International breeding programmes and resource-poor farmers: Crop improvement in difficult environments.

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Summary

Farmers in stressful environments have benefitted little from the spectacular yield increases obtained by formal (or institutional) breeding programs based in environments which are naturally favorable or can be profitably made favorable by using inputs.

Interactions between genotype and environment (GxE) are one of the main reasons for the failure of formal breeding to serve small, resource-poor farmers. Formal breeding has frequently adopted a negative interpretation of GxE interactions by selecting for broad adaptation and replacing locally adapted landraces with input responsive cultivars ill adapted to low input and stress conditions. By contrast, a positive interpretation of GxE interactions implies the exploitation of specific adaptation by direct selection in the target environment. To exploit specific adaptation international breeding programs need to decentralize breeding activities and encourage national programs to use their locally adapted germplasm. A second vital step is to obtain farmers' participation in selection so as to take full advantage of their indigenous and specialized knowledge of the crop and the environment.

Farmers' participation in selection under their own environmental and agronomic conditions will not only benefit the selection process but will also speed up the transfer and adoption of new varieties without the involvement of complex, bureaucratic and often inefficient mechanisms of variety release, seed certification and production, and extension activities. Such mechanisms, commonly introduced from industrialized countries along with the breeding methodologies and philosophies of formal breeding programs, are not used by most resource-poor farmers as their main supply of seed. Most of the seed and information used by these farmers is either generated on the farm, or acquired from neighbors or purchased from local markets. Informal sources of seed and information must be fully understood and exploited if resource-poor farmers are to benefit from formal plant breeding.

Introduction

Formal, or institutional, breeding has been highly efficient in improving yield levels of several crops. However, its efficiency has remained largely confined to favorable environments, or to environments which could be made favorable by adding fertilizer and irrigation, and by chemical control of weeds, pests and diseases.

Resource-poor farmers, who practice approximately 60% of global agriculture, and produce 15-20% of the world food (Francis, 1986) have not known the benefit of the green revolution. Some 1.4 billion people are dependent on agriculture practiced in stressful environments (Pimbert, 1994).

Typical characteristics of formal breeding programs in several crops are: 1) they generally produce genetically uniform cultivars (pure lines, clones, hybrids), 2) they are largely conducted either in good environments or in well-managed experiment stations where growing conditions are optimum or near-optimum, 3) in most grain crops selection is almost exclusively for grain yield and disease resistance, 4) they promote cultivars which can be grown over large areas (widely adapted in a geographical sense), and 5) they do not involve the clients (the farmers) in any of the steps which will eventually lead to new cultivars, except perhaps in the final field testing of a few promising lines.

Assumptions of formal breeding programs are that 1) selection must be conducted under good growing conditions where heritability is higher, and therefore response to selection is also higher, 2) yield increases can only be obtained through replacement of locally adapted landraces (Brush, 1991) which are low yielding and disease susceptible, 3) breeders know better than farmers the characteristics of a successful cultivar, and 4) when farmers do not adopt improved cultivars it is because of ineffective extension and/or inefficient or insufficient seed production capabilities: the hypothesis that the breeder might have bred the wrong varieties is rarely considered.

Because of the success that breeding has had in good environments, these characteristics and these assumptions are not questioned even when the objective is to improve yield and yield stability for poor farmers in stressful environments. The implicit assumption is that what has worked well in favorable conditions must also be appropriate to unfavorable conditions, and very little attention has been given to developing new breeding strategies for less favorable environments.

In the last few years there has been mounting evidence that these assumptions are not valid, and that the special problems of marginal environments and their farming systems must be addressed in different ways.

In this paper we address the question of why the improvement of crop production in stressful environments has remained such an elusive objective in spite of major national and international research investments. The emphasis will be on crop breeding, because it has historically received the higher allocation of resources in research and development at both national and international level. However, the conceptual framework applies equally well to other disciplines.

Agricultural diversity in unfavorable environments

Throughout this paper unfavorable environments are defined as those where crop yields are commonly low due to the concomitant effects of several abiotic and biotic stresses. The semiarid areas of Syria, where barley-livestock is the predominant farming system, are a good example of such environments (Fig. 1, zone C) where not only low annual rainfall, but also rainfall distribution, low winter temperatures, high temperatures and hot winds from anthesis to grain filling are important abiotic stresses. The frequency, timing, intensity and duration of each of these stresses, as well as their specific combinations, vary from year to year. However, low yields of barley are common, crop failures occur one year out of ten, and yields of 3.0 t/ha or more are expected less than 15% of the time. By contrast, in relatively favorable environments (Fig. 1, zone B) yields of 1 t/ha or less have a frequency of about 10%, and yields above 2.5 t/ha occur more than 40% of the time.

Because of the probability of low yields and crop failures in unfavorable environments, the use of inputs such as fertilizers, pesticides and weed control is uneconomical and risky for resource-poor farmers. Therefore, the adoption of "improved agronomic practices" has been limited, and one economic solution to increase crop yields in unfavorable environments can be through breeding.

Many of the environments where "improved technologies" in general, and "improved cultivars" in particular, have had little or marginal impact have some characteristics in common with those described for the semi-arid areas of Syria. These are as the unpredictability and variability of climatic conditions, the consequent high probability of crop failures which discourages the use of inputs.

Resource-poor farmers in many regions of the word practicing agriculture in these or similar situations have adopted a strategy based on both intraspecific and interspecific diversity (Martin and Adams, 1987). Different crops are grown in the same field at the same time (intraspecific diversity), and the cultivars of the different crops are frequently genetically heterogeneous (interspecific diversity). A second level of interspecific diversity is obtained by growing, at the same time and in the same field, different cultivars of the same crops (Haugerud and Collinson, 1990). The type of diversity which prevails in different areas depends on both climatic and socioeconomic conditions and farmers' response to these. In central Africa and central America both intra- and interspecific diversity are exploited at the same time. In other areas, interspecific diversity represented by one heterogeneous cultivar, is predominant. In the dry areas of West Asia and North Africa, for example, barley is often the only feasible rainfed crop, and the cultivars which are grown at present, and which have been grown for centuries, are genetically heterogeneous (Ceccarelli *et al*. 1987; Weltzien and Fischbeck, 1990).

This diversity which is typical of resource-poor farming is in marked contrast with the uniformity pursued by formal breeding and production practices in most crops grown in favorable environments, and is one of the causes for a different mechanism of seed supply. Whilst in high input agriculture served by formal breeding, the seed market is the main source of seed supply, particularly for grain crops, in resource-poor agriculture the seed is usually produced on the farm, after some form of selection done by the farmer, or it is purchased from neighboring farmers (Almekinders *et al*., 1994). Formal breeding thus not only tries to replace diversity with uniformity, but also tries to reach farmers with the seed of new cultivars through mechanisms and institutions which are not familiar, are not efficient, and often are not trusted by resource-poor farmers.

Genotype by environment interaction

Genotype x environment (GE) interaction is almost unanimously considered to be among the major factors limiting response to selection and, in general, the efficiency of breeding programs. GE interaction becomes important when the rank of genotypes changes in different environments. This change in rank has been defined as a crossover GE interaction (Baker, 1988).

GE interactions in general, and GE interactions of a crossover type in particular, are considered to have a negative impact on the success of breeding programs, because breeders tend to search for a few widely adapted cultivars. Whilst this is probably the best strategy in the case of breeding programs targeted at favorable environments, it has been suggested (Ceccarelli, 1989; Hildebrand, 1990; Simmonds, 1991; Stroup *et al*., 1993, Ceccarelli, 1994) that, in case of less favorable environments, breeders may need to look at GE interactions in a different way.

The hypothesis of this paper is that GE interactions of the crossover type are among the major causes of the failure of formal breeding programs to serve resource-poor farmers. Therefore, the question of how frequently these interactions occur is important.

Examples of GE interactions of the crossover type can be found in the literature in a range of crops and environments, and for various stresses: Breese (1969) in cocksfoot, Arboleda-Rivera and Compton (1974), Muruli and Paulsen (1981), Hildebrand (1984), Loffler *et al*. (1986) and Lafitte and

Edmeades (1994) in maize, Simmonds (1984) in sugarcane, Lawn (1988) in chickpea, Ceccarelli (1989) and Ceccarelli and Grando (1991) in barley, Blum and Pnuel (1990) in wheat, Virk and Mangat (1991) in pearl millet, and Shannon and Francois (1978) in muskmelon in relation to salt tolerance.

A typical example of GE interaction of a crossover type in barley is given in Table 1. The highest yielding genotypes in the lowest yielding site had an average yield in the highest yielding site which was not significantly different from the population mean. Similarly, the highest yielding genotypes in the highest yielding site had an average yield in the lowest yielding site which was not significantly different from the population mean. Therefore, selection in high yielding sites, such as well-managed experiment stations, does not allow the identification of the best genotypes for poorer conditions, and promotes genotypes which are not superior in stressful conditions.

A similar picture emerges from the few published data on genetic correlation between yield measured in high and low yielding conditions (Atlin and Frey, 1989, 1990; Ud-Din *et al*. 1992; Ceccarelli *et al*. 1992; Cooper and DeLacy, 1994).

In general, when different genotypes of a given crop are evaluated in a sufficiently wide range of environments, GE interactions of a crossover type (Fig. 2) seem to be very common. This indicates that, as a general phenomenon, genotypes selected under optimum growing conditions do not perform well under poor growing conditions, and vice-versa. This is hardly surprising as physiologists have long recognized, with specific reference to drought, that high yield in favorable conditions and high yield in unfavorable conditions are associated with different physiological mechanisms and different phenologies (Hsiao, 1982; Blum, 1993).

The range of environments in Fig. 2, and their associated yield levels, may represent either variation over time within one given geographical area, or variation over space (different geographical areas within or across countries). We assume that the yield levels below the crossover point are fairly representative of variation over time within a given geographical area. In areas of this type, the probability of climatic events that will determine yields above the crossover point are possible but rare as shown in Fig. 1.

The implications of a crossover GE interaction have been discussed by Hildebrand (1990), Stroup *et al*. (1993), Simmonds (1991) and Ceccarelli (1994). Formal breeding has taken a negative attitude towards GE interaction, and because selection is frequently conducted only in high yielding conditions, has been unable to serve farmers in environments which are at the other side of the cross-over point (Fig. 3). Figures 2 and 3 indicate that breeding for environments below the cross-over point must be based on direct selection in the target environments because the best genotypes for these environments can only be identified if selection is done in unfavorable environments.

Selection in unfavorable environments

Breeding for unfavorable environments based on selection (not merely testing) in the target environments is undoubtedly more complex than selection for favorable environments largely because of the year-to-year variation. Procedures and methodologies developed for favorable environments need to be modified. The methodology for barley enhancement at ICARDA is the following:

a. Breeding material (including parental material and segregating populations) is evaluated in the target environments using farmers' agronomic practices, including rotations. In the driest site (long term average rainfall of 233 mm) this means no use of fertilizers, pesticides and weed control. Farmers' fields are inspected over one or two cropping seasons earlier and those where the farmer's crop is sufficiently uniform are selected as "experiment sites". Concurrently, the material is evaluated at the main experiment station (long term average rainfall of 373 mm) with a level of inputs commonly used in moderately favorable areas. In all the "experiment sites" the material is evaluated strictly under rainfed conditions.

b. Experimental designs have evolved from the randomized block design to the lattice design -lattice design (introduced in 1993). This has progressively improved our control of environmental variability.

c. Segregating populations are evaluated as bulks for three years taking advantage of the large year-to-year variation in total rainfall, rainfall distribution and temperature patterns. Each year bulks yielding less than the check are discarded. Individual plant selection is done only within the selected bulks.

d. Selection is done for high grain yield et each of the experiment sites, regardless of the performance in other experiment sites. This promotes breeding material with specific adaptation.

e. In addition to grain yield, traits used as selection criteria are: plant height, tillering, straw softness and disease resistance in the two driest sites; earliness, lodging and disease resistance in the wettest sites.

Using this methodology for barley breeding at ICARDA, direct selection in unfavorable environments revealed that locally adapted landraces could be a useful source of breeding material that would have been missed had the evaluation taken place only in high yielding environments (Table 2). In Table 2 the term landraces refers to pure lines isolated by pure-line selection from syrian landraces. The data of Table 2 would suggest that repeated cycles of selection in a given type of environment will reduce the frequency of lines specifically adapted to other environments. This explains why testing lines in marginal environments, after a number of cycles of selection in near-optimum environments, has led many breeders to believe that the expected gains with breeding for marginal environments are small. Table 2 also shows that not only do landraces have, as a group, a higher average yield under stress than non-landraces, but that there is considerable variation within landraces. Also, the landraces with the lowest yield under stress, always yielded much more that the lowest yielding non-landraces in the same group. The presence of useful diversity within landraces has been documented in many crops. The diversity within barley landraces collected in Syria and Jordan has been documented by Ceccarelli *et al*. (1987), van Leur *et al*. (1989), Weltzien (1988, 1989), Weltzien and Fischbeck (1990) and Ceccarelli *et al*. (1995). More recent evidence of this diversity is given in Table 3 for four populations collected along the Euphrates river (Fig. 4). The first three populations (collected in sites 21, 22 and 23) are black-seeded, while the population collected in site 24 is white-seeded. The black-seeded populations gave, in general, lower yields both at Breda (290 mm rainfall) and Tel Hadya (373 mm rainfall) but were taller than the white-seeded population in the driest site. Plant height is very important to farmers because it determines whether the crop can be harvested by combine or has to be hand-harvested, which is much more expensive. These data explain why farmers in the driest areas of Syria grow mainly the black-seeded barley landrace. For all the five traits evaluated there was a large diversity within each population, as shown by the range. The highest yielding lines gave a much higher yield than the improved cultivars Harmal and Rihane-03, and comparable with Arta, the best improved landrace. Within site 24 there were lines outyielding significantly Arta at Tel Hadya.

The exploitation of the diversity within barley landraces, an ongoing activity in the barley breeding program at ICARDA during the last 10 years, has been a powerful means to improve barley yields in marginal environments and in areas where the landraces are the predominant cultivars. Arta, a recently released barley variety, is perhaps the best example of the usefulness of the diversity within landraces. Arta is a white-seeded pure-line derived from one head collected in 1981 in a farmers field at Um-Zeitoun, near Sweida, about 100 Km east of Damascus, in the Haurani plateau. It has outyielded the landrace from which it has been selected, as well as the black-seeded landrace (A.Aswad) in many trials and in many locations in Syria (Table 4).

These data provide a strong indication that a) it is indeed possible to make progress with selection under unfavorable conditions, and b) that a large amount of potential improvement in unfavorable environments is missed by breeding programs using only selection in favorable conditions and neglecting the locally adapted germplasm.

Decentralization: using specific adaptation in international breeding programs

International breeding programs aim to assist national programs to increase agricultural production by developing superior cultivars. This is traditionally done through very large breeding programs which develop fixed or semi-fixed lines with an average good performance across many environments (often well managed experiment stations). The interaction between international and national programs has been largely a one-way, "top-down" process (Simmonds and Talbot, 1992) where international programs develop germplasm, distribute it as "international nurseries", and national programs test and eventually release it as varieties. This has commonly excluded the use of locally adapted germplasm, which often performs poorly in favorable conditions such as those of experiment stations, and encouraged its displacement.

The adoption of a positive interpretation of GE interaction by international breeding programs has been advocated as a way to address the need of small, resource-poor farmers, who have been by-passed by the Green Revolution (Stroup *et al*., 1993).

To exploit specific adaptation fully and make positive use of GE interactions, an international breeding program should devolve most of the selection work to national programs by gradually replacing the traditional international nurseries with earlier generation material. Early distribution of breeding material reduces the danger of useful lines being discarded because of their relatively poor performance at some test sites. This problem is illustrated by 288 barley lines evaluated both in the Maghreb countries (Libya, Tunisia, Algeria, Morocco) and in ICARDA's preliminary yield trials grown at three sites in Syria (ranging from moderately favorable to unfavorable) in 1991/92 (Table 5). In the Maghreb countries visual selection was used, whereas in Syria selection was for yield potential, yield under stress, and heading date. 103 entries were selected in Syria and 154 in the Maghreb but only 49 of these were selected both in Syria and in Maghreb. More than half of the lines selected in Syria were discarded in Maghreb, and almost 70% of those selected in Maghreb were discarded in Syria. This gives a measure of the danger of discarding lines potentially useful in other areas in a centralized breeding program.

In 1991 ICARDA's barley breeding program started a gradual process of devolution of selection work to the four Maghreb countries (Ceccarelli *et al*., 1994). When fully implemented, national programs in north Africa will receive from ICARDA's barley breeding program only targeted F_2 segregating populations (based on crosses partly designed by national programs), and yield trials consisting of lines derived from these F_2's selected in-country. Selection between F_2 populations will be in the different agroecological environments within each country under conditions as similar to farmers' fields as possible. Lines selected from superior F_2 populations will be advanced at ICARDA and then yield tested in different locations within each country.

Other breeding programs at ICARDA, such as barley and lentil breeding for the Anatolian plateau in Turkey, lentil breeding for the Indian subcontinent, and durum wheat breeding for Morocco are based on the same philosophy.

However, decentralization to national programs of the selection component of an international breeding program will not respond to the needs of resource-poor farmers if it is only a decentralization from one experiment station to another. This can be solved by what may be considered the most extreme decentralization and possibly the most effective way of exploiting specific adaptation, i.e. farmers' participation in selection under their own conditions.

Maximizing specific adaptation through farmers' participation

The idea of farmers participating in the development of new technology is not new. It was introduced in 1982 (Rhoades and Booth, 1982) as "the farmer-back-to-farmer model", later modified into the "farmer-first-and-last-model" (Chambers and Ghildyal, 1985) and more recently discussed by Sperling *et al.* (1993) and Stroup *et al*. (1993). Using Sperling's terminology, "formal breeding programs" can be described as a sequential and cyclical process in which 1) an extremely large amount of genetic variability is continuously created, 2) this variability is drastically reduced through selection (we have seen that this is often done in conditions which have little in common with those of resource-poor farmers), and 3) the few lines surviving step 2 are presented to farmers who are asked to verify if the choices made for them are appropriate (Fig. 5A).

As discussed the process has been very effective for those farming systems which are sufficiently similar or not too dissimilar from those on experiment stations. It has however been used as a model even for target environments very different from those of experiment stations, and it is now acknowledged that the process has been ineffective for unfavorable environments. The reason is likely to be associated with GE interaction. It is also possible that the plant characteristics which are used as selection criteria in a high yielding environment, such as an experiment station, are not those which give the future variety an advantage when grown by a resource-poor farmer. Indeed, there is evidence that when farmers are involved in the selection process, their selection criteria may be very different from those of the breeder (Hardon and de Boef, 1993; Sperling *et al.*, 1993). There is also evidence that, when breeders and farmers select in the same environment, farmers' selection can be effective (Table 6) implying that farmers possess considerable knowledge which is almost totally neglected in formal plant breeding programs.

A typical example of different selection criteria between farmers and breeders can be found in crops, such as barley, used as animal feed. Breeders often use grain yield as the sole selection criterion which usually brings with it high harvest index and lodging resistance. However, in unfavorable environments lodging is often not a problem because of moisture stress, and farmers are interested not only in grain yield, but also in forage yield and in the palatability of both grain and straw.

Farmers' participation in the ICARDA barley breeding program to-date has been informal and consisted of discussions during field visits and occasional inspection and selection by farmers of breeding lines. The most significant contribution of this informal participation has been the incorporation by the breeders of plant height under drought and softness of the straw as selection criteria in breeding barley for dry areas. As mentioned earlier, a crop which remains tall even in very dry years, is important to farmers because it reduces their dependence on costly hand harvesting, while soft straw is considered important in relation to palatability. It is obvious that these two characteristics represent a drastic departure from the typical selection criteria used in breeding high yielding cereal crops - short plants with stiff straw and high harvest index. It is also obvious that cultivars possessing the two characteristics considered important by farmers in dry areas will not be suited for cultivation in high yielding environments because of their lodging susceptibility - a further indication of the importance of specific adaptation. Lines extracted from Syrian barley landraces show little variation in straw softness but considerable variation, both between and within collection sites, for plant height (Fig. 6). The most promising avenue to improve plant height under drought is offered by the use of the wild progenitor of cultivated barley (*H. vulgare* ssp. *spontaneum*), still widely distributed along the Fertile Crescent where, particularly in the driest areas, it can be easily identified at a distance because of its tallness. Table 7 shows the tallest of 1532 most recently developed breeding lines tested in 1994/95 at a site which received only 222 mm rainfall. While the mean plant height of all the lines was 23.5 cm, the shortest lines were only 12.5 cm tall, and the most widely cultivated landrace (Arabi Aswad) was about 25 cm, some of the lines derived from crosses with *H. spontaneum* were taller than 40 cm. They were also significantly taller than Zanbaka, a pure line selected from A. Aswad and already grown by some farmers for its plant height.

A formal plant breeding program could combine the concept of a positive use of GE interaction with the utilization of farmers' knowledge by evaluating a wider range of germplasm under farmers' field conditions and in conjunction with farmers (Fig. 5B). In those communities where extension services and conventional seed production systems are not able to reach resource-poor farmers, and farmers traditionally use their own seed from one cropping season to another, this will provide a direct link between formal plant breeding and farmers. The benefit to the farmers will be direct access to improved germplasm. The benefit to all the community will be the maintenance of genetic diversity within a crop because different farmers are likely to select different materials. Eventually, the benefit to formal breeding programs could be a higher efficiency by using farmers' selection criteria.

Conclusions

Breeding for sustainability has been defined as a process of fitting cultivars to an environment instead of altering the environment (by adding fertilizer, water, pesticides, etc.) to fit cultivars. (Coffman and Smith, 1991). Also, it has been recognized that the key to increased production with fewer external inputs, a condition which is more self-sustaining and less harmful to the environment, will be through a reevaluation of the identification and use of selection and testing environments (Bramel-Cox, *et al*. 1991).

This paper has shown that for a typical crop of marginal and unpredictable environments such as barley, it is possible to exploit genetic differences for specific adaptation to marginal environments under farmers' conditions and improve yield without additional inputs. Breeding for specific adaptation not only offers a solution to how to improve agricultural production in marginal environments, but can do so in a sustainable way. This breeding philosophy, based on a positive interpretation of GE interaction, is in contrast with the common belief that the introduction of inputs, such as fertilizer and irrigation, to raise the yield potential is an essential prerequisite for successful breeding work. Breeding for an agronomically improved environment dictates the type of germplasm which will best exploit it,and is based on genetic uniformity-the reverse of the biological diversity requisite for minimizing risk in most natural systems (Wilkes, 1989).

The use of high input selection environments in a market-driven agriculture has been largely responsible for the trend of modern plant breeding towards narrowing the genetic base of our crops accompanied by a trend towards homogeneity: one clone, one pure line, one hybrid (Simmonds, 1983). Uniformity and broad adaptation are very useful attributes to accommodate large scale centralized seed production (Davis, 1990).

Although the merits of genetic uniformity has been questioned in developed countries (Wolfe, 1991), it is still very popular in breeding programs and seed production systems of developing countries at both the national and international level. This is in contrast with the genetic diversity that characterizes agriculture in marginal environments. Genetically heterogeneous landraces are still the backbone of agricultural systems in many developing countries, mainly in marginal environments where their replacement by modern, genetically uniform varieties bred for favorable environments has proved to be a difficult task at the levels of inputs farmers can afford.

Breeding for specific adaptation to unfavorable environments implies a reevaluation of the role of genetic resources such as landraces which can play an important role because they possess adaptive features to these environments. This is the first consequence on biodiversity of breeding for specific adaptation.

A second consequence of exploiting specific adaptation on biodiversity is that the number of varieties (not necessarily homogeneous) of a given crop grown at any time will be large. The benefits of maintaining genetic diversity within a crop over large areas has been discussed extensively in the literature in relation to resistance to pests and diseases and does not need further justification. A major constraint of breeding for specific adaptation is the problem of how to distribute many varieties among farmers. However, the distribution of specifically adapted varieties to resource-poor farmers does not have to follow the conventional release-seed production-seed certification schemes used in developed countries. Indeed, there are examples of successful distribution and adoption of varieties through non-market methods (Grisley, 1993).

In those country where the same crop is grown both in favorable and marginal conditions, breeding has traditionally given priority to the more favorable areas. At the country level, larger increases of national production can be obtained by increasing production in good environments through the joint effect of improved varieties and improved agronomic practices. However, such a strategy will neglect many small and poor farmers who could represent the majority of the farmers in the country. We believe it is possible to increase agricultural production at the country level and, at the same time, to serve small, resource-poor farmers by recognizing that the two types of environments need separate breeding programs, with different objectives, methodologies and type of germplasm.

What we have witnessed at ICARDA has been the convergence and integration of two philosophies into a new approach to crop breeding for low-input and stressful environments. On the one hand we had the "farmer-back-to-farmer" philosophy with all that this entailed in the use of indigenous knowledge through farmer participation, and on the other hand the recognition of the need to breed for specific rather than broad adaptation if the resource-poor farmers living in stressful environments were to benefit from the advances of modern plant breeding. The outcome is that the farmer is becoming an essential partner with national and international plant breeders in an effort to exploit GxE interactions for the benefit of the large number of resource-poor farmers striving for economic advancement in the more stressful agricultural regions of the word.

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Table 1. Average grain yield (kg/ha) of the 5% highest yielding barley genotypes in the lowest yielding site and of the 5% highest yielding barley genotypes in the highest yielding site in the lowest and highest yielding sites, compared with the population means. The data are the means of 10 cropping seasons (1985/86-1993/94).

Selected in:	Average grain yield in:	
	Low yielding sites	High yielding sites
Low yielding sites	1613	3938
High yielding sites	1110	5030
Population mean	1041	3974

Table 2. Grain yield (kg/ha) under stress (YS) and grain yield under non-stress (YNS) of barley breeding lines classified according to the germplasm type

Set[a]			**YS**[c]		**YNS**[d]	
	Type of germplasm	N[b]	Yield	Range	Yield	Range
1	Non-landraces	155	488	0-893	3901	2310-4981
	Landraces[e]	77	788	486-1076	3413	2398-4610
2	Non-landraces	207	589	197-1101	5400	3558-6962
	Landraces	43	734	468-954	4435	2883-5728
3	Non-landraces	296	634	0-1119	2687	1241-3893
	Landraces	83	802	414-1203	2513	1829-3738
4	Non-landraces	165	525	196-852	3631	1339-4862
	Landraces	76	764	567-990	3275	1378-4309

[a] Group of lines tested in the same locations and years
[b] number of lines
[c] Average yield in low yielding sites
[d] Average yield in high yielding sites
[e] Pure lines selected from landraces

Table 3. Variability between and within populations collected in four sites along the Euphrates river in Syria for grain yield in Breda (290 mm rainfall) and Tel Hadya (373 mm rainfall), for days from emergence to heading, for growth habit (1= erect, 5= prostrate) and for plant height in Breda. In parenthesis the number of lines per collection site.

Coll. sites	**Grain yield (kg/ha)**		**Heading**	**Growth habit**	**Plant height (cm)**
	Breda	**Tel Hadya**			
Site 21 (n = 86)					
means	1289	2903	111	3.3	45
min	891	2207	105	2.0	30
max	1837	3695	114	5.0	54
Site 22 (n = 79)					
means	1311	2870	110	3.2	47
min	706	2207	106	2	39
max	1754	3497	114	5	56
Site 23 (n = 70)					
means	1296	2846	110	3.2	43
min	*832*	*1553*	*107*	*2.3*	*28*
max	1837	3725	115	4.3	55
Site 24 (n = 64)					
means	1385	3566	110	3.2	34
min	884	1774	105	1.9	25
max	1823	4491	113	4.3	50
Checks[a]					
Arta	1814	3773	114	3.6	32
Zanbaka	1139	2457	112	4.1	50
Harmal	1164	3309	106	2.6	45
Rihane-03	1284	3624	114	3.0	49

[a] Arta and Zanbaka are two selections from Syrian landraces, Harmal and Rihane-03 are two modern cultivars

Table 4. Performance of Arta during four cropping seasons in the on farm trials[a] in Syria

Year	No. of sites	Mean yield	Rank	% over		
				A.Abiad	**A.Aswad**	**Best line**
1988-89	4	1814	1	+18.6	+10.6	+18.6
1989-90	9	1962	1	+12.3	+5.8	+3.5
1990-91	10	2341	1	+5.0	+18.5	+5.0
1991-92	13	3358	1	+31.6	+10.8	+1.8
1991-92	4[b]	3263	1	+52.5	-	+33.5

[a] two or three replications with 32 m^2 plots
[b] unreplicated with 1000 m^2 plots

Table 5. Number (No) and percent (%) of lines selected in Syria and in Maghreb countries (Libya, Tunisia, Algeria and Morocco) from a common nursery of 288 lines

Selected in	N	%[a]
Syria	103	35.8
Maghreb	154	53.5
Syria and Maghreb	49	17.0
Syria-discarded in Maghreb	54	52.4
Maghreb-discarded in Syria	105	68.2

[a] the first three percentages are calculated on the total number of lines (288) in the nursery, the last two are calculated on the number of lines selected in Syria and Maghreb, respectively.

Table 6. On-farm performance of varieties of bush bean selected from on-station trials by farmers and of varieties selected by breeders in Rwanda (modified from Sperling et al., 1993)

Year	Number of trials	% of trials where new variety outyielded local mixture	Yield increase (%) of new variety over local mixture
FARMER SELECTION			
1989A	11	73 ns	3.9 ns
1989B	19	89 **	33.4**
1990A	36	64 ns	12.9 ns
1990B	18	83 **	38.0**
BREEDER SELECTION			
1987A	32	34 ns	-8.8 ns
1988A	45	49 ns	-18.9 ns
1988B	15	53 ns	0.7 ns

*, ** differences significant at $P < 0.05$ and $P < 0.01$, respectively; ns, not significant

Table 7. Plant height at Breda (222 mm rainfall) in 1995 of barley lines derived from crosses with H. spontaneum, compared with the barley landrace most common in dry areas (Arabi Aswad) and with a cultivar selected specifically for plant height under drought (Zanbaka).

Cross/Name	**Plant height (cm)**
H.spontaneum 20-4/Arar 28//WI2291/Bgs	43.5
SLB 45-40/*H.spontaneum* 41-1	43.0
Zanbaka/*H.spontaneum* 41-2	42.5
Zanbaka/*H.spontaneum* 41-2	41.5
Moroc 9-75/Arabi Aswad//*H.spontaneum* 41-3	41.0
Arabi Aswad	24.8
Zanbaka	26.0
Mean of all breeding lines	23.5
maximum	43.5
minimum	12.5
L.S.D.$_{0.05}$	5.6

LEGEND OF FIGURES

Fig. 1. Frequency distribution of barley yields in unfavorable (Zone C = less than 250-300 mm annual rainfall) and moderately favorable (Zone B = 300-350 mm annual rainfall) environments in Syria between 1983 and 1994.

Fig. 2. Cross-over type of G x E interaction: A and B are typical genotypes selected in high and low yielding environments, respectively.

Fig. 3. Hypothetical GE interaction of cross-over type between experiment stations and farmers fields.

Fig. 4. Locations of the four collection sites of barley landraces in northern Syria used in Table 3.

Fig. 5. Schematic representation of formal (A) and participatory (B) breeding programs: in the first case farmers are passive recipients, in the second they participate in the development of new varieties.

Fig. 6. Frequency distribution of plant height under drought in pure lines extracted from Syrian barley landraces collected in two sites in northern Syria. Plant height was measured in Breda (290 mm rainfall) in 1994 on 86 lines of site 21 and 64 lines of site 24.