 20 cultivars by decade until 2010. Most programmes have released at least one variety every year between 1971 and 2010. The sorghum programme epitomizes this pattern of consistency in releases over time. Between 1961 and 2010, there were only three years when the All-India Sorghum Improvement Programme did not release a variety at the central or state level.

The five improvement programmes also share a history of varietal release that predates independence in 1947. Some of the old cultivars released prior to 1971 are still widely grown today. TMV 2, released by Tamil Nadu in 1940, is the leading groundnut variety in Karnataka and Andhra Pradesh. The sorghum variety M35-1, selected from a local landrace in the late 1930s, is the dominant variety in post-rainy season production. Later releases in the 1960s also still account for large chunks of cultivated area. For example, TMV 7 released in 1968 is the most widely grown variety of groundnut in Tamil Nadu. Across the five crops, releases before 1971 make up about 10% of varietal output. Even though early genetic improvement research started in the early 1920s in chickpea, systematic efforts date only from the late 1950s. Significant momentum in releases can be observed from the 1970s.

The incidence of releases over time varies somewhat by crop. By decade, chickpea, groundnut and pearl millet display a pattern of increasing releases over time (Fig. 14.1). Sorghum adheres to the same increasing tendency with the exception of the last decade when releases declined from their peaks in the 1980s and 1990s. The declining area and production of rainy-season sorghum probably has had a dampening effect on the incidence of releases, especially in states where post-rainy season production is negligible.

In Fig. 14.1, central-level releases (centre releases) represent the difference between total and state-level releases. The importance of state-level versus central-level releases ranges from high in sorghum to very low in pearl millet. This

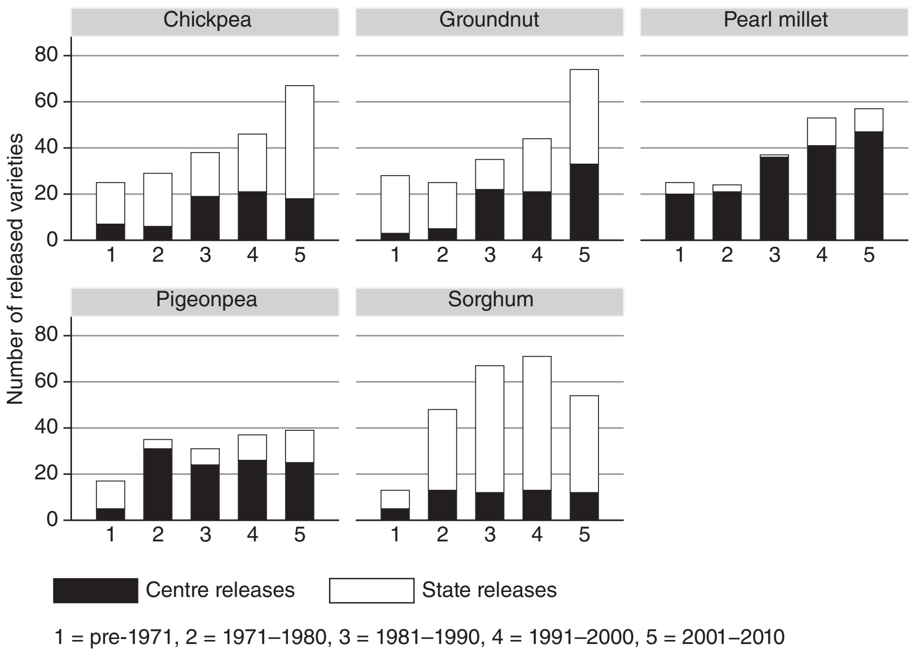

Fig. 14.1. Total and state-released varieties in India from 1971 to 2010 by crop.

variation reflects differences in the level of decentralization between these two crop improvement programmes. Pearl millet research centres in the All-India Coordinated Programme are heavily concentrated in western India in the states of Rajasthan, Haryana and Gujarat, with a sprinkling of locations in the western region of the southern states. Sorghum research centres are distributed in a dispersed pattern across more states with several states having more than one centre to cover different agroclimatic zones. A decentralized distribution of research stations is suited to more subregional adaptation and subsequent state-wise varietal output tailored to varying conditions in each agroclimatic zone. Centre-level releases from the pearl millet improvement programme should be more readily applicable to most of the subregions and zones located in Western India.

Centre- and state-level releases are also qualitatively different in the sorghum improvement programme. Centre releases are about evenly split between new hybrids and improved varieties. Most state releases are improved varieties. This distinction suggests that hybrids are more widely adapted than improved varieties or that they are more difficult to develop to meet release standards. In contrast to crop improvement programmes in sub-Saharan Africa, most improved varieties are the product of crossing parental lines. Only a small minority are selections from landrace materials or elite varieties selected by institutions outside of India.

Parental lines also feature quite prominently in the list of notified materials for release in sorghum and pearl millet. For example, parental lines constitute about 20% of sorghum releases. Their relative importance has not changed appreciably over time. Neither has the share of hybrids in total releases at the state or national level. The absence of trends in relative importance in parental lines and hybrids in total releases is puzzling because the overwhelming majority of modern cultivars in farmers' fields are hybrids. For sorghum, part of the puzzle is explained by the increasing emphasis given to the post-rainy season where most releases are improved varieties.

About 20% of the total of more than 1000 releases was related to ICRISAT materials (Fig. 14.2). From a small beginning of one sorghum and one chickpea variety, related to ICRISAT and released in the 1970s, the total number of ICRISAT-related releases increased to 197 by 2010. Broadly speaking, ICRISAT-related releases

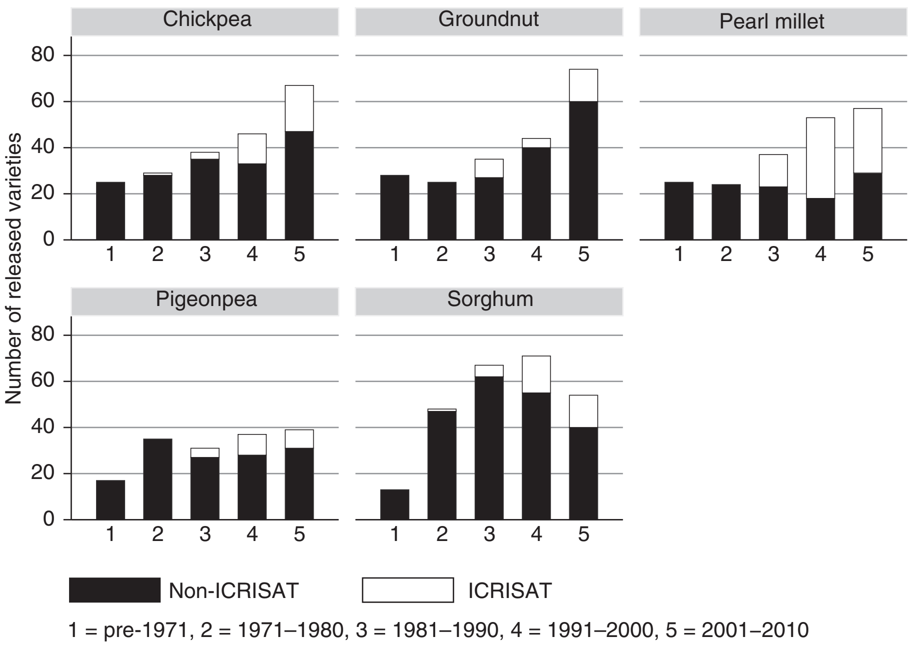

Fig. 14.2. Total- and ICRISAT-released varieties in India from 1971 to 2010 by crop.

have been increasing in all five dryland crops over time. ICRISAT has contributed to at least 20 released cultivars in each of the five crops. Four of the contributions refer to the first pigeonpea hybrids available for commercial production. Most of the recent releases in pearl millet and sorghum are parental lines. The sorghum data in Fig. 14.2 include 14 new cultivars marketed (as truthfully labelled seed) by private seed companies but they have not yet been officially released.

In terms of varietal output, ICRISAT's contribution has been more pronounced in pearl millet than in any of its other mandated commodities. Nearly 40% of ICRISAT-related releases are in this coarse cereal. Historically, pearl millet was one of ICRISAT's stronger crop improvement programmes and, arguably, pearl millet was one of India's national programmes that benefited the most from collaboration with ICRISAT. Differential strengths and weaknesses established a solid basis for sustained collaboration that has nurtured and stimulated varietal output during the past three decades.

Adoption and Varietal Turnover

The level of adoption of improved cultivars and the velocity of varietal turnover are discussed in this section, which is organized by dryland crop. Much of that discussion focuses on the leading improved varieties and hybrids in each of the main-producing states in 2010. Before cultivar-specific estimates are presented, we briefly survey the level of aggregate adoption.

Aggregate adoption of modern varieties

Consistent with the other chapters in this volume, the adoption estimates in Table 14.7 and in the rest of this section refer to modern varieties released since 1970. Estimates of the current popularity of earlier releases were also generated in the expert opinion panels and that information is referred to where it is appropriate.

Some of the adoption estimates in this section are taken mainly from the first-round expert elicitations. These scientist estimates provided a sharper definition of cultivar-specific adoption than later estimates that incorporated more information from various sources. Methodologically, these estimates are also broadly equivalent to the expert elicitation that was carried out for the majority of crop and country observations in sub-Saharan Africa. Survey estimates from ICRISAT's TRIVSA Project for rainy-season sorghum in Maharashtra and chickpea in Andhra Pradesh and from IFPRI's HarvestPlus comprehensive inquiry on pearl millet in Maharashtra and in Rajasthan are used for these four crop-by-state observations. Time-series information from the Government of India on the uptake of sorghum and pearl millet high-yielding varieties (HYVs) complements the expert and survey estimates.

Across the five dryland crops, the simple area-weighted adoption level of modern varieties is 65% in Table 14.7. Between 1970 and 2010, this estimated level is equivalent to an average increase of 1.45% per annum. After 40 years of sustained varietal output in all five crops, there are large tracts where farmers are planting third- and fourth-generation improved varieties. There are also widespread areas, usually of low production potential, where the majority of producers still cultivate desi (local) varieties.

The crops in Table 14.7 can be split into two groups: (i) sorghum and groundnut with moderate adoption levels slightly over 50%; and (ii) pearl millet, chickpea and pigeonpea with appreciably higher adoption performance ranging from 67% to 79%. Relatively low rates of adoption in the former group are attributed to specific states or seasonal production environments where the uptake of improved varieties markedly lags behind other producing-areas in India. Post-rainy season sorghum production in western Maharashtra and Andhra Pradesh and in northern Karnataka epitomizes an environment of low production potential that is almost always associated with terminal drought stress. For groundnut, the problem of lagging adoption finds its greatest expression in the southern state of Karnataka where about 90% of cultivated area is planted to TMV-2, a bold-seeded variety released in 1940 that is widely adaptable to South Indian conditions. The difficulty in replacing well-established, old commercial groundnut varieties is a recurring theme that was discussed in Chapter 7 in the context of West Africa.

Table 14.7. Adoption (%) of modern cultivars across major-producing states and seasons by crop in 2010.

State	Sorghum[a]	Pearl millet	Chickpea	Pigeonpea	Groundnut
Andhra Pradesh	–	–	95	70	40
Rainy (kharif) season	40	–	–	–	–
Post-rainy (rabi) season	40	–	–	–	–
Gujarat	–	95	–	–	–
Rainy (kharif) season	–	–	–	–	90
Irrigated summer season	–	–	–	–	100
Haryana	–	85	–	–	–
Karnataka	–	–	100	60	10
Rainy (kharif) season	90	–	–	–	–
Post-rainy (rabi) season	20	–	–	–	–
Madhya Pradesh	77	–	84	65	–
Maharashtra	–	80	70	70	85
Rainy (kharif) season	100	–	–	–	–
Post-rainy (rabi) season	20	–	–	–	–
Rajasthan	35	52	68	–	64
Tamil Nadu	–	–	–	70	60
Uttar Pradesh	–	30	65	85	–
All-India area weighted adoption (%)	53	67	79	68	54

'–' denotes minor-producing states and seasons that are not covered in the study. [a]Aggregate adoption rate for rainy season was 82%, whereas it was 21% in post-rainy season during 2010.

Sorghum's rather modest aggregate adoption outcome in Table 14.7 is exacerbated by the sharply declining trend in area of rainy-season sorghum that was characterized by 80% level of adoption in 2010. In the late 1960s, rainy-season area accounted for about two-thirds of sorghum hectareage. If that relative importance had been maintained and realized in 2010 instead of a 40% area share, the modern variety (MV) adoption level in Table 14.7 would have exceeded 60%.

Sorghum

Since CSH-1 was released in 1965, graphing the GOI (Government of India) adoption estimates of modern sorghum hybrids and varieties in the rainy season shows a consistent linear pattern of uptake in the principal producing states. In general, adoption at the state level was slower for sorghum than for pearl millet, which is characterized by a typical s-shaped diffusion path. By 2008, Maharashtra, Karnataka, Madhya Pradesh and Tamil Nadu had exceeded or were approaching 80% adoption. Gujarat and Rajasthan lagged behind in MV adoption but both states have recently made substantial progress after very slow early adoption of hybrids. Andhra Pradesh is the only state where MV adoption declined in the past decade. With a steep decline of rainy-season growing area for sorghum in Andhra Pradesh, it is likely that farmers are substituting other crops for sorghum in small subregions where modern cultivars had previously been adopted and are continuing to plant sorghum in other subregions where traditional varieties were not replaced by modern cultivars.

Going from aggregate to variety-specific adoption, several findings stand out in Table 14.8. Adoption outcomes in the rainy season are markedly superior to those in the post-rainy season. In India, sorghum improvement research from all stakeholders during the past 50 years was skewed towards development of the rainy season crop. Very little emphasis was given to the post-rainy season characterized by substantially lower production potential. However, this trend has changed during the last decade. New improved cultivars are slowly replacing the dominant landraces.

Hybrids are more extensively grown than improved open-pollinated varieties (OPVs) in the rainy season. Indeed, in Maharashtra, the largest producing state, the survey results suggested that adoption of improved sorghum varieties was negligible in 2010. Although hybrids have been indicted for poor grain quality at harvest,

Table 14.8. Adoption of modern varieties in % of sorghum-growing area from expert opinion/survey data by major-producing state and season in India.

Andhra Pradesh		Maharashtra		Karnataka		Madhya Pradesh		Rajasthan	
Cultivar	Area (%)	Cultivar[a]	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)
Rainy (kharif) season									
SPV-462 (PSV-1) (1996)	20	MLSH-296 (1995)	22	CSH-14 (1992)	40	CSH-15 (1995)	13.9	CSV-15 (1996)	10.9
CSV-15 (1996)	2.5	CSH-9 (1978)	14	DSV-2 (1986)	18	CSH-18 (1999)	12.3	JKSH-592	4.4
CSV-20 (2009)	2.5	Pro-Agro 8340 (2001)	13	DSV-16 (2009)	15	Ajeet 997 (2002)	10.7	SSG-593 (1978)	2.9
NTJ-2 (1990)	2.5	Mahyco-51 (1982)	10	CSV-16 (1997)	15	Pradhan	10.0	CSV-10 (1986)	2.4
NTJ-4 (1992)	2.5	JK 22 (1999)	10	Others	2	CSH-14 (1992)	8.9	KJH-6363	2.2
Others	10	PAC 537 (2003)	4	All MVs	90	GK-4010	6.5	Others	12.2
All MVs	40	CSH-14 (1992)	3			CSH-16 (1997)	5.8	All MVs	35
		Nirmal-40 (1999)	3			Others	8.9		
		HARITA-540	2			All MVs	77		
		Ajeet-997 (2002)	2						
		MAHABEEJ-7-7A (2000)	1						
		Others hybrids	16						
		All MVs	100						
Post-rainy (rabi) season									
C-43 (1997)	10	Phule Vasudha (2008)	5	DSV-4 (1997)					
CSH-9 (1983)	10	Parbahanimoti (2005)	3	DSV-5 (1998)					
Others	20	RSLG-262 Maulee (2000)	3	CSV-216R (2000)					
All MVs	40	Phule Yashoda (2000)	3	CSV-22 (2007)					
		Phule Chitra (2008)	3	BJV-44 (2012)					
		CSV-18 (2005)	3						
		All MVs	20	All MVs	20				

[a]From ICRISAT survey data.

susceptibility to disease, especially grain mould, and low fodder production, relatively few improved sorghum varieties have found a home in many farmers' fields in rainy season production.

The low popularity of state-level releases in sorghum cultivation in the rainy season is a variation on this theme. With the exception of the DSV (Dharwar sorghum varieties) series selected at the University of Agricultural Sciences at Dharwad, few state-level varietal releases account for sizeable acreages in Table 14.8. Most adopted entries from the public sector in Table 14.8 come from the CS (coordinated sorghum) series that denotes national releases.

Private-sector hybrids are also well represented in Table 14.8, especially in Maharashtra where several larger seed companies have sited their main operations. The evidence in the next section also suggests that the adoption estimates for the private sector in Table 14.8 are likely to be underestimated and estimates for the public sector overstated because the expert panels consist primarily of public-sector scientists who are not current with demand for private-sector hybrids. Underestimation of private-sector participation seems to be more of a problem in Andhra Pradesh and Karnataka than in the other three states in Table 14.8. Additionally, farmers in Andhra Pradesh prefer to grow a local cultivar called 'yellow jowar' for its medicinal properties.

None of the adopted entries in Table 14.8 could be called a mega hybrid or variety, but there are several instances of spill-overs across states. CSH-14, CSH-15 and MLSH 296 (Dev Gen seeds) are adopted cultivars with wider adaptability across three or more states.

Hybrids are conspicuous for their absence in the rabi (post-rainy) season in Table 14.8. Few if any are recommended for the post-rainy season. In general, the estimates of adoption in the post-rainy season are higher than expected. A few of the listed adopted releases, such as Phule Vasudha, are derived from local landrace materials. Hence, they do not represent the level of qualitative change that one usually associates with modern varieties.

Much is known about varietal change and the velocity of varietal turnover in rainy season sorghum in India. Deb and Bantilan (2003) in the context of the 1998 Initiative present information on the composition of modern varieties over eight 5-year intervals from 1966 to 1999. During this timespan, adoption of MVs rose from about 1% of area in 1966, following the release of CSH-1 in 1964, to 69% in 1999. For the first two periods, only CSH-1 appears as an adopted modern cultivar in their graphical analysis. In 1976, CSH-5 joins CSH-1 in the group of modern cultivars. By 1981, CSH-1 is no longer in production because it is replaced in the diffusion of CSH-5 and a new entry, CSH-6. By 1986, CSH-9 has made its debut. CSH-5 and CSH-6 maintain their area shares from the previous period. In 1991, CSH-9 is the dominant MV accounting for slightly over 40% of area. It has replaced the earlier CSH hybrids. The private sector is now also contributing to varietal change via hybrids such as Mahyco-51 and JK 22. During the mid-to-late 1990s, public-sector hybrids CSH-13 and CSH-14 join the set of adopted cultivars together with an expanded group of private-sector hybrids. These new entrants largely replace CSH-9 and they penetrate into some regions still growing local varieties.

The transition in dominance from CSH-1 to CSH-5 to CSH-9 to a larger group of public and private sector hybrids each claiming a relatively small share of MV growing area is consistent with rapid varietal turnover, which illustrates the high productivity of the Indian sorghum improvement programme in generating genetic materials that farmers used in rainy season production. Weighted average age of modern varieties probably fell in the range of 5–10 years throughout much of this period. This low age estimate represents quite an accomplishment for a rainfed crop that does not rely on the breakdown of varietal disease resistance as an incentive for cultivar replacement.

In 2010, most of the entries in Table 14.8 were released in the 1990s. A few were released in the 1980s and the 2000s. Varietal age in 2010 was therefore probably around 15 years. Some but not many of the cultivars in Table 14.8 were already in farmers' fields by the late 1990s when Deb and Bantilan (2003) carried out their research.

Pearl millet

As with sorghum hybrid technologies and their commercialization that was pioneered by researchers at Texas A&M University and the United States Department of Agriculture (USDA) in the 1950s, India was quick to capitalize on the innovations made by Glenn Burton on the hybridization of pearl millet at the University of Georgia. Since their introduction in the mid-1960s, the uptake of pearl millet HYVs as a group has steadily climbed at the all-India level from 3% in 1966–1968 to 67% in 2006–2008. Gujarat, Haryana and Maharashtra have reached or are close to attaining full adoption of high-yielding hybrids and varieties (Table 14.9). Recently, arid Rajasthan has crossed the 50% threshold in the adoption of improved cultivars. Adoption lags behind in Uttar Pradesh. Diffusion of improved cultivars, especially hybrids, was very rapid in institutionally well-developed Gujarat. By 1977, 7 of every 10 hectares of pearl millet in Gujarat were planted to a hybrid. The higher production potential of irrigated summer cultivation was probably a favourable influence in accelerating the speed of adoption in Gujarat.

Recent large-scale national surveys are a basis for the estimates of specific MV adoption in Rajasthan and Maharashtra (Asare-Marfo *et al*., 2013). In Gujarat, national crop improvement scientists could not assign well-defined areas to specific improved cultivars. They could name five to six of the cultivars that they believed were widely adopted but they could not distinguish among them in terms of areal importance. In other words, experts did not have well-founded prior knowledge on the extent of cultivar coverage. In contrast, in Haryana and Uttar Pradesh, experts were able to rank varieties and assign relative areas to their cultivation. Many private-sector and public-sector hybrids are available for use by farmers in all five states. Both expert assessment and the survey results coincided with estimates from the GOI on aggregate adoption.

With the exception of ICTP-8203, all the cultivars listed in Table 14.9 are hybrids. Most of the cultivars are from the private sector. The public sector is, however, well represented with ICTP-8203, HHB-67 improved, HHB-197 and GHB 558. Most of the private-sector hybrids are derived from public-sector materials (Pray and Nagarajan, 2009). Pro Agro-9444 is an apt example of private-sector collaboration with the public sector, which in this case is ICRISAT. Indeed, numerous pearl millet hybrids commercially marketed in India have made intensive use of ICRISAT-developed male sterile lines and restorers. Without a liberalized seed policy featuring open access to basic research materials, the dominance of private-sector hybrids in varietal change in pearl millet would not have been realised to the depth and extent that it has (Pray and Nagarajan, 2009).

The results in Table 14.9 also confirm some cases of spill-over varieties, namely Pioneer 86M32, the leading hybrid in Rajasthan and the second leading modern cultivar in Maharashtra. In IFPRI's HarvestPlus survey conducted by the Institute of Development Studies in Jaipur, the 'other hybrids' entry for Rajasthan in Table 14.9 sum to a total of 55 distinct names, mostly hybrids that were identified from their seed packaging. The majority of these were adopted by only 1–3 farmers in the sample of 2144 households.

The very small production areas of pearl millet in Rajasthan are one of the most relevant findings from the HarvestPlus survey (Asare-Marfo *et al*., 2013). The average sown area per hybrid per household was only about 0.1 hectare. With an average cultivation area of 0.2 hectares, Eknath 301 was characterized by the largest growing area per household. In contrast, mean planted areas in Maharasthra were 5–10 times larger, but they still averaged less than 1 hectare. The fact that farmers who each plant such limited areas to the crop have access to such a wide array of pearl millet hybrids is impressive. Some of the diversity of hybrids in Rajasthan is attributed to different emphases in end uses among households and in varying subregional production conditions. Of the popular hybrids, heat-tolerant Pro Agro-9444 has penetrated into several of the arid districts of western Rajasthan. The Pioneer hybrids are mainly found in central and eastern Rajasthan. In general, the hybrids seem to be competitive with local varieties in all districts except Barmer and Jaisalmer, which represent the most arid production environment in the Rajasthan.

The velocity of varietal turnover of pearl millet hybrids in farmers' fields is rapid in India. The simple average varietal age across the five states in Table 14.8 is only 10 years. About 70% of pearl millet cropped area in modern varieties is occupied by cultivars released in the 2000s. The predominance of recent releases is especially marked in Gujarat and Haryana. Among the five ICRISAT mandate crops in India, the decadal-age profile of pearl millet adopted releases is consistent with the fastest rate of varietal change (Fig. 14.3).

Table 14.9. Adoption of modern varieties in % of pearl-millet-growing area from expert opinion/survey data by major-producing state in India.

Rajasthan[a]		Maharashtra[a]		Gujarat		Uttar Pradesh		Haryana state	
Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)
Pioneer 86M32 (2002)	7	Mahyco 204 (1995)	22	GHB 558/568 (2002)	95	Kaveri Super Boss (2007)	6	Pro-Agro-9444 (2004)	40
Pioneer 86M52	6	Pioneer 86M32 (2002)	14	Pioneer 86-M-86		ICTP-8203 (1988)	5	HHB-67 Improved (2005)	30
Bayer Proagro 9444 (2004)	6	Mahyco 2210 (2010)	9	MLBH 1012		Pioneer hybrids	4	HHB-197 (2008)	10
Eknath 301 (1991)	3	Nirmal 9	7	Sagarlaxmi (2008)		Others	15	Others	5
Nandi 42	3	Mahalaxmi 308 (1998)	7	Pro Agro-9444 (2004)		All MVs	30	All MVs	85
HHB-67 Improved (2005)	2	Mayhco 167	6	Ratan 666					
HHB-67 (1990)	2	Dhanya 7870	6	Others					
Guhu MH 169 (1987)	2	Mahabeej ICTP 8203 (1988)	4	All MVs	95				
Nandi 52 (2004)	2	Ganga Kaveri 1044 (1997)	3						
Other hybrids	19	Nirmal 40 (2002)	3						
All MVs	52	Other hybrids	18						
		All MVs	99						

[a]From survey data from Asare-Marfo *et al*., 2013.

A very competitive private sector coupled with the need for new sources of downy mildew resistance are two forces that drive the rapid replacement rate of improved pearl millet cultivars by farmers in India.

Chickpea

The state-wise cultivar specific adoption estimates elicited through expert consultations are summarized in Table 14.10 where the high MV

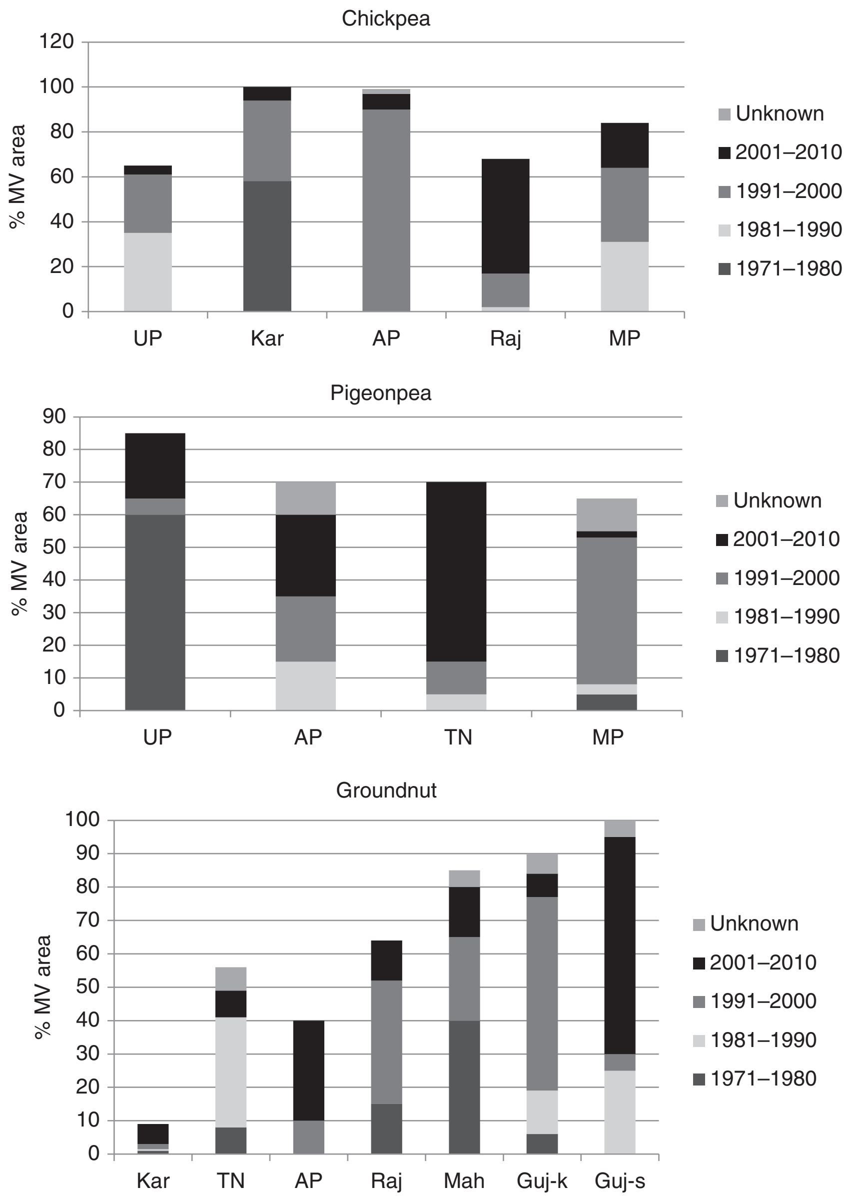

Fig. 14.3. Proportion of MV area by varietal age. AP, Andhra Pradesh; Guj, Gujarat; Har, Haryana; Kar, Karnataka; Mah, Maharastra; MP, Mahdra Pradesh; Raj, Rajahastan; TN, Tamil Nadu; UP, Uttar Pradesh; k, kharif (rainy season); r, rabi (post-rainy season); s, summer. Source: Expert elicitation surveys conducted from 2010 to 2012.

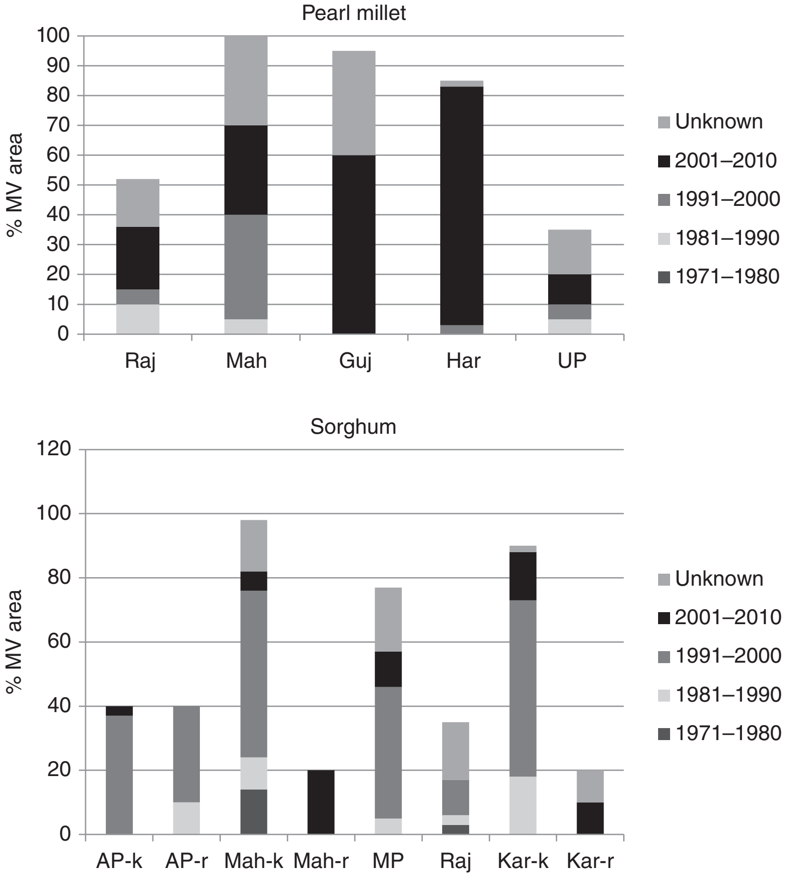

Fig. 14.3. Continued.

Table 14.10. Adoption of modern varieties in % of chickpea-growing area from expert opinion/survey data by major-producing state in India.

Andhra Pradesh[a]		Karnataka		Uttar Pradesh		Rajasthan		Madhya Pradesh	
Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)
JG-11 (1999)	84	Annegiri-1 (1978)	58	Avarodhi (1987)	25	RSG-888 (2002)	19	JG315 (1981)	27
		JG-11 (1999)	34						
Vihar (2002)	7	BGD 103 (2000)	4	KWR 108 (1996)	10	GNG-663 (1995)	15	JG130 (2002)	13
KAK-2 (1999)	6	MNK-1 (2010)	2	DCP 92-3 (1998)	7	RSG-973 (2004)	14	JG322 (1997)	13
Others	2	Others	2	Pusa 256 (1985)	5	RSG-963 (2005)	5	Vijay (1994)	7
All MVs	99	All MVs	100	Others	18	Others	15	Others	24
				All MVs	65	All MVs	68	All MVs	84

[a]From ICRISAT survey data.

adoption level in Andhra Pradesh stands out. The lion's share of cropped area is occupied by a single dominant cultivar, JG 11 (a desi type released in 1999). JG 11 was developed by ICRISAT and JNKVV University in Madhya Pradesh. Its strengths are high yield, early maturity, large attractive seed and resistance to fusarium wilt. It is replacing the old landrace cultivar Annigeri that dominated the southern states for several decades. The rapid adoption of JG 11, Vihar and KAK-2 has been described as the 'silent chickpea revolution' in Andhra Pradesh (see Bantilan *et al*., 2013, for more details).

Madhya Pradesh has also exhibited tremendous growth in area and production of chickpea during the last five decades. The bulk of the cropped area in the state is under desi types, whereas the remainder is sown to kabuli types. Nearly 95% of desi-type area is covered with improved cultivars. In contrast, only 5% of kabuli area was planted to improved cultivars.

The extent of adoption of MVs is lower in the other states. Annigeri, released in 1978, still accounts for more than half of the chickpea-growing area in Karnataka. Farmers' fields in Uttar Pradesh are also the home to some rather old released cultivars. Radhey, released in 1968, was believed by the expert panel to comprise 25% of chickpea plantings in Uttar Pradesh. If we ignore the cultivars released before the 1980s or exclude landrace varieties such as Annigeri, the aggregated weighted adoption level estimated at the all-India level was around 70%.

The proportion of chickpea cropped area under recent releases (2000–2010) is quite high in Rajasthan and Madhya Pradesh. Most of chickpea cropped area in Andhra Pradesh and Karnataka is also cultivated in recent releases because JG-11 was only 11 years old in 2010. The weighted average varietal age of 10–15 years indicates a reasonable speed for varietal turnover in a pulse crop.

Pigeonpea

Maharashtra, Karnataka, Andhra Pradesh, Uttar Pradesh, Madhya Pradesh and Gujarat are the major pigeonpea growing states, which together represent more than 90% of cropped area and production in the country. In the two leading producing states, expert estimates were not that informative. In Maharashtra, experts could estimate an aggregate level of adoption and name a few of what they believed to be the leading improved cultivars. In Karnataka, the information was coarser as the expert panel could only venture an estimate that improved varieties covered 60% of pigeonpea-growing area. More precision was obtained in the other states where released varieties appear with estimated areas in Table 14.11.

In compiling Table 14.11, we did not include one old long-duration variety, Bahar, released in

Table 14.11. Adoption of modern varieties in % of pigeonpea-growing area from expert opinion by major-producing state in India.

Uttar Pradesh		Tamil Nadu		Andhra Pradesh		Madhya Pradesh		Maharashtra	
Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)
MAL 13 (2003)	25	LRG 41 (2007)	29	LRG-41 (2007)	15	ICPL87119 (1993)	37	BSMR-786 (1996)	70
NDA 1 (1996)		CORG 9701 (2004)	26	LRG-30 (1982)	10	No. 148 (1975)	4	BSMR-853 (2001)	
NDA-2 (2008)		Co 6 (1993)	10	ICPL-85063 (1997)	10	JA4 (1991)	4	BSMR-708	
All MVs	25	TTB 7 (1987)	5	ICPL-87119 (1993)	10	Others	20	ICPL87119 (1993)	
		All MVs	70	PRG-158 (2007)	10	All MVs	65	Others	
				PRG-100				All MVs	70
				Others	15				
				All MVs	70				

1980. Bahar is believed to still account for 60% of growing area in Uttar Pradesh. In spite of the fuzziness of the information in Table 14.11, it is apparent that several varieties are characterized by a wide adaptability because they are popular in multiple states. For example, ICPL 87119 is the first medium-duration variety with combined resistance to two of the most devastating diseases of pigeonpea, sterility mosaic and *Fusarium* wilt.

Pigeonpea is characterized by a mix of younger and older releases in farmers' fields but most were notified between 1980 and 1999. About 30% of MV area is made up of varieties released since 2000. The velocity of varietal turnover for pigeonpea is somewhat slower than that for chickpea because varietal age averages 15–20 years for the varieties in Table 14.11 that were released after 1980.

Groundnut

Cultivar-specific adoption across major groundnut-growing states is described in Table 14.12. In spite of a solid and improving performance in varietal output, recent groundnut releases have not been widely adopted by farmers. In Gujarat (kharif), the single most dominant variety is GG 20 released in 1991. GG 2 (released in 1984) is the leading cultivar in summer cultivation in Gujarat. JL 24 (1978), TAG 24 (1991) and TMV 10 (1970) are the most widely grown cultivars in Maharashtra; they are 20–40 years old. TMV 2 (1940), which is not listed in Table 14.12 because of its age, still occupies nearly 90% of the cropped area in Karnataka and 60% in Andhra Pradesh. TMV 7 (1967, not listed in Table 14.12) and VRI 2 (1989) are dominant cultivars in Tamil Nadu. This research highlights the problem of the permanency of old vintages and the lack of significant dynamism in varietal replacement across states. If we ignore cultivars released before the 1980s, weighted aggregate adoption at the all-India level is estimated at 45%. Weighted average varietal age exceeds 25 years. Massive systematic efforts, coupled with both institutional and policy support, are required to enhance adoption. In general, the lack of varietal change in groundnut in peninsular India has a lot in common with the adoption experience for the crop in West Africa that was discussed in Chapter 7.

Unlike the other four crops, for groundnut relatively few ICRISAT-related varieties are listed in the cultivar-specific adoption table. ICGV 91114 in Andhra Pradesh is one of the exceptions. It is suited to the difficult production conditions in Anantapur in the dry semi-arid Rayalaseema region where groundnut is one of the few cash crops available to farmers in rainy-season production.

Validating Expert Opinion on Cultivar Adoption

Comparisons among different methods for generating adoption estimates are highlighted in this section. In particular, estimates from village focus-group meetings and representative household surveys are used to validate estimates from expert opinion. The recent and relevant experience of HarvestPlus in eliciting cultivar-specific adoption for pearl millet in Rajasthan and Maharashtra is also reviewed. Three crop- and state- specific adoption and diffusion contexts are presented to deepen understanding about any systematic differences that could emerge between expert elicitation and focus group and survey methods.

Adoption of rainy-season sorghum improved cultivars in Maharashtra

All five of the ICRISAT mandate crops are grown extensively in Maharashtra but the spatial distribution of production is concentrated in different agroclimatic zones by crop and growing season in this very large state in central India. Initially, ICRISAT tried to develop an integrated sampling framework to address adoption and diffusion of several crops in the state. But the uneven pattern of sown area of these five dryland crops in Maharashtra was not conducive to a multi-crop adoption survey. After several iterations and interactions with various sampling experts, ICRISAT decided to conduct an independent survey for two of the crop-by-state observations discussed in this exercise. ICRISAT selected rainy-season sorghum as the first case and conducted a state-level survey

Table 14.12. Adoption of modern varieties in % of groundnut-growing area from expert opinion by major-producing state and season in India.

Gujarat (rainy)		Maharashtra		Karnataka		Tamil Nadu		Andhra Pradesh		Gujarat (summer)		Rajasthan	
Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)	Cultivar	Area (%)
GG 20 (1991)	50	JL24 (1978)	30	GPBD-4 (2004)	4	VRI 2 (1989)	25	Kadiri 6 (2005)	18	GG 2 (1984)	25	GG-20 (1991)	30
GG 11 (1987)	7	TAG 24 (1991)	25	TAG-24 (1991)	2	VRI 3 (1990)	8	TAG 24 (1991)	10	TG 37A (2004)	35	M-13 (1978)	15
GAUG 10 (1973)	6	TMV- 10 (1970)	10	Others	3	JL 24 (1978)	8	ICGV 91114 (2007)	10	TPG 41 (2004)	30	TG 37A (2004)	5
GG 5 (1996)	8	SBXI/JL 11 (1965)	5	All MVs	9	Others	15	Others	2	Others	10	Others	14
GG 2 (1984)	6	JL501 (2009)	5			All MVs	56	All MVs	40	All MVs	100	All MVs	64
Others	13	Others	25										
All MVs	90	All MVs	100										

covering 13 districts, 20 tehsils (blocks equivalent to townships), 60 villages and 360 sample households.[1]

Maharashtra is the leading sorghum-producing state, contributing a share of 55% in the country's total acreage and 49% of production. The performance of kharif sorghum is dominated by hybrids, whereas the post-rainy (rabi) crop is still sown to varieties and landraces only. Nearly 45 state-specific sorghum improved cultivars have been developed and released during the past 50 years. The vast majority of these have been released for the rainy-season crop, which is at or approaching full adoption. The private sector dominates the sorghum seed market in the state. Nearly 70–75% of total kharif sorghum seed is marketed by private seed companies; the remaining 25% is supplied by the public sector. Because of the adoption of hybrids, more than 95% of farmers buy seed from the market every year. Therefore, the focus of this case study is not on the level of aggregate adoption but on the estimated level of cultivar-specific adoption in the context of widespread diffusion of hybrids developed and multiplied by the private sector and, to a lesser extent, by the public sector.

The comparative results in Table 14.13 suggest good agreement between the focus-group and survey estimates, but poor concurrence between the expert estimates and focus-group estimates and the expert and survey estimates. Because of the relatively large number of improved cultivars available in the market in the state and private-sector dominance in the crop, experts, who were public-sector crop improvement scientists, were unable to provide estimates for all cultivars during the two rounds of expert elicitation process. They provided estimates only for some of the public-bred cultivars that they were familiar with and were not that cognizant about the uptake of specific private-sector hybrids that account for 70% of cultivated area according to the village focus groups and household surveys. Indeed, the public-sector experts substantially overstated the importance of improved OPVs, which, for all intents and purposes, were not mentioned in the 60 village focus groups and the 360 household interviews.

Between the community focus-group interviews and the household surveys, noticeable differences were observed for only one or two cultivars. However, like expert opinion, the focus-group participants placed more importance on public-sector hybrids than the household- survey respondents. The focus-group participants estimated the adoption level of the four public-sector hybrids (indicated by superscript 'a' in

Table 14.13. Comparison of estimates of adoption of modern sorghum varieties by source.

Cultivar name	Expert elicitation (% area)	Community level (% area)	Household survey (% area)
CSH-9[a]	40	19.0	13.9
MLSH-296 (Dev Gen)	–	18.2	22.2
Mahyco-51	–	10.4	10.1
Mahabeej-7[a]	–	9.4	1.0
Pro Agro-8340	–	7.4	13.2
JK-22	–	6.0	9.8
CSH-14[a]	30	3.4	2.5
MSH-296[a]		3.4	0.0
NSH-18	–	2.3	0.0
PAC-537	–	2.3	3.8
Nirmal-40 (NJH-40)	–	0.0	3.4
HARITA-540	–	0.0	2.4
Ajeet-997 (Ajeet company)	–	0.0	2.3
Other hybrids	10	18.2	16.1
Other OPVs	20	0.0	0.0
Area under total MVs	100.0	100.0	99.7
Area under locals	0.0	0.0	0.3

[a]Public-bred cultivars.

Table 14.13) at about 35%; the estimate for the household survey was only 17.5%. One can speculate that because the public-sector hybrids were somewhat older than their private-sector counterparts, the focus-group participants, some of whom may not have planted rainy-season sorghum in the last cropping season or even in the very recent past, may not have been up to date with the newer private-sector hybrids.

In the context of widespread adoption and annual market purchase of rainy-season sorghum hybrids, the household survey seems to have provided the most reliable results of the three sources of information. Survey responses were not plagued by the endemic problem of unknown improved varieties, the names of which vary from place to place. Because of their commercial importance and the prevailing tendency of farmers to purchase hybrids each year, almost all interview responses could be readily identified and correctly tagged with a cultivar name.

Adoption of pearl millet improved cultivars in Maharashtra

Pearl millet is the second crop in Maharashtra state chosen for understanding the cultivar specific adoption estimates across three different methods (expert versus community versus household level). A similar sampling framework was adapted by using block-level data collected from Maharashtra Department of Agriculture. The primary household survey collected data from nine districts, 20 thesils, 60 villages and 360 sample households in the state. Similarly, 60 focus group meetings were also organized in each sample village.[2]

Maharashtra stands third in pearl millet production in India, with an 11% share both in area and in production. Pearl millet is mainly produced in western Mahrashtra where rainfall is low and erratic in the kharif season. Around 30 improved cultivars have been released and made available to farmers in the state during the past 50 years.

Hybrids have penetrated profusely into the markets and the fields of farmers in Maharashtra. Since the 1980s, private-sector seed companies have had a higher market share of the seed market in pearl millet than in sorghum. In general, an improved hybrid cultivar produces nearly 30–40% yield advantage than any OPV grown in that particular location; however, OPVs are still preferred by farmers that have shallow soils and low rainfall regimes.

Cultivar-specific adoption estimates by method are compared in Table 14.14. The estimates from community and household surveys (more or less) coincide; the mean differences between them are insignificant. In this context with an overwhelming dominance of private-sector materials, representative and well-conducted focus-group meetings may be competitive with household surveys in lowering research costs. It is important, however, that constituents of the focus groups are pearl millet producers from the most recent cropping season. Even in this case, it is likely that many minor hybrids will be missed in the interview process.

There is a large gap in information between expert elicitations and the survey results. Experts assessed the aggregate level of adoption at or near 80% but they could name only five leading pearl millet cultivars – Pioneer 86-M-32, Pioneer 86-M-64, Mahyco 2240, Mahyco 2210 and Pro-Agro (XL-51). From the perspective of the survey results in Table 14.14, they underestimated aggregate adoption by 20 percentage points. Only one of their five leading varieties appears in the top three cultivars in Table 14.14 with more than 10% adoption.

Table 14.14. Comparison of pearl millet adoption estimates, community level (focus group) versus household level.

Cultivar	Community level (% area)	Household level (% area)
ICTP-8203[a]	25.86	27.80
Pioneer 86-M-32	17.15	15.40
Mahyco-204	15.71	18.40
GK1044	6.62	2.70
MDBH-318	6.17	0.00
Dev Gen 308	4.69	3.90
Nirmal-9	4.04	2.00
Dhanyaa 7872	2.68	4.50
Mahyco-163	2.57	2.50
Mahyco-2210	1.58	0.00
Other hybrids	12.52	22.8
Area under total MVs	99.59	100.00
Area under locals	0.41	0.00

[a]Public bred cultivars.

In general, experts were good at providing the estimates of adoption when the incidence of releases was low and well known. Because most pearl millet improved cultivars are developed and marketed by private seed companies, awareness of public-sector experts on field-level adoption was limited. Very few public-sector varieties and hybrids were present in farmers' fields in 2010.

Expert opinion on the adoption of improved pearl millet cultivars can also be validated from the perspective of the recent HarvestPlus surveys in Maharashtra and Rajasthan (Asare-Marfo *et al*., 2013). Based on a large-scale representative survey of more than 2000 households, the HarvestPlus survey results were presented in Table 14.9. From the perspective of the HarvestPlus survey, experts were able to name the top two leading hybrids but two of their top five were not in the top ten from HarvestPlus.

The results from the HarvestPlus and ICRISAT survey differed markedly over the uptake of the improved OPV ICTP-8203. It fell from the top-ranking cultivar with 28% of area in the ICRISAT survey to eighth position with only 4% of area in the HarvestPlus survey, which pointed to its lower yield than hybrids and its importance as stover for livestock.

HarvestPlus also conducted a mail/interview survey of 58 block agricultural extension officers and 789 seed suppliers in Maharashtra. Interviewees were asked to name the three leading improved cultivars on the basis of area sown or on their own seed sales information. ICTP-8203 ranked first among the extension officers but dropped to sixth position in seed sales. In general, seed sales information was a better match to the survey results than the responses of the extension officers.

Compared to the smaller ICRISAT survey, the HarvestPlus survey sampled twice as many blocks, three times as many villages and six times as many farmers. Both surveys were conducted in the nine most important pearl-millet-producing districts in the state. The fact that the two surveys show such a large discrepancy in the estimated leading variety warrants more comparative analysis of sampling design and results, especially at the block level.

In Rajasthan, where none of the adopted hybrids exceeded 7% of area coverage in 2010, experts faced a more formidable challenge than those in Maharashtra (Table 14.9). The expert elicitation resulted in the following position of hybrids with their area shares: Pro-Agro 9444 (11%); HHB-67 Improved (10%); MH 169 (7%); JKBH 26 (4%); and others (20%). Experts correctly assessed aggregate adoption and they correctly perceived the importance of Pro-Agro 9444 and HHB-67. MH 169 and JK 26 also rank in the top 15 varieties. They did not perceive the importance of the top-ranked hybrids from Pioneer in Table 14.9 but that may because those hybrids are not notified, that is, officially released. They did about as well as agricultural officers at the block level and agricultural input suppliers in the private sector who were also surveyed in the HarvestPlus research. Overall, scientists in Rajasthan did better than their peers in Maharashtra.

Adoption of chickpea improved cultivars in Andhra Pradesh[3]

Chickpea was not even a minor crop in Andhra Pradesh until 1985. Short winters, terminal moisture stress, wilt disease and pod borer were the major constraints for growing chickpea in this southern state of India. Offsetting these disadvantages were two major advantages: it was easy to grow and it was characterized by a higher harvest index, indicative of a shorter growing period. Until 1985, late-maturing varieties namely Gulabi and Jyoti (selections from landraces) were under cultivation in Andhra Pradesh. Research collaboration between NARS partners and ICRISAT on crop improvement and management addressed the above constraints and harnessed opportunities to develop new cultivars that could make chickpea a most suitable crop for the region. The close and sustained collaborative efforts led to the development of short-duration chickpea varieties that were introduced in late 1990s and have been widely adopted by farmers in the state. All local cultivars have been replaced by these improved short-duration cultivars which resulted in what is now referred to as the 'AP chickpea silent revolution' with a fivefold increase in area, doubling productivity and a tenfold increase in production in Andhra Pradesh.

A representative sampling framework was developed based on Objective-2 DIIVA guidelines

(Walker and Adam, 2011). A total of 810 sample chickpea-growing households were interviewed with well-structured survey instruments from 30 mandals, seven districts and 90 villages of Andhra Pradesh. For enhancing the proper identification of improved cultivars at the farm-level, a varietal identification protocol was developed and administered for the chickpea adoption study in Andhra Pradesh. This has increased efficiency in proper identification of chickpea cultivars through a systematic validation process. A well-designed protocol not only minimizes the misidentification of improved cultivars but also reduces outliers.

The comparisons of cultivar-specific adoption estimates are summarized in Table 14.15. The estimates are much closer in community (focus group) and household level surveys. Compared to the sorghum and pearl millet validation discussed above, expert perceptions on chickpea varietal adoption were more precise; however, a few significant differences emerged between their perceptions and the survey results. Experts overstated the importance of KAK-2, an improved kabuli variety, and underestimated the importance of Vihar, also an improved kabuli variety. They correctly perceived that JG-11 was a truly dominant variety and that adoption of modern varieties approached 100%. Because of the low incidence of released chickpea improved cultivars in Andhra Pradesh, experts were able to provide a reasonable picture of the varietal reality in farmers' fields. Moreover, the role of the private sector in crop improvement, as well as in seed multiplication, is almost negligible.

Table 14.15. Comparison of chickpea adoption estimates, expert versus community level (focus group) versus household level.

Cultivar	Expert elicitation (% area)	Community level (% area)	Household level (% area)
JG-11	70.00	84.57	84.19
Vihar	0.00	8.35	7.39
KAK-2	20.00	4.03	5.92
Bold/Dollar	2.00	1.04	0.57
JAKI-9218	0.00	0.44	0.31
JG-130	0.00	0.02	0.08
Divijay	0.00	0.01	0.0
Annigeri	3.00	1.55	1.52
Total	95.00	100.00	100.0

Summary and Conclusions

This assessment of performance in crop improvement for five of the most important dryland crops in South Asia from the perspectives of scientific capacity, varietal output and adoption has shed light on many strengths and accomplishments and has also uncovered some areas for improvement. Although most of the findings in this chapter are not new, they are worth repeating.

Stability in making more varieties available via increasing releases over time is arguably the most impressive achievement of the dryland crop improvement programmes in India. There are few dry spells in output because the five programmes have consistently been able to release varieties annually during the past 50 years. Only pigeonpea is characterized by stagnant varietal output over time. Most of the programmes show a diversified mix of central- and state-level releases. Private-sector participation is also increasing over time in the provision of sorghum and pearl millet hybrids. For pearl millet and sorghum, recent survey results cited here show that more than 50 well-identified, notified cultivars from the public and private sector and unreleased but commercialized private-sector cultivars have been adopted by at least one farm household in large-scale surveys in Maharashtra and Rajasthan. An abundant provision of improved cultivars for adoption is especially noteworthy in western and central Rajasthan where the network of input-supply stores is sparse and where growing areas of pearl millet only average about one-tenth of a hectare.

The finding that aggregate adoption is still increasing at a rate exceeding 1% per annum in many major-producing states is also a laudable outcome that speaks to the stability of crop improvement programmes over time. Although the area-weighted average level of MV adoption across the five crops was estimated at less than 70% in several producing states, MVs are now at or approaching full adoption in several large-producing states. In pearl millet, the diffusion experience with the bajra hybrids since the mid-1960s in some states, like Gujarat, rivals the speed of adoption in irrigated wheat and rice. In terms of adoption, the conventional wisdom that dryland farmers would be bypassed by the Green Revolution does not hold for the ICRISAT-mandated crops. Diffusion of the public- and private-sector hybrids in rainy season sorghum has also been rapid and efficient in most major-producing states, especially in Maharashtra.

The high estimated velocity of varietal turnover in both the dryland cereals is another impressive finding. The weighted average age of pearl millet improved cultivars in farmers' fields is only about 10 years from their date of notification. Early adopters are planting their fourth or fifth different hybrid since HB-1 was released in 1964.

Some areas for improvement are transparent and well known. For example, the uptake of modern groundnut cultivars has lagged behind the other crops in MV adoption. The 'permanency' of old released varieties in farmers' fields has also translated into very slow varietal turnover. In particular, the dominance of TMV-2 in South India since the 1950s has eroded returns to groundnut improvement. The absence of varietal change in post-rainy season sorghum production is another formidable challenge that requires some out-of-the-box thinking because past research has not resulted in practical impact.

Sustained progress in MV adoption does not require new thinking for all lagging areas. For example, pearl millet hybrids are increasingly penetrating into central and even western Rajasthan. Following the same course with private-sector hybrids supported by public-sector parental lines should continue to lead to more positive adoption outcomes.

Other findings point to areas for improvement that are more subtle. Since the founding of ICRISAT in 1972, the dryland crops have not changed their rainfed character. But their locus of production has shifted substantially since then. Chickpea was displaced by the Green Revolution in irrigated wheat in northern India; it has shifted to central India, mainly Madhya Pradesh, and to southern India, primarily Andhra Pradesh and Karnataka. Likewise, Uttar Pradesh in the North has lost three-quarters of its pigeonpea area. As a result, long duration pigeonpea is no longer as relevant as it once was. Increasingly, medium-duration pigeonpea is the dominant maturity type. Rainy-season sorghum has secularly declined over time, especially in the wet semi-arid tropics where it is being displaced by soybean and Bt cotton. Sorghum is increasingly a crop produced and consumed in the very large state of Maharashtra. Post-rainy-season sorghum is not declining as fast because few alternatives compete with it in an environment of terminal drought stress. In India, post-rainy-season sorghum is produced in a compact production region spanning three states. Hence, sorghum-growing area is declining and its spatial concentration is increasing. Pearl millet is increasingly being relegated to the drier regions in the states in which it is produced. In the mid-1960s, the weighted mean annual rainfall of the districts in which it was produced was 900 mm; by the early 2000s, the mean had declined to 600 mm. Effectively, it was losing area in the wetter districts of higher production potential. Anecdotal evidence suggests that groundnut is also increasingly produced in droughty environments, although there is no solid empirical basis to support this conjecture. These shifts are not short-term phenomena. They reflect longer-term agronomic and economic trends.

Like the federal-state agricultural research system in several countries, such as the USA, the centre-state system in India imparts stability to agricultural research. It is difficult to understate the importance of stability as an attribute for productive agricultural research. But a two-tier integrated system can be an unwieldy institutional structure to respond to longer-term change such as geographic shifts in production. Several of the findings in the section on scientific capacity suggest frictions and impediments in responding to change. Largely because of its declining importance, the estimated research intensity of sorghum is rising and it has now reached a level that is high for a cereal with several million hectares of growing area. Both chickpea and pigeonpea are still characterized by a relatively high deployment of FTE scientists in the North relative to Central and South India. The regional location of research stations, centres and sub-centres seems highly appropriate for the 1970s but not for the 2000s. There may be good reasons to maintain the status quo; however, a priority-setting exercise would seem to be in order to take an analytical and critical look at research resource allocation in these dryland crops.

Over the past 50 years, the major institutional change has been private-sector participation in varietal development and multiplication in pearl millet and sorghum. When the private sector becomes very active in the generation and the multiplication of hybrids, the public sector moves upstream to support the activities of the private sector. The character of public-sector research qualitatively changes from adaptive to more applied and even strategic. Variation in the disciplinary composition of the five improvement programmes was seen as responding to different constraints in each crop. However, the disciplinary composition did not vary that much between the grain legume programmes on one hand and the cereal programmes on the other. In other words, there was not much evidence to indicate that the sorghum and millet improvement programmes had moved or were allocating more resources for upstream research that exploited the comparative advantage of each sector engaged in improvement research.

The adoption data also are indicative of what worked and what did not work in terms of varietal types. For example, in pigeonpea we did not see any adoption of extra-early short-statured pigeonpea varieties that were actively promoted by ICRISAT in the 1980s. These high-yielding materials were sole-cropped, highly regarded by scientists and economists, and widely tested in peninsular India. However, they were severely attacked by pod borer because they matured at a time when few other host plants were available.

We also found that improved varieties have only played a minor role in sorghum and are largely absent in varietal change in pearl millet. Improved varieties may have been competitive with hybrids in the 1970s and the 1980s but their window of opportunity seems to have closed in the production of rainy-season sorghum and pearl millet. Negligible adoption in turn suggests a low rate of return on varietal improvement compared to hybrid development. That improved sorghum varieties and improved pearl millet composites and OPVs are still being released for rainy-season production is puzzling given their limited uptake in the recent past.

Methodologically, the validation results confirmed that expert elicitation is not an effective means of generating adoption estimates when the private sector is actively engaged in hybrid development. In this context, there is no substitute for household surveys and complementary enquiries at the level of agricultural supply stores. In the case of pulses and oilseeds without private-sector participation in varietal development, the example of chickpea in Andhra Pradesh shows that responses on cultivar-specific adoption were very similar for village-focus groups and household surveys. In the chickpea example, expert panel estimates were also reasonably congruent with the results from the focus groups and household surveys when the number of improved varieties was low. But expert panels also gave fuzzy and diffuse information for pigeonpea in the major-producing states of Maharashtra and Karnataka. The lack of clarity in cultivar-specific adoption for pigeonpea in these two states was, arguably, the most disappointing outcome of this research. The uncertainty attached to cultivar adoption in pigeonpea underscores the importance attached to future survey research in Maharashtra and Karnataka. Less is still known about adoption of MVs in pigeonpea than about any of the other dryland crops in ICRISAT's mandate.

The TRIVSA Project has updated and enriched ICRISAT's knowledge on the adoption and diffusion of these five dryland crops in India. It also helped the team to better understand the adoption process as it affects different crops. Familiarization with the crop and its market players (public or private) is an important step before undertaking any adoption and diffusion study. Enlisting a senior breeder throughout the entire process helps enhance understanding. In general, expert opinion seems to be more accurate when a particular cultivar is in its early stages of adoption or at its peak stage. Disaggregated (district/mandal) estimates lead to greater precision in the adoption estimates. In the long run, institutionalization of a monitoring and adoption process is important for bringing more credibility to information on adoption.

Several of the findings also have implications for the prospects for varietal change in sub-Saharan Africa. Those implications are discussed in Chapter 19 of this volume.

Notes

[1] The sample design and the survey questionnaire are discussed in Kumara Charyulu *et al.* (2014a), a rainy-season sorghum technology adoption and impact study in Maharashtra State.
[2] The sample design and the survey questionnaire are discussed in Kumara Charyulu *et al.* (2014b), a pearl millet technology adoption and impact study in Maharashtra State.
[3] This particular activity was additionally co-funded by the Standing Panel on Impact Assessment (SPIA) to understand the cultivar specific adoption pattern of chickpea improved cultivars in Andhra Pradesh through a state-level representative survey.

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