The ICARDA Strategy for Global Barley Improvement

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1. The Crop

Barley (*Hordeum vulgare* L. emend. Bowden) was domesticated about 10000 years ago in the Fertile Crescent of the Near East, at sites not far from where today ICARDA' headquarters are located, from wild forms morphologically identical to present-day *Hordeum spontaneum*. The main difference between cultivated barley and *Hordeum spontaneum* is the fragile (brittle) rachis of the wild progenitor.

From this origin, barley is now grown over a broader environmental range than any other cereal from 70^{o}N in Norway to 46^{o}S in Chile. Also, in Tibet, Ethiopia and the Andes, it is cultivated higher on the mountain slopes than other cereals. Barley is considered to be a drought resistant crop and in many dry areas of North Africa, West Asia, Afghanistan, Pakistan, Eritrea, Yemen, and other countries it is often the only possible rainfed crop.

Today barley is grown on 73 million hectares (average of the last five years, Table 1). The area has increased from 59 million hectares in the period 1961-65 to a maximum of more than 80 million hectares in the period 1976-80. The largest barley growing regions are in Russia and the Central Asian States with almost 29 million hectares, and in Europe (about 15 million hectares). There are 25.2 million hectares of barley in the developing countries of Asia, including CAS, and Africa.

Table 1. Area (million hectares) of barley by region.

Region	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95
Africa	4.20	4.33	4.36	4.85	4.93	5.29	5.18
Asia	14.85	12.99	11.72	10.86	11.64	12.48	12.51
N.America	7.04	7.70	8.96	8.07	9.22	8.58	7.23
S.America	1.14	1.04	1.03	0.84	0.56	0.63	0.66
Europe	12.90	15.58	17.79	19.95	19.36	18.15	15.77
Russia+CA	18.30	20.33	28.37	34.00	30.52	28.50	28.70
Oceania	0.87	1.39	2.15	2.57	3.00	2.31	2.94
World	59.40	63.40	74.47	81.21	79.33	76.04	73.06

Source: Agrostat, 1997

The world production of barley (Table 2) is about 160 million tonnes (compared with 530 million tonnes of bread wheat and 29 million tonnes of durum wheat) with Europe being the largest producer, due to the highest yields (Table 3).

The Canadian Wheat Board (CWB) estimates that barley production will increase by almost 5% by the year 2000 (compared with the average 1989-93) and by 10% by the year 2005 (Table 4), while the increase in wheat production will be slightly larger (6 and 12%, respectively). These predictions assume that there are few significant new production technologies on the horizon that might sharply raise grain yields beyond existing trends.

Table 2. Production of barley (million tonnes) by region.

Region	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95
Africa	3.034	3.392	3.800	4.197	4.162	5.412	4.986
Asia	17.296	15.445	14.675	16.080	17.272	18.651	20.244
N.America	12.711	16.316	19.534	19.74	24.346	23.035	21.520
S.America	1.264	1.063	1.194	1.039	0.695	1.004	1.136
Europe	33.777	44.817	57.167	66.800	70.904	71.198	60.567
Russia + CAS	18.693	28.018	39.819	50.77	40.545	48.154	47.213
Oceania	0.978	1.586	2.5766	3.124	4.127	3.672	4.975
World	87.852	110.810	139.037	162.043	162.487	171.5412	161.019

Source: Agrostat, 1997

Table 3. Yield of barley (kg/ha) by region.

Region	1961-65	1966-70	1971-75	1976-80	1981-85	1986-90	1991-95
Africa	0.72	0.78	0.87	0.86	0.84	1.03	0.96
Asia	1.16	1.19	1.25	1.48	1.48	1.50	1.62
N.America	1.82	2.11	2.17	2.45	2.64	2.67	2.98
S.America	1.10	1.02	1.15	1.23	1.25	1.58	1.72
Europe	2.60	2.87	3.21	3.34	3.67	3.93	3.84
Russia + CAS	1.02	1.37	1.41	1.51	1.33	1.70	1.64
Oceania	1.13	1.14	1.20	1.22	1.34	1.58	1.66
World	1.48	1.74	1.87	1.99	2.05	2.26	2.20

Source: Agrostat, 1997

Table 4. World production of major grains (from Brophy, 1996)

	1989-93 Average base Period	Projections	
		1999/2000	2004/2005
All wheat	559	593	625
Durum wheat	29	27	29
Coarse grains	813	842	910
Barley	169	177	186
Total	1570	1639	1750

Brophy, 1996.

Barley grain is used as feed for animals, malt and human food. Barley straw is used as animal feed in West Asia, North Africa, Ethiopia, Eritrea, Yemen, in the Andean region and the Far East. Barley straw is also used for animal bedding and as cover material for hut roofs. After combine-harvesting barley stubble are grazed in summer in large areas of West Asia and North Africa. Barley is also used as animal feed at the vegetative stage (green grazing) or is cut before maturity and either directly fed to the animal or used for silage.

Malt is the second largest use of barley, and malting barley is grown as a cash crop in a number of developing countries.

In the highlands of Tibet, Nepal, Ethiopia, Yemen, Eritrea, in the Andean countries, in North Africa, Turkey, Iran, Iraq, Afghanistan, India and Russia, barley is used as human food either for bread making (usually mixed with bread wheat but also with other cereals or food legumes) or for traditional recipes. In history, barley was the energy food of the masses, its use as human food was very popular during the Roman Empire (gladiators were fed on a strict barley diet before fighting against the lions, and for this they were known as *hordeari*) and has been common in many European countries until the first part of this century.

In many developing countries barley is typically a crop of less-favored, low input, stressful environments, and in many areas of West Asia and North Africa (WANA) barley is often the only possible rainfed crop, and the last crop possible before the steppe, and the desert.

With the exception of China, Ethiopia and India, the developing countries with the largest area of barley are either in WANA or in Central Asia (Table 5). The two main agroecological environments where barley is grown in WANA and Central Asia are the continental dry lowlands mostly with cold winters, and the continental dry highlands with very cold winters. A third agroclimatic environment is represented by the tropical highlands (Andes, Ethiopia, Yemen, Eritrea, the Himalayan countries). This is not very large in area but is inhabited by some of the poorest people in the world for whom barley is one of the main sources of calories. In the Andes barley is the staple food for farmers at altitudes ranging from 2,200 to 4,000 meters above sea level. Above 3,000 meters, barley, faba bean, potatoes and quinoa are the four crops that support human and animal life. Barley is used by subsistence farmers in the preparation of several dishes; barley flour, finely ground and roasted called machica or pito; barley rice, a coarsely broken grain used for soups, and more recently barley flakes as a breakfast cereal.

In India barley is grown as rainfed crop on residual moisture. In many of these situations barley yields have not significantly increased and vary mostly in response to fluctuations in climatic conditions.

The major constraints to barley production are associated with the reputation of the crop of being able to withstand the most severe conditions such as elevation, aridity, salinity, poor soil fertility, and poor agronomic management. Because in several environments where the crop is grown in developing countries, the risk of crop failures is high, the use of inputs such as fertilizer, herbicides or pesticide is virtually absent.

In the majority of developing countries the seed of barley is usually produced on farm. Even in those countries with a rather developed seed production and distribution system such as Morocco, only 3% of the barley seed is certified seed (compared with 25% for durum wheat and 80% for bred wheat).

The consequence of stagnant yields and of increased demand due to population growth is that substantial import growth is expected (by the CWB) for Latin America, Asia Pacific, West Asia and Africa (Table 6).

Table 5. Area, production and yield (kg/ha) of barley in the fifteen developing countries with the largest barley growing area (the data are averages of the period 1991-1995).

Country	**Area (million ha)**	**Production (million t)**	**Yield (kg/ha)**
Russian Fed.	15.289	24.168	1.58
Kazakhstan	5.890	5.936	0.99
Ukraine	4.286	11.950	2.80
Turkey	3.488	7.340	2.11
Morocco	2.180	1.938	0.83
Syria	2.105	1.353	0.65
Iran	1.972	3.074	1.57
Iraq	1.680	1.137	0.67
China	1.290	3.220	2.51
Belarus	1.146	2.953	2.58
Ethiopia	1.053	1.232	1.16
Algeria	1.014	0.878	0.78
India	0.903	1.531	1.69
Lithuania	0.602	1.132	1.88
Tunisia	0.406	0.399	0.87

Table 6. World barley imports by regions, in thousand tones (from Brophy, 1996)

	1989-93 Average base Period	**Projections**	
		1999/2000	2004/2005
Europe	1,448	650	670
Former USSR	4,940	1,130	1,010
Middle East	6,469	7,440	8,440
Africa	1,275	1,570	1,420
Asia Pacific	2,757	4,050	4,290
Latin America	580	790	930
Total	14,132	10,790	11,540

2. The objective of the project

The long term objective of the barley improvement project at ICARDA is a sustainable increase in barley productivity by adapting the crop to the different farming systems and uses in developing countries **with special emphasis in those areas where the crop is grown by resource-poor farmers, thus contributing to alleviation of poverty**.

The specific objectives of the barley project are:

to collaborate with national programs in germplasm development,
to strengthen national barley breeding programs
to develop a conceptual framework to improve efficiency of breeding in different environments with emphasis on low-input, stressful environments.

These objectives are pursued with strategies which have evolved over the last 20 years and which differ according to the changing research capacity of the cooperating national programs. Initially the main emphasis was on the centralized development of varieties; gradually the program has given increased emphasis to the development of breeding methodologies. In the last few years the project emphasized the decentralized selection of segregating populations based on targeted crosses partially designed by NARS.

3. Project's philosophy: Decentralized Breeding

To target the poor, the breeding philosophy of the project is based on exploiting specific adaptation through direct selection in the target environments using locally adapted germplasm and sustainable levels of external inputs (Ceccarelli et al., 1994).

The two major implications of this philosophy are that (1) many varieties will be generated by national programs, each adapted to specific conditions, and (2) the superior performance of the varieties developed for low-input and less-favored lands will not depend on agronomic practices that require large amount of inputs. A breeding program based on this philosophy will not endanger biodiversity, and is environmentally benign.

A fundamental question addressed by the barley program is why plant breeding has been beneficial to those farmers who either enjoy favorable environments or could profitably modify their environment to suit new cultivars, and it has not been equally beneficial to those farmers who could not afford to modify their environment through the application of additional inputs. Farmers in favorable environments, using high quantities of inputs, are now concerned with the adverse environmental effects and the loss of genetic diversity. Poor farmers in less-favored environments continue to suffer from chronically low yields, crop failures and, in the worse situations, malnutrition and famine. Because of its past successes, conventional plant breeding has tried to solve the problems of poor farmers living in unfavorable environments by simply extending the same methodologies and philosophies applied earlier to favorable, high potential environments. We have hypothesized that difficult environments and resource-poor farmers require a different type of breeding.

Using contrasting sites in NW Syria we found repeatable genotype x environment (GE) interactions of crossover type between the main experiment station and experiment sites managed according to farmers' practices (Ceccarelli, 1994). GE interactions of crossover type are common in the literature, in different crops and in different types of stress environments. We concluded that selection in high input experiment stations is very effective in generating varieties for favorable environments, but does not allow the identification of the best genotypes for less-favored areas, and promotes genotypes which are in fact inferior to local landraces in stressful conditions.

Formal breeding has taken a negative attitude towards GE interactions of crossover type, in the sense that only breeding lines with low GE interaction (good average grain yield, across locations and years) are selected, while lines with good performance at some site and poor performance at others are discarded. Because lines with good performance in unfavorable sites and poor response to favorable conditions have a low average grain yield, they are systematically discarded. Yet they would be the ideal lines for farmers in unfavorable locations (Ceccarelli et al., 1998). Therefore, having recognized the importance of GE interactions of crossover type, a major conclusion was that **breeding for difficult environments must be based on the exploitation of specific adaptation, and this in turn can only be done by selecting directly in the target environments**.

While the application of this philosophy started being successful in Syria with the adoption of three varieties in stress environments, the next question was: how to reconcile the mandate of an international breeding program with the importance of specific adaptation?

The response to this question has been the decentralization of the breeding work. The term decentralization has been used often to describe two fundamentally different processes, namely decentralized selection and decentralized testing.

Decentralized selection is a term first used by Simmonds (1984) and defined as selection in the target environment(s). Decentralized selection has been also termed *in-situ* or on-site selection. In the case of self-pollinated crops it consists in selection of early segregating populations (such as F2) in a number of locations representing the target environment(s) (climate, soil, farming system and management) the breeding program aims to serve. Decentralized selection becomes selection for specific adaptation when the selection criterion is the performance in specific environments rather than the mean performance across environments.

Decentralized selection is different from decentralized testing, which is a common feature of breeding programs and takes place, usually in the form of multilocation trials and on-farm trials, after a number of cycles of selection in one or few environments (usually with high levels of inputs).

In decentralized selection, the barley project at ICARDA continues to generate genetic variation by maintaining a large crossing program, but selection is carried out by the breeders in the National Programs. At this moment, decentralization of barley breeding is fully implemented in North Africa, in Iraq and in Ethiopia, and it is gradually being implemented in the Mediterranean highlands in the framework of the ICARDA/Iran Project, and in other countries (Table 7).

Table 7. Countries and regions where decentralized barley breeding has been initiated.

Country/Region	Countries/Area	Status
North Africa	Egypt, Libya, Tunisia, Algeria, Morocco	Fully implemented
Iraq (Baghdad)	Central Iraq	Fully implemented
Iraq (Mosul)	Northern Iraq	Fully implemented
EARS (East Africa/Red Sea)	Yemen, Eritrea, Tigray	First crosses made in 1998
Ethiopia	Ethiopia (except Tigray)	Use of local landraces fully implemented, first crosses in 1998.
CAC (Central Asia & Caucasus)		First special nursery in 1997
Turkey		First nursery planned for 1999
Cyprus	Cyprus	First special nursery in 1995, first crosses in 1998
Far East	India, Thailand, Vietnam, China	First special nursery in 1996, first crosses in 1997
Pakistan	Pakistan	First special nursery in 1997
Gulf Countries	S. Arabia, Qatar, Oman	First crosses made in 1992
Ecuador	Ecuador	First nursery planned for 1999

The details and the different ways in which decentralized selection has been implemented in the barley project are given by Ceccarelli et al (1999). Here we only emphasize that (i) decentralization is a form of acknowledgment of the increased expertise of national programs during the last twenty years, and (ii) the operational approach to decentralization is pragmatic and can take several forms depending on the nature, the capacity, and the expertise of the cooperating national programs.

For each country and/or region where the two most important conditions for decentralized breeding exist — namely (1) large GE interactions with ICARDA research station(s) and (2) availability of local expertise in plant breeding — decentralization follows generally three steps: first, we send a special nursery to identify suitable parents; second, we start a specific crossing program aimed at developing a specific germplasm pool for that country/region, and, third, we distribute the segregating populations.

When fully implemented, the first step is replaced by the routine in-country screening of various germplasm sources. This, together with the decentralized screening for resistance to pests and diseases (see below), assures that more and more parental material is supplied by the national programs.

Identification of sources of resistance to pests and diseases follows the same concepts, and the identification of sources to resistance to the major barley diseases in North Africa (scald, powdery mildew and net blotch) is entirely conducted in Tunisia and Morocco, while the screening for resistance to barley stem gall midge (*Mayetiola hordei*) is only conducted in Morocco. The Latin-America project follows the same principle by screening segregating populations for disease resistance in the target countries.

The future challenge of the project is to implement the concept of decentralized selection towards all the major barley growing areas of the world. For this purpose the target areas of the project can be divided in the six geographic regions shown with circles in Figure. 1, namely:

Central Asia and Russia
Far East
North Africa
West Asia
Horn of Africa and Yemen
Central and Latin America

These six regions represent a barley area exceeding 47 million hectares, which is more than 60% of the total barley grown in world (73 million hectares).

These regions differ in the type of barley grown (for example, mostly 6 row in North Africa and mostly 2 row in West Asia and West Africa), and in its use (for example, mainly as animal feed in West Asia and North Africa, both as animal feed and human food in North Africa, and as animal feed, human food and malt in the other regions). In the East Africa and Yemen and in Central and Latin America, large part of barley is grown at high elevations, is photoperiod insensitive and it develops and matures at decreasing temperatures, the opposite of the lowland barley grown in North Africa and West Asia, where the crop develops and matures at increasing temperatures and water stress. Central Asia and Russia on the one hand, and the Far East on the other, are very heterogeneous since both winter and spring barley are grown in both high and low rainfall areas. These last two geographical areas are grouped based more on tactical than biological reasons. In fact they would probably require specific sub-projects conducted by staff acquainted not only with the crop but with the culture of these populations.

Fig. 1. A global barley project to serve 47 million hectares in four continents.

The project works with a very wide range of germplasm to cope with the variety of environments where barley is grown and with the variety of its uses. Thus, the germplasm base ranges from spring to winter, from hulled to hulless, and from the wild progenitor, *Hordeum spontaneum* to landraces and modern cultivars.

These six areas can be effectively served, under the common philosophy of breeding for specific adaptation, and with levels of external inputs that are not harmful to the environment, by developing specific germplasm pools for the specific needs of each geographical area.

When the breeding in the six areas indicated in Fig. 1 will be fully decentralized, including the screening for resistance to pests, diseases and viruses, 80% of the germplasm development will be in the form of targeted segregating populations, while 20% will be in the form of fixed lines. This residual responsibility for complete cultivar development will be targeted to the environments in which ICARDA has selection sites, and to those countries where the barley area is too small and/or the National Program does not have the technical possibility of handling segregating populations.

3. 1. Project's philosophy: From Decentralization to Participation

Although National programs accepted decentralization very positively, we recently recognized that decentralization *per se* does not necessarily respond to the needs of resource-poor farmers in less-favored areas. Often it is only decentralization from the research station(s) of ICARDA to the research stations of the national programs, and therefore it is still missing the target because the research stations seldom represent the difficult environments where the majority crop is grown. To exploit the potential gains from specific adaptation to low-input conditions, breeding must be decentralized from research stations to farmers' fields in target production areas. Participation of farmers in the very initial stages of breeding, when the large genetic variability created by the breeders is virtually untapped, is expected to exploit fully the potential gains from breeding for specific adaptation through decentralized selection by adding farmers' perception of their own needs and farmers' knowledge of the crop (Ceccarelli et., 1996). Although decentralization and farmer participation are unrelated concepts, decentralization to farmers' fields almost inevitably leads to the participation of farmers in the selection process. Therefore, the ICARDA barley program considers farmer participation as a type of decentralized selection to exploit GE interactions and to benefit, within a formal breeding program, from the farmers' knowledge of the crop, its specific uses and its specific adaptation (Ceccarelli et., 1997).

The first participatory breeding project ("Farmer Participation and Use of Local Knowledge in Breeding Barley for Specific Adaptation", supported by BMZ) started in Syria in 1997. The objective was to test an alternative way to produce improved varieties of crops grown in marginal environments such as barley. This alternative way is to introduce early- generation segregating populations into selected farmers' fields for farmer selection between populations. During the first two years the project demonstrated that farmers' selection is an efficient alternative to old paradigms, and could become a generalized strategy for the improvement of crops in marginal conditions (Ceccarelli et al., 1999).

All the national scientists who have visited ICARDA during the last three years have been exposed to the activities of this project, and many of them at the end of their visit ask ICARDA to help in developing similar activities in their own countries. As a result, there are now participatory barley breeding projects in Tunisia and Morocco (funded by the International Development Research Center, Canada), in Yemen (funded by the System Wide Program for Participatory Research and Gender Analysis), in Ethiopia (funded by the Government of the Netherlands), and in Eritrea, supported by Italy. Participatory barley breeding projects are in preparation in Jordan, in collaboration with the University of Jordan in Amman, the National Center for Agricultural Research and Transfer of Technology, the Jordan University of Science and Technology, and the Jordanian Hashemite Fund for Human Development, and in Egypt, in collaboration with the Matrouh Resource Management Project.

The most recent development in the area of farmer participation is the study of methodologies which allow the participation of small farmers: the question we are addressing is how to reconcile the large number of entries which are usually handled by a formal breeding program with the space limitations faced when dealing with small farmers.

4. Interaction with NARS

The major areas of interaction with NARS have traditionally been the distribution of germplasm, collaborative research, and training.

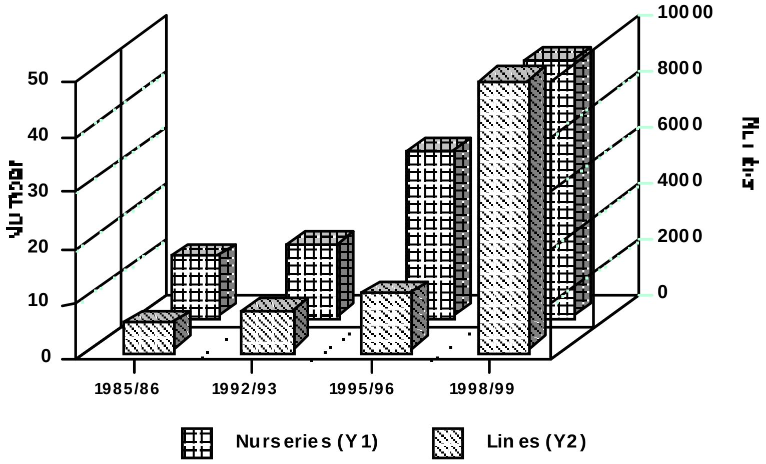
4.1 Distribution of germplasm: from International to Special Nurseries

The major mechanism of germplasm distribution has been through the “International Nurseries”. In the case of barley and until 1984 the international nurseries were mostly fixed lines with about 20% of segregating populations. There was little contribution by NARS scientist in the composition of the nurseries and in the crosses which generated the segregating populations.

Fig. 2 Evolution of barley nurseries from 1985/86 to 1998/99. The number of different types of nurseries (on the left Y axis) raised from 11 to 46, while the total number of lines in all nurseries (on the right Y axis) raised from 959 to 5770.

The progressive emphasis on specific adaptation, the better understanding of the characteristics of different agroecological environments achieved also through exchange of visits from National Programs, and the availability of more and more barley breeders in the National Programs, has lead to a progressive increase of special nurseries designed to serve the particular needs of a specific country or group of countries.

The trend towards the distribution of early segregating and targeted germplasm has considerably accelerated during the last few years with the implementation of the decentralized approach (Fig. 2).



4.2 Collaborative Research and Training

The barley project has trained more than 150 scientists through four types of activities:

- long term residential training course at Aleppo
- specialized training courses, either in country or in Aleppo
- visiting scientists
- degree training

Specialized training courses on barley improvement were held in Ethiopia in 1987, in Nepal in 1989, and on pedigree and data handling across years and nurseries in Cairo in 1995 and in Tunis in 1997.

There have been a number of collaborative research activities conducted with NARS, many of which associated with the decentralization of the breeding activities.

The future trends in training will largely depend on the demand from National Programs. However, within the limits imposed by the concept that training is a service, we expect:

1. Training of technical staff should become a responsibility of NARS (the long term residential course has been discontinued).
2. Individual training and degree training will be emphasized and should become a component of special projects.
3. Training courses should be used as opportunities to spread through the NARS scientific community new breeding methodologies.

5. Interaction with Advanced Research Institutions (ARI)

The strategy followed in setting up collaborations between the barley project and Advanced Institutions has evolved from a largely passive to a more pro-active role.The future of basic research in barley will largely depend on our ability to identify suitable scientific partnership in ARI's to tackle a number of key research topics in barley improvement. We expect that the majority of our work on various aspects of molecular breeding will be conducted in a collaborative mode with ARI's.

6. Resistance to Biotic Stresses and Biotechnology

As described earlier, the project will move in the direction of developing, in partnership with national scientists, genetic variability targeted to different environments and uses to be exploited by the end users in their own conditions. Emphasis will be given to using the approach in those geographical areas where the project has been only using the traditional approach (notably Latin America, China, Vietnam, Korea, Nepal and other countries in the Far East).

The strategy followed in germplasm development also affects the strategy to be followed in breeding for resistance to biotic stresses and in biotechnology.

6.1. Resistance to Biotic Stresses

Barley is affected by several foliar and root diseases, several insects, nematodes, and viruses. The organisms which can potentially damage a barley crop can be divided in two broad categories, namely those which are specific (either as organism or as a physiological race) to a given country or area, and those which are widespread to several countries.

The overall strategy, once the priority biotic stresses have been identified together with NARS, is to decentralize the work on biotic stresses of the first type to NARS following the development of the necessary expertise, and to concentrate at the headquarters on the second type of biotic stresses. The latter will be ideal ground for collaboration with ARI's.

Within this broad strategy, the work on biotic stresses will be integrated in the more general, decentralized approach to plant breeding followed by the project.

In the case of foliar diseases, insects and viruses, the screening of large amount of breeding material, which has represented 90% of the activities in the past, will be gradually reduced to about 10% of the total work on biotic stresses. Eventually, screening will be entirely transferred to NARS. Specific pests will be tested at hot spots, and information circulated to all collaborators. Sources of resistance will be characterized at the headquarters which will focus on the transfer of genes for resistance into the breeding material developed by the decentralized program for specific countries and/or regions. In these cases the national programs will receive F4 families homozygotes for the resistance gene(s), but variable for everything else. This will be done at the headquarters in the case of genes with non-specific resistance (for example, the genes for resistance to RWA and BYDV), and within five years it will be done routinely with the aid of molecular markers. These first molecular markers assisted selection programs will also be used to train national program scientists.

In the case of foliar diseases, where a large variability exists for physiological races, the responsibility of the headquarter pathologist will be the identification of genes which are effective against the virulences of target countries/regions. Sources of resistance for these genes will be used in the targeted crosses at the headquarters, but the selection of the segregating populations will be done in the target environments. Marker assisted selection will be made available to NARS increase the efficiency of selection.

Two areas which need expansion are a) scab, root diseases and nematodes, and b) durable resistance and population improvement.

To be able to work on resistance to scab, to root diseases and to nematodes the project needs additional scientists (initially post-doc) to focus on these issues, to identify molecular markers which can then be used for selection.

The entire area of durable resistance, and of the consequent changes in the breeding strategies which are needed, must be addressed perhaps not only by the barley project, but at the program level. In barley, we will develop at least one case-study to address one of the most variable foliar diseases (powdery mildew) with two alternative strategies, one based on deployment of major genes and one based on the increase of horizontal resistance through population improvement.

6.2. Biotechnology

The project has considerably expanded the use of various biotechnologies in the last two-three years. At the moment we are completing the work on two mapping populations (WI2291/Tadmor and Arta/*H. spontaneum* 41-1), we have identified two markers (for scald and powdery mildew, respectively), we have studied the genetic diversity within Syrian landraces with microsatellites, and we have determined the genetic diversity within three populations of RIL developed to analyze the adaptation to abiotic stresses using RAPD.

There are four major areas where barley biotechnology will expand:

1. **Molecular breeding**: as mentioned above, breeding for resistance to some pest and diseases (particularly root diseases) will be routinely based on molecular markers within five years. During that period we will make available molecular markers to those NARS for which diseases and/or pest are the major constraint to barley production to allow them to start decentralized marker assisted selection. Within the next five years we will have molecular markers for the undesirable traits of *H. spontaneum* (brittle rachis and rough awns), for osmotic adjustment, and for traits associated with drought resistance.
2. **Double haploid breeding**: although efficiencies with anther culture have been low so far, microspore culture might offer an alternative with increased efficiencies in green plan production. If microspore culture can improve the efficiency of DH production, a combination of DH-breeding and molecular breeding will increase the efficiency of the breeding program by developing targeted crosses for the marker assisted selection, and their double-haploidization with the microspore system.

   Use of double haploids for genetic studies and for the production of mapping populations is currently limited by the lower response of landraces, and even more so of *H. spontaneum* to various double-haploidization techniques. However, in terms of acceleration of the breeding programs, particularly for the material developed for North Africa and West Asia, the program is mature to make full use of the technique.
3. **Transformation**: transformation in barley might become a reality at any time now. A new project beginning in 2000 will give us the possibility of using the technology as soon as it available. Priority genes will be those for self-incompatibility to allow exploiting the heterosis, genes for herbicide resistance, the dehydrin genes, and genes controlling nutritional properties.
4. **Strategic research**: molecular markers will be increasingly used to understand plant adaptive strategies, population structure of landraces and wild relatives.

7. Barley as human food

Barley was a staple food as far back as 18,000 years ago and it is still an important staple food in several developing countries.

The largest consumer of barley as human food is Morocco, where per capita consumption of barley is 64.1 kg per year (FAO estimates for the period 1990-1994), followed by Iraq, Algeria, and Ethiopia with 22.4, 19.3, and 14.1 kg/person/year, respectively. Barley grain accounts for over 60% of the food of the people in the highlands of Ethiopia. for whom barley is one of the main sources of calories. In the Andes barley is the staple food for farmers at altitudes ranging from 2,200 to 4,000 meters above sea level. Above 3,000 meters, barley, faba bean, potatoes and quinoa are the four crops that support human and animal life. The largest use of barley for food is found in regions where other cereals do not grow well due to altitude, low rainfall, or soil salinity. A common feature of these diverse regions where barley is a staple food, is that they are home to some of the poorest farmers in the world.

Table 8. Consumption of barley as human food in various countries (FAO estimates for the period 1990-1994).

Country	kg/person/year	Country	kg/person/year
Morocco	64.1	Libya	11.5
Iraq	22.4	Afghanistan	10.9
Algeria	19.3	Tunisia	10.2
Ethiopia	14.1	Peru	2.8

Most of the efforts in barley breeding has been devoted to improve feed and malting cultivars. Attributes such as kernel weight, kernel size, protein and lysine content have been determined in the majority of lines in the yield trials, but we have neglected a number of quality characters associated to the use of barley as human food. Because of the interest of a number of NARS, we have recently started investigating -glucans (also important for malting), hardness (also important for animals) and cooking time to increase the acceptability of barley as food.

In the future the work on grain quality aspects will be expanded, taking into consideration attributes such as high energy and starch type, in addition to protein, lysine and cooking time.

8. International Barley Information System

For many researchers, especially in developing countries, the information revolution has been more a promise than a reality. An efficient management of information is one of the challenge researchers at International Centers are facing. A large amount of information is generated every year on germplasm distributed by International Centers. Most of the information is scattered in several institutions, in different countries, often stored in different formats, and not easily accessible and shared. Increasing research coasts mean that experimental data must be exploited to achieve greater cost-effectiveness and they must be managed as one of the most valuable resources of NARS and Centres. The International Crop Information System (ICIS) gives researchers the tools to manage and share data more effectively. ICIS is a database system for the management and integration of global information on genetic resources, crop improvement and crop management. Separate implementations of ICIS can be created for individual crops, groups of crops, or crops common to a set of farming systems.

ICIS is currently being developed by a team of scientists and programmers, led by a steering committee of two scientists from CIMMYT and one from IRRI. Versions of ICIS are available for rice, wheat, cowpea, and common bean.

The project will promote the efficient development and use of the barley information system (IBIS), will ensure that it is designed to meet the needs of national and international institutions, and will guide acquisition of data.

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