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Germplasm enhancement for diverse riskprone environments: Approaches and results with chickpea, pigeonpea and pearl millet

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Zusammenfassung

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) hat ein Mandat für landwirtschaftliche Forschung, das die Erhaltung der genetischen Ressourcen von sechs Kulturpflanzen, deren züchterische Nutzung und das Ressourcenmanagement in den semiariden Regionen auf drei Kontinenten umfasst. Die Diversität der Anbausysteme und die Vielzahl der Faktoren, die sich limitierend auf die Ertragsentwicklung auswirken können, bedingen, dass am ICRISAT mit einer Vielzahl von Ansätzen gearbeitet wird, um die Erfolgschancen von Landwirten in diesen Regionen zu erhöhen. Am Beispiel der Kichererbse

(*Cicer arietinum* L) zeigen wir, wie die Züchtung zur besseren Anpassungsfähigkeit an die spezifischen Stressbedingungen tropischer Anbausysteme angelegt wurde, und welche Fortschritte im Anbau mit derartigen neuen Sorten erzielt werden konnte. Das zweite Beispiel, an Hand der Straucherbse (*Cajanus cajan* [L.] Millsp.) erläutert, zeigt, wie sich ein verbessertes Verständnis der physiologischen Faktoren, die die Ertragsentwicklung steuern, dazu nutzen lässt, mit Hilfe von Wachtumssimulationen, die Anpassungsfähigkeit bestimmter Sorten an neue Anbaubedingungen vorherzusagen, bzw. Lösungsansätze für Anpassungsprobleme zu entwickeln. Im dritten Beispiel zeigen wir an Hand von Arbeiten mit Perlhirse (*Pennisetum glaucum* [L.] R.Br.) wie Bauern aktiv in den Forschungs- und Sortenentwicklungsprozess miteinbezogen werden können. Die Arbeiten zeigen, dass das Wissen und Urteilsvermögen der Landwirte für eine adäquate Orientierung eines Zuchtprograms entscheidend sein kann. All diese Arbeiten sind Beispiele für intensive interdisziplinäre Vorgehensweisen in der Forschung, wobei einmal die Rolle der Phytomedizin im Vordergrund steht, während im zweiten Beispiel die Pflanzenphysiologie und im dritten Beispiel die Sozial- und Kommunikationswissenschaften als die Hauptpartner der Pflanzenzüchtung agieren.

Summary

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) has a broad mandate including germplasm enhancement of six crops as well as natural resources management of production systems in the semi-arid tropics (SAT). With such a diversity of challenges, it is not surprising that the approaches to genetic enhancement research used at the institute are diverse themselves, and cover a wide range of interdisciplinary interactions. Based on an example with chickpea (*Cicer arietinum* L.) we show how overcoming specific stresses occurring under tropical growing conditions through breeding for tolerance and adaptation can benefit farmers in these regions. In a second example, based on pigeonpea (*Cajanus cajan* [L.] Millsp.), we show how an improved understanding of adaptive responses to specific environmental factors can lead to improved utilisation of specific genotypes in new cropping situations, or development of specific concepts for manipulating adaptation to new cropping situations, through the use of crop simulation models. In a third example we show, based on research with pearl millet (*Pennisetum glaucum* [L.] R.Br.), how the participation of farmers in the research and development process leads to specifically targeted breeding programs, focusing on meeting farmers' most urgent needs on a priority basis. These three approaches are not mutually exclusive, nor independent of each other, but have different strengths and weaknesses.

Introduction

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), has a wide ranging mandate for agricultural research that includes germplasm conservation and enhancement of sorghum, pearl millet, chickpea, groundnut and finger millet, as well as natural resource management research in the semi-arid tropical regions across three continents, set in a multitude of different cultures and socio-economic conditions. The challenge to improve sustainability and productivity of such a diversity of production systems in these regions places the institute in a major dilemma (Evans 1993): On the one side there is a the need by large-scale globally oriented crop improvement programs to develop germplasm and breeding materials with broad adaptation to a wide range of diverse environments. On the other side is the need of farmers for new cultivars and other technologies that assure relatively reliable performance from year to year in a specific locality. ICRISAT's projects are based on the now widely acknowledged condition that crop improvement and technology development for broad adaptation could limit the potential for genetic and other productivity gains in specific environments (Cooper and Byth, 1996). ICRISAT's projects focus on specific crops and production systems. The production systems are mostly rainfed, with often very short rainy seasons, large variations in the total rainfall, and its distribution within seasons. Crop production is thus highly risk-prone, and farmers in these regions are faced with the task to produce enough to meet a set of minimum requirements in as many years as possible, while their families are growing steadily. The task for genetic enhancement research and crop improvement in this context is to increase farmers' opportunities for meeting and/or exceeding these minimum needs by reducing specific production by reducing specific prodcution risks, and exploiting environmental conditions and specific niches better. With the diversity of crops and production conditions that ICRISAT's research teams are addressing, necessarily a diversity of approaches has been explored and used. Three approaches will be described and discussed using resukts from three different species: 1) Overcoming specific factors that limit adaptation, using an example with chickpea (*Cicer arietinum* L.) 2) improving the understanding of adaptive responses through the application of crop simulation models, using an example with pigeonpea (*Cajanus cajan* [L.] Millsp.) and 3) farmers' participation in formulating goals for a breeding program using an example with pearl millet (*Pennisetum glaucum* [L.] R.Br.).

First approach: Overcoming specific limits in adaptation

This approach includes the understanding of specific production systems and the subsequent identification of specific stresses that contribute to production risks. The development of screening techniques for these specific stresses, as well as the identification of specific source materials, that show resistance, or higher levels of tolerance, and subsequently the combination of these traits, with useful agronomic characteristics, so that new materials with new advantages can become available to farmers. As an example for this approach, the work with chickpea for tropical production conditions will be discussed.

Chickpea for tropical environments

Chickpea is the third most important food legume crop in the world, grown in 45 countries. It is a major food legume crop in Algeria, Ethiopia, India, Iran, Mexico, Morocco, Myanmar, Pakistan, Spain, Syria, Tanzania, Tunisia, and Turkey. In all these countries, chickpea is an important source of protein in human diets, and forms an important component of the farming systems. Chickpea is a temperate (= cool season) crop. However, it has shown wide adaptability and has been cultivated in the sub-tropics during winter months, and at higher altitudes (> 1500 masl) in the tropics (Saxena and Singh 1987, Gowda 1993). Changes in farming practices in some of the major chickpea producing regions have occurred during the past 20 years, that have affected the crop distribution dramatically.

In India, for example, chickpea was grown mostly in central and northern India, above 20°N latitude, during winter months. However, due to increased availability of irrigation, most areas previously cultivated to chickpea are now dedicated to irrigated wheat cultivation (Kelley & Rao 1994). Much of the land in north-western India has also become unsuitable for chickpea cultivation because of rises of the water table (that results in excessive vegetative growth leading to foliar diseases) and salinity (to which chickpea is extremely sensitive). Therefore, chickpea cultivation has shifted to southern latitudes (<20° N) which are warmer, where soil moisture is limiting, and there is greater incidence of soil borne diseases (wilt and dry root rot) (Kelley and Rao 1994, Kumar *et al.* 1996). This situation has necessitated a concerted crop improvement effort to develop chickpea cultivars adapted to tropical climates by improving heat and drought tolerance, combined with resistance to wilt and root rots, and early maturity.

Chickpea is an annual herbaceous plant, and can grow up to 1 m in height under favorable environments. However, average crop height is around 30-60 cm. Plants are normally erect, or semi-erect, but spreading types are also found. There are two major types of chickpea, differing mostly for seed characteristics. The 'desi' types are usually small seeded, angular in shape, mostly with a reticulated surface, and the seed coat color varies from yellow to black. The 'kabuli' types are usually large seeded, owl's head shaped with smooth surface, and the seed coat color is usually cream, or beige. The 'desi' type chickpeas account for about 85% of the world area and production (mostly in the Indian subcontinent, Iran, Ethiopia, Mexico, Australia, and Tanzania), while the 'kabuli' types are grown mostly in the countries of the Mediterranean region, West Asia, North Africa, and the Americas (Gowda 1993).

Constraints to chickpea production in risk prone areas of South Asia

Among the abiotic stresses, drought, heat, and salinity are important in the major chickpea growing areas (Saxena *et al.* 1993). *Fusarium* wilt, dry root rot, *Aschochyta* blight, *Botrytis* gray mold, *Helicoverpa* pod borer and leaf miner are the major biotic constraints (Nene and Reddy 1987; Reed *et al.* 1987).

Drought. Drought is one of the major factors limiting yield in chickpea. The importance of drought as a yield limiting factor in chickpea increases with a decrease in latitude from the sub-tropics to the tropics because of the increase in atmospheric evaporative demand during the growing season. This can be overcome, to some extent, by short-duration varieties which can escape terminal drought stress (Johansen *et al.* 1994). Studies have indicated genotypic differences for drought tolerance. For example, ICC 4958 is reported to have high root mass that helps the plants to increase water uptake (Saxena *et al.* 1993). Field and greenhouse screening techniques have been developed to identify tolerant genotypes, and also to assist in selection for drought tolerance traits, such as high root mass. Saxena *et al.* (1995) have reported that selection (among segregating generation of crosses involving drought resistant lines) for higher root size was effective, but these selections were not necessarily high yielding. The low yield of root-based selections seems to be due to high selection pressure for root mass alone (and not yield) in early generations (F_4 and F_6). In this process the recombinants with high yield potential may have been eliminated. Exerting a combined selection pressure for root traits and yield from early generation onwards may be more effective (Saxena *et al.* 1995). This is feasable in the context of the general breeding strategy followed at ICRISAT whereby selection for yield under natural stress conditions occurs from the F_3-F_4 generation onwards.

Heat stress. The effect of heat stress on chickpea is severe if it occurs during the reproductive stages of crop growth, although the seedling stage is also very sensitive (Saxena *et al.* 1988). Heat stress causes mortality in seedlings, while at flowering it results in severe flower and pod drop, leading to yield losses. High root-zone temperatures also restrict nodule formation and nitrogen fixation. However, there are no reports of laboratory techniques to screen for heat tolerance in chickpea. Most studies have relied on field screening, under variable soil and climatic conditions (Saxena *et al.* 1988).

Fusarium wilt and dry root rot. Wilt caused by *Fusarium oxysporum* f.sp. *ciceri* and dry root rot caused by *Rhizoctonia bataticola* and/or *Macrophomina phaseolina* are the most important diseases in the sub-tropical and tropical chickpea growing regions. They cause substantial yield losses averaging 10% (Nene and Reddy 1987). Effective field screening techniques have been developed using naturally infested and disease-sick plots. Several germplasm lines with resistance to one or both fungi have been identified and used in the breeding program to develop resistant cultivars.

Sources of adaptive traits

At the time when the chickpea breeding project was initiated at ICRISAT in 1973, sources of tolerance to drought and heat stress were not available. Hence, the crop improvement scientists evaluated the germplasm collections that were grown for characterization, and selected individual lines based on visual evaluation and grain yield. The evaluation was carried out at ICRISAT Asia Center in Patancheru (18°N) under tropical conditions. More recently, two field methods have been used to screen and select chickpea genotypes for drought tolerance, one using irrigation and no irrigation, and the other using a line-source sprinkler method. After screening around 1500 germplasm lines, five lines were identified as drought resistant. Of these, ICC 4958 is widely used in crosses.

Several germplasm accessions having resistance to wilt and dry root rots were identified using multiple-disease sick-plots. Many of these lines have been tested multilocationally over 3-5 years and the resistance was reported to be stable across locations and seasons. Many wilt resistant lines have not shown breakdown of resistance even after 15 years, although some of them are not resistant to all the races of the *Fusarium* wilt pathogen.

Methods used for combining traits and testing for adaptation

Chickpea is a self pollinated crop, hence most commonly used were pedigree, and bulk-pedigree methods. Single-, double-, 3-way, or multiple crosses were made to combine good agronomic characters (early vigor, branching, pod number, seed weight) and tolerance/resistance to biotic and abiotic constraints (van Rheenen 1991). During early generations (F_2 to F_4), the progenies were screened for individual stresses either in artificially induced (such as wilt and dry root rot), or natural conditions (drought and heat stress, *Helicoverpa* pod borer). Selected F_4-derived F_5 to F_7 progenies were evaluated for yield in progeny rows and later in replicated trials. Selected lines were either evaluated in multilocation trials as a part of ICRISAT's chickpea International Trials and Nurseries Network, or more recently, offered to NARS collaborators for testing and possible inclusion in regional trial networks prior to release for general cultivation. Prior to 1991, ICRISAT scientists were developing experimental varieties and supplying these to NARS scientists for further testing and release, but more recently the policy has been to develop and supply intermediate breeding products and improved germplasm to NARS collaborators (Gowda *et al.* 1996).

Success and impact

Over the past years many chickpea varieties have been released for cultivation by the national programs of Bangladesh (Nabin, Barichchola 2 to 6), India (ICCV 1, ICCV 2, ICCV 10, ICCC 37, ICCC 42, ICCV 6, RSG 44, GNG 149), Myanmar (Shwe Kyemon, ICCV 2, ICCC 42), Nepal (Radha, Sita, Kalika, Kosheli) and Pakistan (Noor 91, DG 92, Rizki). The total number of chickpea varieties released by national programs in Asia, using ICRISAT or ICRISAT/ICARDA-supplied germplasm and breeding material is 34 in 6 countries (Bantilan *et al.* 1996). In this paper, we discuss the adoption of ICCV 2 and ICCC 37 in Andhra Pradesh, India, a region representing the harsh semi-arid tropical environment.

ICCV 2 is an extra-early maturing, 'kabuli' type chickpea cultivar. It matures in about 85-90 days in peninsular India (18°N latitude) (Kumar *et al.* 1985). It was released as "Swetha" in Andhra Pradesh in 1989. 'Kabul'i type chickpeas are usually medium- to long-duration (120 to 150 days), and are sensitive to terminal drought heat stress that is prevalent in peninsular India. However, ICCV 2 can be successfully cultivated and gave 1.07 t ha^{-1} grain yield compared to

0.83 t ha^{-1} of control cultivar Annigeri in Andhra Pradesh (Table 1). This is the first 'kabuli' cultivar to be released for cultivation in Andhra Pradesh, and for peninsular India (Amin *et al.* 1990, ICRISAT 1990a). ICCV 2 has been reported to be tolerant to drought, salinity, and heat stress.

ICCC 37 is a high yielding, short-duration variety maturing in 90-100 days in peninsular India. It was released as 'Kranthi' (meaning revolution) in Andhra Pradesh in 1989. It is resistant to wilt and fairly tolerant to root rots. Seeds of ICCC 37 are bolder than control variety Annigeri, light brown and attractive. In the multilocational trials, ICCC 37 gave 1.50 t ha^{-1} compared to 1.27 t ha^{-1} of Annigeri (Table 2) (ICRISAT 1990b).

Table 1. Seed yield (t ha^{-1}) of ICCV 2 and control Annigeri in trials in Andhra Pradesh, India, 1986/87 - 19988/89 (ICRISAT 1990a).

Variety	1986/87 (7)[1]	1987/88 (4)	1988/89 (8)	Weighted mean
ICCV 2	1.18	1.01	1.01	1.07
Annigeri	1.07	0.50	0.70	0.83

1. *Figures in parenthesis indicate number of locations.*

Table 2. Seed yield (t ha^{-1}) of ICCC 37 and control Annigeri in trials in Andhra Pradesh, India, 1986/87 - 1988/89 (ICRISAT 1990b).

Variety	1982/83	1983/84	1984/85	1985/86	Weighted mean
ICCC 37	2.38 (5)[1]	1.70 (6)	0.79 (4)	0.79 (4)	1.50
Annigeri	1.86 (3)	1.69 (6)	0.77 (4)	0.69 (4)	1.27

1. *Figures in parenthesis indicate number of locations.*

Adoption of improved varieties in southern India

Availability of adapted, high yielding, and short duration varieties such as ICCV 2 and ICCC 37, coupled with market driven forces (low supply and high prices) and technology for managing pod borer (that provided assured productivity), has ushered a revolution in chickpea cultivation in Andhra Pradesh, India. As shown in Table 3, there is almost a 2.5 times increase in area and 3 fold increase in production during 1991/92 to 1994/95.

Table 3. Increase in area, production and productivity of chickpea in Andhra Pradesh, India.

	Area (ha)	Production (t)	Productivity (t ha^{-1})
1991/92	61,000	43,000	0.71
1994/95	168,000	136,000	0.81

Source: A. Satyanarayana, RARS, Lam, Guntur, A.P., Personal communication.

Considering the phenomenal increase in area and production, studies were undertaken to determine the adoption of ICCV 2 and ICCC 37 in Andhra Pradesh, India. Based on area cultivated with chickpea, three districts (Anantapur, Kurnool, and Medak) were selected for this detailed adoption study (Joshi *et al.* 1996). Area cultivated to chickpea increased rapidly during 1991/92 to 1994/95: Anantapur (25.9% annually), Kurnool (13.1%), and Medak (13.4%). ICCV 2 and ICCC 37 were among the most preferred improved varieties. Adoption data showed a large temporal and spatial variation among cultivars. Overall, about 30% of the sampled farmers were cultivating improved chickpea varieties. Spread of ICCC 37 had reached more than 50% of the chickpea area in 1994, and dropped to 48% in 1995 in Medak district (Table 4).

Table 4. Adoption (%) of improved chickpea cultivars in three selected districts of Andhra Pradesh (Joshi *et al.* 1996).

Year	Medak ICCC 37	Anantapur ICCC 37	Kurnool ICCV 2
1990	10.13	0.03	0.01
1991	25.13	2.86	2.49
1992	38.29	5.69	4.92
1993	49.04	5.14	8.40
1994	51.45	12.15	8.90
1995	48.09	19.40	22.28

In Anantapur district, area under ICCC 37 was around 20% by 1995. In Kurnool, where kabuli variety ICCV 2 is popular, the adoption was 22% in 1995. It was evident that the improved varieties are slowly replacing the local and other cultivars, notably Annigeri. Interviews with farmers indicated that they preferred short-duration and stress tolerant varieties in areas where soil moisture is a major constraint. Farmers' preferences for specific cultivars and hence the adoption pattern are largely influenced by the cultivars' ability to adapt to agroclimatic conditions, farmers resources, and market forces (Joshi *et al.* 1996).

Second approach: Use of crop models for predicting crop adaptation

Building on new breeding materials, often developed in the context of the first approach, it has become possible to investigate the physiological basis for adaptation to specific environmental factors. This type of understanding is increasingly being used, through crop growth models, to predict potential yield and crop production risks for a diverse range of environments. All models assume relations between environmental factors and physiological attributes of a genotype and between different physiological attributes, and use the predictive value of physiology for estimating the yield of a genotype in a given environment. Experiments that check for existing combinations of weather and soil by growing the genotype in a range of environments are slow and laborious, not to mention expensive. The use of models can replace such experiments. Skeptics argue that physiological principles governing many processes are not well understood and consequently models may be unable to predict outcomes with any certainty. However, an important virtue of crop models is to show which attributes might mainly govern a process and the condition resulting from the process. We use flowering in pigeonpea to illustrate how simple basic concepts of the environment that control crop growth could serve as a basis for describing environmental challenges a crop in a new cropping system faces.

Time to flowering - physiological concepts

The timing of flowering is critical for the adaptation of crops to their environment. It is controlled by an integration of the daylengths and daily temperatures experienced by the crop in the vegetative phase. The duration (t) to flowering usually decreases with rising temperatures (T) to a minimum at an optimum temperature, and increases with further rise in temperature above the optimum. The rate of development (1/t) increases more or less linearly with a rise in temperature above a base temperature (T_b), at which duration is infinite, to an optimum temperature (T_o) at which rate is fastest and duration shortest. As temperature rises above the optimum this rate declines, more or less linearly again, to a maximum temperature (T_c). The duration of such a process is an integral of time and temperature, and is captured by the concept of thermal time, i.e., the accumulated temperature which is required for a process to happen. Thermal time is measured in units of degree-days (°Cd) and is based on the cardinal temperatures discussed above. Plants of a genotype grown in any environment have the same cardinal temperatures, T_b, T_o and T_c, and require the same thermal duration to commence flowering. The conservatism of these physiological attributes is useful in predicting time to flowering.

Like in most plants, photoperiod influences the period between sowing and the start of reproductive development in pigeonpea. The period before flowering is extended if photoperiod is longer than a certain base value P_b. The developmental rate for flowering is maximum (time to flowering is shortest) and unaffected by photoperiod below P_b and the rate decreases (time to flowering increases) as photoperiod increases above P_b. Some tropical plants do not flower when daylength exceeds a critical value. When daylength is below the base value, the crop shifts to the reproductive stage when the thermal time accumulated reaches the threshold value. By examining the photothermal outcome, the simultaneous effect of temperature and photoperiod, on time to flowering, it is possible to characterize the response of a cultivar to both environmental factors.

Pigeonpea, ranked sixth in area and production after other grain legumes such as beans, peas and chickpeas, is a major crop of the tropics and sub-tropics. Attributes of much of the pigeonpeas grown today - perenniality, long crop duration, indeterminateness, photoperiod sensitivity and low harvest index - are considered to be indicators of the little genetic enhancement that pigeonpea has undergone through sustained input of agricultural scientists and producers (Troedson et al. 1990). However, in the context of the environment in which it grows, pigeonpea is considered to be a well adapted crop that provides more stability of productivity over environments and seasons than the crops with which it is intercropped (Singh and Subba Reddy 1988). In the Indian subcontinent, pigeonpea is almost always sown at the beginning of the rainy season (*kharif*) as an intercrop with shorter duration crops. It is traditionally grown in marginal environments with little or no inputs and where its deep and lateral roots provide access to limited but otherwise unavailable reserves of water. Seed productivity is of less consequence than the ability of pigeonpea to survive and produce forage, firewood and craft material.

However, in response to a growing trade in pigeonpea for local consumption and export in Southern and Eastern Africa (Laxman Singh *et al.* 1990), America (Marsh 1994) and India (Laxman Singh *et al.* 1996), seed productivity issues have become much more important than total biomass yield and survival related traits. The traditional adaptive behavior of pigeonpea may not be required, advantageous, or appropriate. Research on adaptation is now shifting towards options for modification to suit new environmental circumstances and understanding limitations to productivity.

Short-duration pigeonpea in northern India

Local landraces and cultivars of pigeonpea are of medium to long duration (180-280 days). However, these traditional cultivars find little use in the new intensive cropping systems where the need is for a short-duration crop that matures before the optimum time for sowing wheat. From the wide diversity that exists in time to flowering in pigeonpea, selections for short duration genotypes have been made that mature in 140-160 days. When these new genotypes are sown in northern India at the start of the rainy season in July, as per the traditional practice, maturity is delayed and grain yield is low (Chauhan 1990). The delay in maturity results in a late wheat sowing which is unacceptable to farmers. An April sowing for pigeonpea has been encouraged to allow for a timely sowing of wheat. However, an April sown pigeonpea crop is difficult to establish and flowering sometimes takes over a 100 days compared with an expected 60-70 days (Y S Chauhan, personal communication).

When grown in environments where daylength varies little (0 - 4 °S), Omanga et al. (1995) demonstrated that short-duration cultivars had a base temperature in the range of 7 to 10°C and an optimum temperature between 20 and 22°C. Rate of progress to flowering increased from a base temperature of 10°C to a maximum rate when mean temperature were between 20 and 22°C. Although short duration pigeonpea is reported to be relatively insensitive to photoperiod, there is little information available whereby the effects of temperature and photoperiod on flowering of pigeonpea can be predicted in a reliable manner.

In northern India when the crop is sown in July, mean daily temperatures are in the supra-optimal temperature range of 26 to 35°C. Research has shown that high pre-flowering temperatures cause flowering to be non-synchronous, thereby delaying maturity. Assuming daylength plays no role in moderating the number of days to flowering, even when sown in April, the crop is likely to experience daily mean temperatures higher than the optimum 22°C leading to non-synchronous flowering. Short duration genotypes were developed from selections of early maturing segregants of medium and late maturing cultivars. Pigeonpea has been reportedly grown in the Indian continent for centuries (van der Maesen 1990) and in a variety of cropping systems and seasons. Since most species of plants have adapted their cycles of reproduction to coincide with the best conditions of their parents and to maximize the survival of their offspring, we speculate that in the case of the medium-duration genotypes, the low optimum temperature evolved as a response to the cool periods that the crop experienced when daylength signaled a shift from vegetative to reproductive stages. As a strategy for breeding cultivars with better adaptation to the new environments where short-duration pigeonpea is targeted, selection of parents must include cultivars with an appropriate optimum temperature for flowering.

The confounding effects of temperature and photoperiod make it difficult to estimate the effect of temperature alone on days to flowering from data collected in the field. Controlled environment studies that seek to establish the photoperiod response of pigeonpea cultivars and interaction, if any, of temperature and photoperiod, must be part and parcel of an effective breeding program. Differential genotypic sensitivity to photothermal regime has major implications for adaptation of pigeonpea with respect to latitude, altitude and season.

Third approach: Farmers' participation in formulating targets for a breeding program

The goals of a breeding program influence the choice of breeding method, the type of germplasm used, and the selection sites and screening facilities required. With the rapid developments in genetics and their application to crop improvement, the linkage between genetic, agronomic and farming system improvements has weakened (Gaede 1993). Plant breeders may be unfamiliar with the specific production conditions and thus appropriate goals are not obviously set (Haugerud and Collinson 1990). This is particularly critical in marginal environments where farming is frequently subsistence rather than market oriented, and farmers' strategies for coping with large seasonal variations are not well understood (Matlon 1987). In the process of establishing a pearl millet breeding program for the drier regions of Rajasthan in northwestern India (Fig. 1), one of the main issues we needed to understand was what the farmers' concepts of a preferred plant type are, and which specific traits they associate with yield stability and adaptation to the growing conditions in their fields.

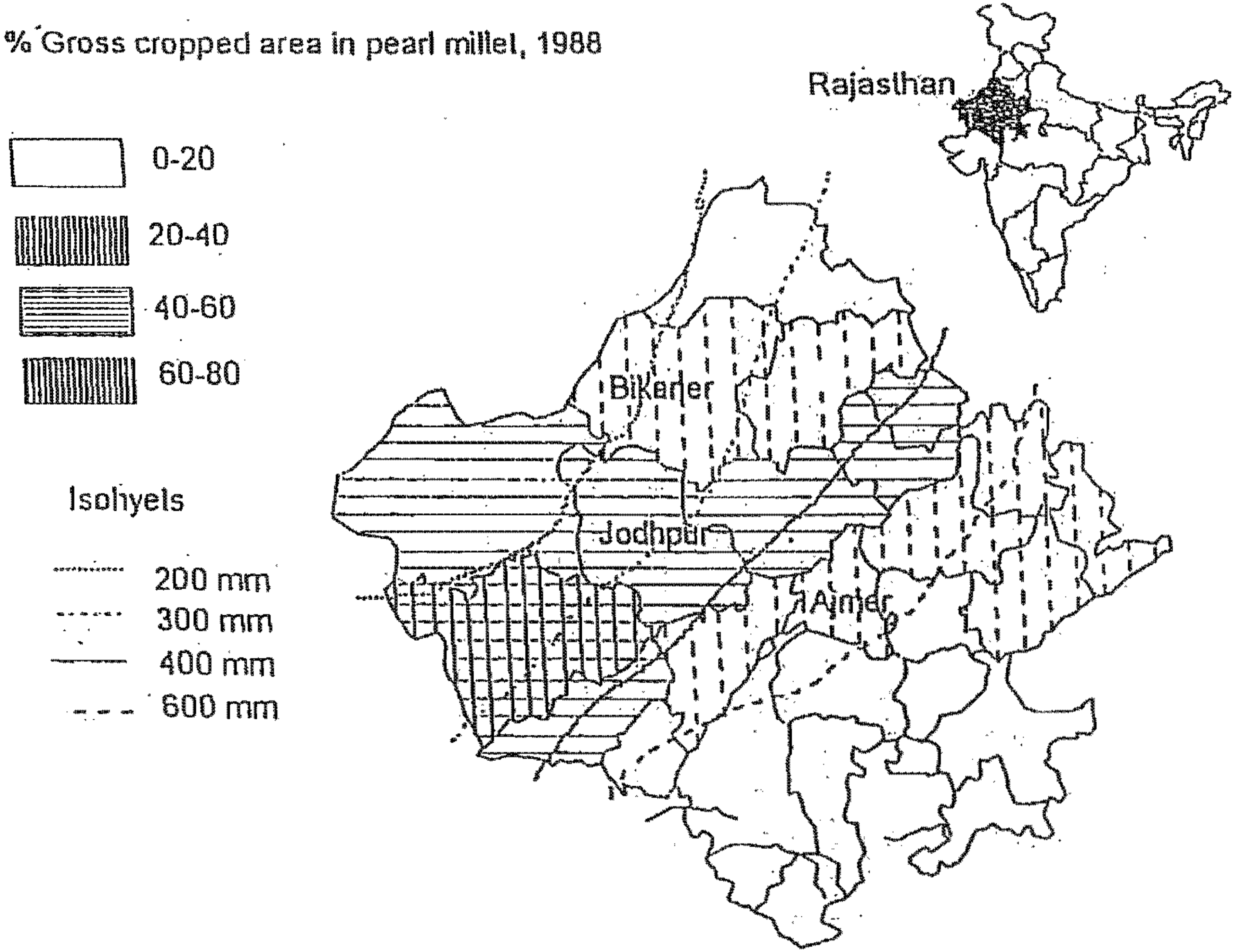

Figure 1: Distribution of pearl millet (% gross cropped area, on a district basis), rainfall isohyets in Rajasthan and on-farm trial locations.

Methods used for interaction with farmers

We used a wide range of methods and approaches to improve our understanding of this issue. These consisted of on-farm variety evaluations, farmers' selection in on-station trials, and discussions with farmers to understand their strategies for seed management.

Initially we had used formal, structured, pretested questionnaires in a study to understand the causes for non-adoption of modern pearl millet varieties in western Rajasthan. Most of the discussions with farmers centered around farmers' perceptions of the relative importance of grain versus stover yield (Kelley et al. 1996). The informativeness of this survey was limited by the farmers' lack of experience with the full range of newly released pearl millet varieties and pre-release advanced experimental varieties. These varieties differ for many agronomic traits, particularly for earliness. We found that it was difficult for farmers to conceptualize the full range of available varieties and plant traits while expressing their preferences and concerns, if they have not experienced them in their own fields.

Farmer managed on-farm trails were therefore initiated with a range of newly released or pre-release varieties as a way of facilitating this dialogue with farmers (Weltzien *et al.* 1996b). Individual interviews were conducted with each participant to compare a single test variety with the adjacently sown local variety. The farmers were asked to indicate which traits differed between the two varieties, and which traits were desirable and important. The results of these discussions were influenced by the particular genotype under evaluation and by the growing conditions in the experimental field. We tried to overcome the first limitation by discussing with each farmer the characteristics he or she would consider essential for an ideal variety. This discussion gave farmers the opportunity to mention traits that were not exhibited by the experimental or farmers' own variety, and to mention preferred trait combinations. Furthermore, interested farmers were invited to participate in group discussions comparing all varieties being tested in the village, and to visit the research station to examine a broader range of experimental varieties.

Groups of farmers from different villages, men and women, participants and non-participants in on-farm varietal trials were invited to the research station at Jodhpur during 1992, 1993 and 1994. Farmers observed one replication of a trial which evaluated the most advanced breeding materials produced by the collaborative breeding programs of ICRISAT with the Central Arid Zone Research Institute (CAZRI) at Jodhpur, and the Rajasthan Agricultural University at Fatehpur-Shekhawati and at Jaipur (Durgapura). The trial consisted of 40 to 60 entries each year, and included unimproved local varieties and a range of released varieties (hybrids and open-pollinated varieties) as controls. The composition of the trial changed each year. We assessed the farmers' varietal selections in three ways:

1) by identifying the most commonly selected varieties,
2) by determining the range of varietal types selected by individual farmers, and
3) by determining the frequency that varieties with specific critical traits such as earliness, tillering ability and large panicle size were selected.

The second and third approaches to examining farmers' selections relied on the classification of the experimental varieties into groups of contrasting plant types according to their maturity, tillering habit and panicle size. We then compared the frequency of selection of the different plant trait groups by sets of farmers grouped by gender and village to help us understand gender and location specific patterns of varietal and trait preferences. As the composition of the trial varied each year, not all varietal groups were represented each year, and the genotypes within each group were not always the same.

Preferred plant type

The on-farm variety comparisons and descriptions of an ideal variety indicated that farmers' preferences differed most strongly in the attention paid to tillering (Tables 5, 6). Tillering was important to farmers from western Rajasthan as it is a component of both grain and fodder yield as well as stover quality. Farmers also associated tillering ability with better adaptation to water scarcity and poor fertility conditions. They further consider it to be a component of stover quality. Nodal tillers frequently do not mature before harvest and thus increase the feed quality of the stover. Higher tillering varieties commonly have thinner stems, which result in higher intake by the animals, without the need to chop the stover. The type of varieties selected by farmers in on-station trials (Figure 2) as well as the type of panicles chosen in panicle-selection simulations further supported the preference for high basal and nodal tillering in Jodhpur and Bikaner districts.

Table 5. Percentage of farmers using productivity related traits to distinguish the experimental variety from their own variety, 1992 and 1994 results combined across all experimental varieties.

Trait	Ajmer 1992/93	Jodhpur 1992/94	Bikaner 1992/94
No. of farmers surveyed	39	59	62
Grain yield	43	53	65
Stover yield	65	31	47
Earliness	50	41	50
Large panicles	59	41	51
Large grain size	43	46	39
High tillering	22	23	56

Long and/or large (girth and length) panicles (Tables 5, 6) were also frequently mentioned during individual variety comparisons and as a trait of an ideal variety. Panicle size was always a criterion used by farmers when simulating panicle selection for obtaining seed for sowing. Farmers from Ajmer district always preferred larger panicles over high tillering (Figure 2), whereas farmers from Jodhpur district consider these traits to be of equal importance, while those from Bikaner district, where soils are mostly poor and rainfall is lower, preferred high tillering over large panicle size. However, further discussions with farmers from the same village revealed that differences in preference for these two traits exist (Figure 2), due in part, to highly variable soil conditions.

Table 6. Percentage of farmers using a trait to describe an ideal pearl millet variety, based on surveys conducted in 1992 and 1994 in Ajmer, Jodhpur and Bikaner districts.

Total	Ajmer 1992	Jodhpur 1992/94	Bikaner 1992/94
No. of farmers	22	32	33
High grain yield	32	56	67
High stover yield	23	28	42
Earliness	55	50	61
Large panicles size	77	75	45
Large grain size	45	34	30
High tillering	27	72	70
Low water needs	0	6	42
Good grain filling	32	9	42

The farmers' selections in an on-station trial were widely distributed across a large number of varieties. The most preferred variety in each year received only about 12% of the total labels (Table 7). However, these varieties were selected by most of the participating farmers, indicating wide-spread interest in these materials. The six most preferred varieties represented contrasting plant types. Each year, varieties from four different "Plant Type Groups" (Table 8) were identified as most preferred.

Individual farmers selected varieties from 2.8 to 4.1 different Plant Type Groups, averaged within each of the three years (Table 9). Individual farmers identified varieties with very differing maturity, tillering ability and panicle and grain characteristics as being most suitable for their region. This selection of a wide range of plant types occurred with farmers from different villages (production environments) and gender groups, although women tended to select a slightly narrower range than men.

However, the frequency of selecting varieties in particular "Plant Type Groups" did differ between villages and gender groups. Farmers from Jodhpur district more frequently selected earlier and higher tillering varieties than did farmers from wetter Ajmer district in 1992 (Figure 2). In 1993, farmers from further west, in Bikaner district, had more frequently selected early, high tillering and taller varieties, most of which were landrace accessions from another low rainfall district (Barmer) (Figure 2). This contrasts markedly with the wide range of maturity, tillering and panicle types of varieties selected by farmers from Jodhpur in the same year.

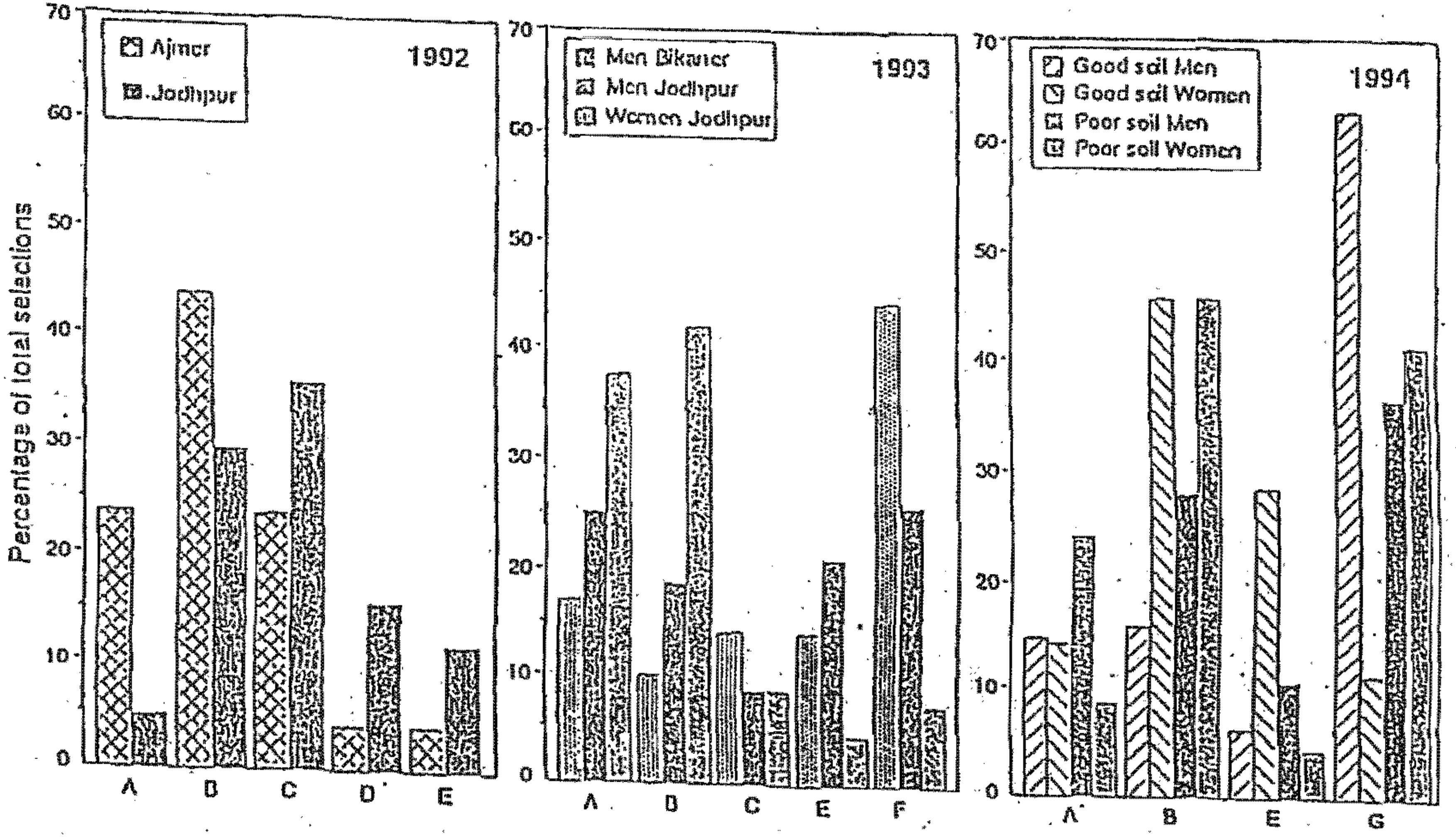

Figure 2: Selections made by farmer groups from different districts in Rajasthan among groups of pearl millet varieties differing in plant type, as percentage of total selections made in 1992, 1993, 1994.

Legend:
A: medium maturity, low tillering, large panicle
B: early maturity, low tillering, large panicle
C: medium maturity, basal tillering, medium panicle
D: extra early maturity, basal tillering, small panicle
E: early maturity, high tillering, small panicle
F: early-medium maturity, hightillering, medium panicle
G: early maturity, medium tillering, medium panicle

Table 7. Most commonly selected varieties during farmers' on-station visits to Jodhpur in 1992, 1993 and 1994.

	1992			1993			1994		
Rank	Variety/plant type[a]	Percent of labels	Percent of farmers	Variety/plant type	Percent of labels	Percent of farmers	Variety/plant type	percent of labels	Percent of farmers
		(N = 138)	(N = 14)		(N = 266)	(N = 27)		(N = 289)	(N = 38)
1	CZ-IC 922(A)*	12.3	93	RCB-IC 924(B)*	7.5	59	HHB 67(D)*	12.5	61
2	ICMH 89951(B)[1]	10.9	93	RCB-IC 911(B)*	7.5	33	RCB-IC 911(B)*	8.7	34
3	CAZRI 1002©	10.1	64	RCB-IC 912(A)+	7.1	37	CZ-IC 923(A)*	6.6	32
4	HHB 67(D)*	10.1	50	CZ-IC 912(A)*	6.8	44	RCB-IC 926(B)*	6.2	24
5	CZ-IC 923(A)*	9.4	50	WRajPop(E)*	5.3	44	AAG(G)	5.5	29
6	RCB-IC 926(B)*	8.0	71	Barmer LR(F)	5.3	44	ICMH 90852(E)	5.2	37

* Tested in 1992, 1993 and 1994.

\+ Tested in 1992 and 1993, very similar to CZ-IC 923.

a. Classification of plant type groups (see Table 8).

1. Very similar plant type to RCB-IC 911.
2. Very similar plant type to RCB-IC 926

In 1993, women farmers from Jodhpur district selected large panicled and less tillering varieties much more frequently than the men from the same village, whose selections were more equally split between large panicle, high grain yield potential varieties and varieties with more tillering and better stover yield and quality (Figure 2). Women in 1994 from both the same village and a new study village with more productive soils had also selected large panicled, lower tillering varieties much more frequently than men from the same villages. Follow-up discussions indicated that women from these villages especially valued grain yield, earlier availability of grain for food security and the ease of harvesting by hand resulting from lower panicle number and lower plant height.

Table 8. Contrasting plant type groups used for classifying experimental varieties in the Rajasthan Varieties and Population Trial.

Plant type group	Maturity	Tillering	Panicle size	Representative variety
A	Medium	Low	Large	ICMV 155
B	Early	Low	Large	RCB-IC 911
C	Medium	High basal	Medium	HiTiP 89
D	Extra early	High basal	Small	HHB 67
E	Early	High basal and nodal	Small	ERajPop 91
F	Early-medium	Medium basal and nodal	Medium	Barmer landrace
G	Early	Medium	Medium	Interpool populations

A novel class of varieties which combines the high tillering of local varieties with large panicles of introduced varieties (group "G") was frequently selected in the very favorable 1994 season (Figure 2). This group of varieties was selected with equal frequency by men and women from the village with previous experience of growing some of these varieties. Men from the new study village with more productive soils had selected this group of varieties even more frequently, whereas the women had almost completely ignored it.

Table 9. Average number of variety groups selected by individual farmers during on-station visits in 1992, 1993 and 1994, number of farmers in parentheses.

Year	Total no. of groups	Overall average	Ajmer	Jodhpur poor soil condition		Bikaner	Jodhpur good soil condition	
			Men	Men	Women		Men	Women
1992 N	5	4.1	3.5	4.6 (6)	-	-	-	-
1993 N	5	3.6	-	4.0 (13)	3.0 (7)	3.4 (7)	-	-
1994 N	4	2.8	-	3.3 (11)	2.9 (7)	-	2.9 (11)	2.3 (9)

Discussion

Our varied interactions have shown how farmers' priorities and preferences for different plant types vary by region as well as within a region, within a village, and within a household according to production conditions and the range of seasonal variations. The range of preferred traits and plant types of individual farmers even covers almost the whole range of available breeding material in India, which makes the description, identification of a farmer preferred plant type or ideotype difficult, if not impossible. The follow-up discussions during the on-station visits, the group discussions about trade-offs between traits, but most prominently series of discussions about seed management strategies, i.e., local seed production, farmers' selection in their own seed stocks, preferred utilization of improved varieties available from the market (Dhamotharan et al. 1997) indicated a better understanding of this situation. Farmers differentiate clearly between different plant types of pearl millet, and associate very strongly adaptation to different types of growing conditions with these different plant types. However, when they do prepare seed for sowing these different plant types are usually mixed, because the growing conditions can not be anticipated at that time. When they make selections from their own fields or harvest, panicles associated with different plant types are kept for seed, but most commonly in one lot of seed, and not separate lots for the different plant types. Also when seed is purchased at sowing time, it is usually mixed with farm produced seed, for the same reason. Only if farmers can expect specific conditions for plant growth, e.g., with the availability of irrigation water, or delayed sowing time, or extremely poor soil conditions do they prefer only one specific plant type. Usually, however, each farmer has a number of different fields, which differ sharply in their productivity potential, and thus each farmer has a need for a variety of different plant types.

These results suggest that a range of pearl millet varieties is needed to meet farmers' needs in this region. While the private and the public sector pearl millet breeding programs in India have been very successful in supplying new varieties and hybrids that respond well to improved growing conditions, i.e., the large panicled plant types that have been described and discussed earlier, there is a shortage of improved materials that do meet farmers' needs under poorer growing conditions, i.e. poor fertility, low rainfall and late sowing conditions. It is farmers' experience that the local landraces are best suited for this type of growing conditions. With the availability and more widespread use of modern varieties in seed mixtures in these dry regions, farmers observe a shortage of the pure local landrace type of material, and its' advantageous characteristics. It is therefore not surprising that farmers regularly express most urgently the need for new varieties that outperform the available seed materials under poor growing conditions, especially in view of the fact, that poor growing conditions are the most widespread in this region, and that seasons with adequate rainfall are rare.

Based on our interactions with farmers, our collaborative breeding work with public sector pearl millet breeders in Rajasthan has placed greater emphasis on breeding earlier, higher tillering populations and varieties with improved seed setting ability. The methodology we developed for on-farm testing of new materials as a basis for a better dialogue with farmers was modified and used for evaluating with farmers new experimental varieties that are in the advanced stage of testing for possible release in India. We have further initiated the comparison of farmer-generated population crosses, the result of mixing seed of improved and local varieties, as base populations for further breeding efforts. Thus, as a result of the initially diagnostic work with farmers, interactions with them at various stages of the breeding program have developed and will intensify further.

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