Evolutionary Plant Breeding

A method to adopt crops to climate changes, Increase on-farm biodiversity and support sustainable livelihoods

Evolutionary Plant Breeding

A method to adopt crops to climate changes, increase on-farm biodiversity and support sustainable livelihoods

Cenesta (Centre for Sustainable Development)

2013

Agricultural biodiversity is widely recognised to be essential for adapting successfully to climate change, particularly the conservation and use of landraces and crop wild relatives (FAO 2010; Cardinale et al. 2012; Hooper et al. 2012; HLPE 2012). Despite wide recognition for the importance of agricultural biodiversity for adaptation, the policies (and budgets) of most governments, research institutes and international agencies continue to favour breeding and marketing of single varieties. Single varieties can yield well under ideal conditions, but this means the manufacturing of "ideal" environments through the use of chemicals and great amounts of water. Rapidly increasing on-farm biodiversity is a matter of urgency in an era of climate change.

These policies benefit the companies that produce such varieties – as well as the toxic pesticides and chemical fertilisers that they are dependent on (out of the 12 most dangerous chemicals, 9 are pesticides). However, they do not benefit the millions of farmers who are searching for low-cost solutions that promote not only the health of their ecosystems, but also their own health and that of the consumers who depend on their production.

A production system that produces healthy food, sustainable ecosystems and livelihoods for small farmers is achievable through the use of biodiversity, but one major challenge is that farmers' access to genetic resources is very limited. Farmers need greater access to the genetic material in research stations and gene banks (which would not exist without their own investments in on-farm research over millennia). They also need the collaboration of sympathetic scientists who are willing and able to draw on their respective strengths to create knowledge together. Both access to genetic resources, and genuine collaboration with scientists, is lacking in most parts of the world.

The programme on Participatory Plant Breeding (PPB) and Evolutionary Plant Breeding (EPB) in Iran is one example of what can be achieved when these challenges are overcome. We have developed a model for giving a large number of farmers access to a great amount of biodiversity in a relatively short time. Farmers participating in the PPB trials developed a greater appreciation for biodiversity and this led to a move beyond single lines and varieties to working with mixtures of several varieties, and finally to cultivating "evolutionary populations" – mixtures of mega-diversity (see map of all trials in Iran).

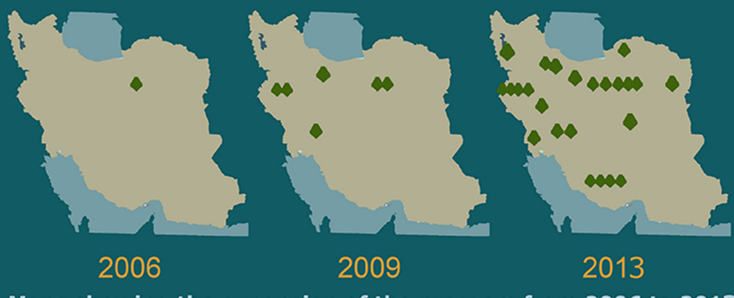
Map of participatory research to enhance agricultural biodiversity in Iran

PPB Participatory Plant Breeding is a dynamic and permanent collaboration that exploits the comparative advantages of plant breeding institutions that have the institutional responsibility for plant breeding, and of farmers. Germplasm is planted in farmers› fields and it is they who decide which to select for further cultivation. This methodology has been shown to increase farmer›s access to locally adapted seeds, and to increase biodiversity in the field.

EPB Evolutionary Plant Breeding (EPB) represents a dynamic and inexpensive strategy to quickly enhance the adaptation of crops to climate change. The method consists of deploying populations with large genetic variability in the hands of farmers and letting them gradually evolve and adapt to both climate and management changes. This process of natural selection can be supplemented by farmer selection to select adapted germplasm for further multiplication, thus using the populations as a “living gene bank in farmers› fields”.

EPB Mixtures are populations made by different varieties of the same or different crops. They are made because in general mixtures give more stable yields over different seasons than uniform crops. Also, mixtures are generally more resistant to disease than uniform crops.

Landraces commonly known as traditional or local varieties, are an important tool for building resilience to climate change, and also for improving quality. This rich genetic heritage is steadily being eroding due to replacement by modern varieties, but some is preserved in gene banks. Farmers are accessing the landraces in gene banks and evaluating them in their own fields to revive the promising ones.



Maps showing the expansion of the program from 2006 to 2013

Making the best of "left over" experimental seed

One day talking to a group of farmers in Iran, Dr. Salvatore Ceccarelli shared the story of Syrian farmers engaged in a PPB project. Their experiment had started with 160 different lines of barley in 200 plots. Each year the breeders would harvest only a small, representative sample from each plot, leaving the rest of the plot for the farmers to harvest and use as they wished. During one visit, he asked the farmers if they were happy with the lines that they had selected. They responded that they were, but that nothing was better than the mixture. "Which mixture?" asked Salvatore. The farmers explained that after the breeders had taken their samples, they had harvested the entire field – all 200 plots – with a combine harvester and instead of using it as animal feed (as the breeders had assumed they would), they had decided to plant it as a mixture. The result was a mixture that was better than any of the individual lines – and the commercial varieties – on their own.

From single lines to mixtures

The first PPB trials started in Iran in 2006 with the cooperation of CENESTA, local farmers, ICARDA, the Department of Agriculture of Kermanshah province, and the Dryland Agriculture Research Sub-Institute (DARSI, at Sararood station). The trials of wheat and barley were conducted on several farms in the provinces of Kermanshah and Semnan. As with most PPB trials, we started with a large number of lines. Four years of selection by farmers successively narrowed these down to a handful of locally adapted varieties and farmers cultivated these as single varieties.

During the second year a parallel line of work started to develop. Dr. Salvatore Ceccarelli who helped us start the PPB programme in Iran and who launched ICARDA's work on PPB, shared experiences of farmers from other parts of the world. Many farmers he had met insisted that mixtures of several different varieties (and sometimes even several crops) led to good yield stability and in some cases to a higher quality product. They believed that the enhanced genetic diversity of the mixtures brought greater stability to their yields over time (see text box, left). In fact, the benefits of crop diversity have been well documented in the scientific literature. Di Falco and Chavas (2006) review literature which shows that cultivating several varieties that respond differently to weather and temperature randomness contributes to resilience, including to drought, pests and diseases. Both pest populations and weeds are more likely to grow and spread when they face a genetically uniform crop.

This led the Iranian farmers to sow mixtures of their selected lines from the PPB trials. At harvest time they were pleased with the results and many farmers have continued experimenting with making their own mixtures. There are now so many different mixtures of wheat and barley that they have decided to start trials of mixtures which include 16 distinct mixtures of wheat and 21 distinct mixtures of barley. Some of these mixtures contain only a handful of varieties, some several hundred, some contain only landraces, some new lines and commercial varieties, and others contain both.

Syrian farmer Ali Turkye with ICARDA's Michael Michael in a field of "Yana" – the name Ali gave to the mixture of the leftovers

Year 1

Year 10

Our ideas evolve, as do our seeds

Since creating mixtures, we have found a way to bring even greater biodiversity into farmers' fields: **Evolutionary Plant Breeding (EPB)**. EPB represents a dynamic and inexpensive strategy which will quickly enhance the adaptation of crops to climate change (Ceccarelli et al. 2013; 2010). The idea of EPB is not new. In 1929, Harlan and Martini proposed the Composite Cross method (CC method) of breeding barley. The method relies on the bulking of F1 progenies, obtained by hybridization of varieties of diverse origin and genetic make-up, to generate an heterogeneous population of recombinant genotypes. The population should then be multiplied in the specific environments where locally adapted varieties are needed. The procedure should guarantee that the frequencies of adapted genotypes increase without creating a uniform population. Suneson further developed the idea into a formal "evolutionary plant breeding method" (Suneson 1956). Using this method, Suneson registered nine barley composite crosses meant to be used for the generation of new varieties, as parent lines and material for the study of population genetics. The success of such breeding methods depends upon recombination and segregation and the extent to which survival over many generations in mass-propagated populations is positively correlated with agricultural value (Allard and Hansche 1964).

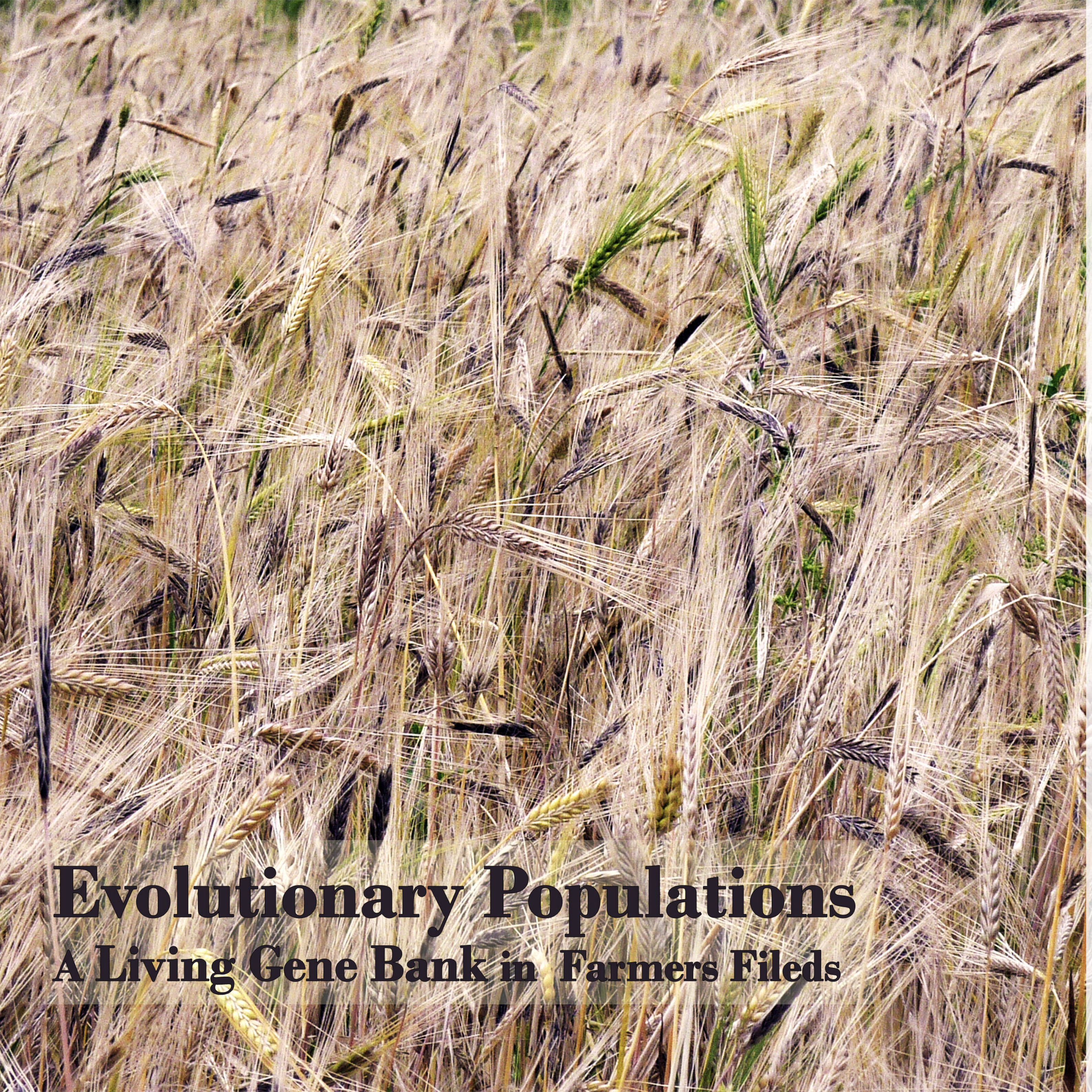
We implemented the first participatory-evolutionary breeding programs in 2008 by planting a mixture of nearly 1600 barley F2. This represented ICARDA's entire barley crossing program of that year and included a wide range of germplasm: from the wild progenitor, Hordeum spontaneum, to landraces from several countries and to modern breeding materials. Besides Iran, this barley population was planted in Syria, Jordan, Algeria, and Eritrea, and two years later in Italy. The barley population, together with two wheat populations are currently evolving in a multitude of environments, chosen by the farmers and characterized by single abiotic or biotic stresses or combinations of stresses and under different types of agronomic management.

In EPB, farmers can plant and harvest a small (4-5kg) sample of seed in the same place for successive years. The expectation is that the frequency of genotypes with adaptation to local conditions will gradually increase.

It is also possible and actually desirable, to plant samples in other locations affected by different stresses or different combinations of stresses by sharing the population with other farmers. For example, in Iran the barley population which was planted by two farmers in two provinces in 2008, spread to 50 farmers in nine provinces in the cropping season 2010-2011 and is currently grown on more than 40 ha by 80 farmers. In Italy the evolutionary populations of wheat and barley were grown in more than 10 provinces in 2014.

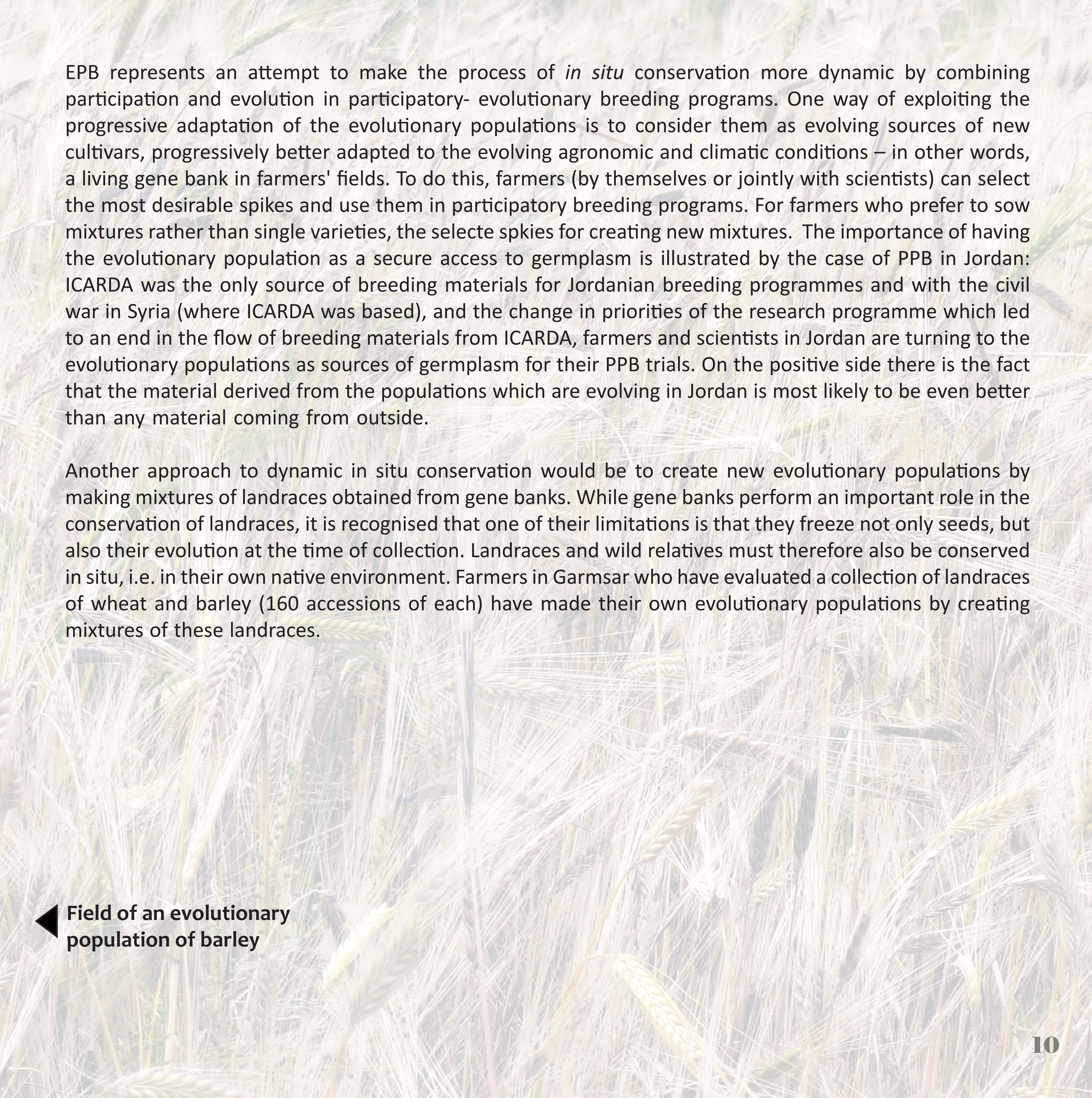
Evolutionary Populations

A Living Gene Bank in Farmers Fileds



EPB represents an attempt to make the process of *in situ* conservation more dynamic by combining participation and evolution in participatory- evolutionary breeding programs. One way of exploiting the progressive adaptation of the evolutionary populations is to consider them as evolving sources of new cultivars, progressively better adapted to the evolving agronomic and climatic conditions – in other words, a living gene bank in farmers' fields. To do this, farmers (by themselves or jointly with scientists) can select the most desirable spikes and use them in participatory breeding programs. For farmers who prefer to sow mixtures rather than single varieties, the selecte spkies for creating new mixtures. The importance of having the evolutionary population as a secure access to germplasm is illustrated by the case of PPB in Jordan: ICARDA was the only source of breeding materials for Jordanian breeding programmes and with the civil war in Syria (where ICARDA was based), and the change in priorities of the research programme which led to an end in the flow of breeding materials from ICARDA, farmers and scientists in Jordan are turning to the evolutionary populations as sources of germplasm for their PPB trials. On the positive side there is the fact that the material derived from the populations which are evolving in Jordan is most likely to be even better than any material coming from outside.

Another approach to dynamic in situ conservation would be to create new evolutionary populations by making mixtures of landraces obtained from gene banks. While gene banks perform an important role in the conservation of landraces, it is recognised that one of their limitations is that they freeze not only seeds, but also their evolution at the time of collection. Landraces and wild relatives must therefore also be conserved in situ, i.e. in their own native environment. Farmers in Garmsar who have evaluated a collection of landraces of wheat and barley (160 accessions of each) have made their own evolutionary populations by creating mixtures of these landraces.



Field of an evolutionary population of barley

Unexpected findings: Immediate out-scaling of the evolutionary populations

In the first year of the EPB trials each farmer was given 4 kg of seed for a small experimental plot. The expectation was that they would continue to sow only 4 kg each year, enough to allow the population to evolve and to act as a source of locally adapted germplasm. The principle in all participatory research is that plot sizes should be kept to a minimum in order to avoid a large burden to farmers who dedicate land for research.

One of the most unexpected outcomes of the evolutionary population trials was that some farmers decided to sow all the seed they had harvested because of the promising yields they achieved (see text box left).
In other words, they immediately started multiplying the seed and cultivating it on a wide scale as their main crop. We had not expected that the populations would be so well adapted (this was especially the case in rain-fed regions) that farmers would be inspired to cultivate it on a wider scale.

Early and Promising Results

In 2008-2009 We started an Evolutionary Plant Breeding (EPB) program for rainfed barley using a mixture of 1600 F2 populations received from ICARDA. The seed was planted in a farmer’s field in Dalahoo region, Kermanshah, West Iran. In spite of late sowing, undesirable in that cold region, the farmer noted its good performance and in 2009-2010, he planted the harvested seed on 0.5 hectares. The evolutionary population out-yielded the local barley and perfor-med almost as well as the improved barley cultivar, Sararood-1. The farmer was satisfied with the population’s performance even in a dry season, and decided to cultivate it on a wider scale and to distribute the seed to other farmers.

Based on the success of EPB with barley, in 2009-2010, Dr. Reza Haghparast, wheat breeder at DARSI, established a similar program for bread wheat. He used the backup bread wheat seeds conserved in DARSI's seed store, together with seeds from segregating populations from its wheat breeding program. The evolutionary population was planted in a farmer’s field in Sahne region in Kermanshah province in 2009-2010, a year which saw higher than average rainfall in Kermanshah. The population yielded 3,500 kg/ha under rainfed conditions while the very popular local variety, Sardari, suffering from lodging and rust, produced only 1,500 kg/ha. The following year, which was relatively dry and characterised by many stresses, the evolutionary population outperformed Sardari again.

Results were also promising in very hot regions. In 2012-2013, the evolutionary population of wheat produced 1700 kg/ha in a hot region of Kermanshah province (Sar-e Pol-e Zahab) while the local variety produced only 800 kg/ha. Also in Kermanshah province, in Ravansar the yield was on average 16% greater than local varieties and in Sarab-e Niloofar, yields were 51% greater than Sardari. That same year, the Department of Agriculture of Kermanshah province approved and funded a multi-year project on EPB throughout the province.

Outscaling has been less wide-spread in irrigated regions, but there are nevertheless promising results. In 2011-2012 an evolutionary population of wheat, also provided by DARSI, was cultivated in Garmsar (Semnan province) under irrigated conditions and produced 9.2% more than Pishtaz, an improved variety used as the local check. The farmer who cultivated this field claimed that the evolutionary population had less weeds and pests than Pishtaz and while the former was not treated with pesticides and herbicides, the latter had to be heavily treated. This suggests that evolutionary populations could be both very useful in organic agriculture and cheaper to grow.

Evolutionary populations and the question of the consumer

Many people who hear about EPB are concerned about the quality of the final product. Is the final product of suitable quality or even usable? In Iran, we have so far worked only with wheat and barley and we have not come across reasons for concern. In the case of barley, which is mostly used as an animal feed in Iran, there are no concerns about cooking quality. In terms of quality as animal feed, farmers in Garmsar (some of whom also raise livestock) requested a protein analysis of several varieties of barley in their PPB trials. The results showed that the evolutionary population of barley had more protein than the local barley variety (an improved variety from the national research system).

In the case of wheat, farmers and bakers in the provinces of Seman and Kermanshah have tried making bread from the evolutionary populations and have been pleased with the results. Some are even marketing the bread in local artisanal bakeries. Farmers we have met in meetings in both France and Italy (associated with the Reseau Semences Paysannes and the Rete Semi Rurali respectively) confirmed that creating mixtures not only brings greater yield stability, but also greater aroma and quality to the bread.

Obviously the suitability of evolutionary populations as the main crop depends on the use of the crop and the cultural preferences of local farmers and consumers. What is clear is that in the case that the crop does not lend itself to being consumed as a mixture (such as in the case of many vegetable varieties), the evolutionary populations can still serve as living gene banks and the source of new, adapted germplasm that can be multiplied as single lines. For example, the use of EPB with vegetables is currently underway in Italy with tomato, beans and zucchini.

Biodiversity, Evolutionary populations and seed laws

Farmers make up an important portion of the Iranian population (%25) and economy (%20). The vast majority of Iranian farmers are small holders (%75 of farmers have less than 5 hectares of land) and rely mainly on farm-saved seed for the vast majority of cereals, legumes, paddy rice and forage crops. These crops make up the major part of the crops grown in the country: %86 of the total area under cultivation.

Iran`s seed law (SPCRI 2003) states that all registered seed must uphold the criteria of being new, distinct, uniform and stable. It is clear that evolutionary populations could never meet these criteria: it is precisely their diversity and dynamic evolution that are their main advantages. However, this law only addresses seed that is marketed and since the evolutionary populations are not marketed, but simply exchanged between farmers, there is currently no legal impediment to this work. According to the Seed and Plant Policy Document of the Islamic Republic of Iran (SPCRI), "Farmers who produce farm-saved seed and plants have the right to store, use, exchange, and distribute their own plant materials."

The negative impacts on biodiversity of seed laws that benefit breeding companies have become the cause of concern from the perspective of farmers' rights. According to the Special Rapporteur on the Right to Food, "The expansion of IP rights can constitute an obstacle to the adoption of policies that encourage the maintenance of agrobiodiversity and reliance on farmers' varieties" (Special Rapporteur on the Right to Food 2009). If Iran were to join UPOV (and there is interest among some breeders in Iran to do so) then there would be major limitations on evolutionary populations. First, while the 1961 and 1978 versions of UPOV automatically allow the use of farm-saved seed by farmers, the 1991 version (which Iran would have to accept if it decided to join UPOV) would allow the use of farm-saved seed only as an optional exception and only if royalty is paid on seed (GRAIN 2007). Second, in many countries that have developed seed laws based on the UPOV system, marketing of seeds is based on the prerequisite of registration and certification. IPR regimes such as UPOV require that all certified seed adhere to the criteria of distinctness, uniformity and stability. As already mentioned, the evolutionary populations are useful precisely because they do not adhere to these criteria that favour uniformity and outlaw diversity.

Where next?

The evolutionary populations of wheat and barley continue to be spread throughout Iran, both through farmer-to-farmer exchanges and through exchanges organised through DARSI, the Department of Agriculture of Fars province, and CENESTA. Our main challenge is to keep up with the fast spread of these seeds in terms of tracking the spread and the outcomes, giving support to farmers (explaining what these populations are and how they can be used), etc. The first national workshop on EPB was organised in Shiraz in January 2013 in which farmers from several provinces shared their experiences with each other. Regular local, regional and national workshops and field visits are needed to strengthen farmers' knowledge about how to use these populations. At the same time, it is important to develop awareness of the potential impacts of different seed laws and policies on farmers' rights to save, exchange, develop and sustainably use their seeds.

References

Allard, R.W. and Hansche, P.E. (1964) Some Parameters of Population Variability and their Implications in Plant Breeding. Advances in Agronomy, 325–281 ,16.

Cardinale BJ, Duffy JE, Gonzalez A, et al. (2012). ‹Biodiversity loss and its impact on humanity›, *Nature*, 67 –59 ,486.

Ceccarelli, S., Grando, S., Maatougui, M., Michael, M., Slash, M., Haghparast, R., Rahmanian, M., Taheri, A., Al-Yassin, A., Benbelkacem, A., Labdi, M., Mimoun, H. and Nachit, M. (2010). ‹Plant breeding and climate changes›, *Journal of Agricultural Science*, 638–627 ,148.

Ceccarelli, S. (2012). ‹Living Seed – Breeding as Co-evolution›, in Seed Freedom: A Global Citizens Report, Navdanya.

Ceccarelli, S., Galié, A., and Grando (2013). ‹Participatory Breeding for Climate Change-Related Traits›. In C. Kole (ed.), *Genomics and Breeding for Climate-Resilient Crops,* Vol. 1, Springer-Verlag Berlin Heidelberg, 376-331.

Di Falco, S. and Chavas, J.P. (2006), ‹Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture›, *European Review of Agricultural Economics*, 314–289 ,(3) 33.

FAO (2010), Second Report on the State of the World›s Plant Genetic Resources for Food and Agriculture, Rome.

GRAIN, (2007), ‹The end of farm-saved seed? Industry’s wish list for the next revision of UPOV›, available at *http://www.grain.org/fr/article/entries/-58the-end-of-farm-saved-seed-industry-s-wish-list-for-the-next-revision-of-upov*
Hahgparast, R. et. al. (2013), Ahamiat-e Behnjedai-e Takamoli Ghalaat-e Deym Dar Moghaabele Ba Ta›aghirat-e Eghlimi, (article submitted to the Second Iranian Conference on Agriculture and Climate Change)

Harlan, H., and Martini, M. (1929) A composite hybrid mixture. Journal American Society of Agronomy, 490–487 ,21.

High Level Panel of Experts on Food Security and Nutrition (2012). *Food Security and Climate Change*, Rome:FAO.

Hooper, D.U., Adair, E.C., Cardinale, B.J., et al. (2012). ‹A global synthesis reveals biodiversity loss as a major driver of ecosystem change›, *Nature*, 8–105 ,486.

SPCRI (2003)*, Act of Plant Varieties Registration, Control and Certification of Seeds and Plant Materials*, available from *http://spcri.org/en/Pages/ActofPlantVarietiesRegistration,Control.aspx*

SPCRI (2003), *Act of Plant Varieties Registration, Control and Certification of Seeds and Plant Materials*, available from http://*spcri.org/en/Pages/ActofPlantVarietiesRegistration,Control.aspx*

SPCRI, Seed and Plant Policy Document of the Islamic Republic of Iran, available from *http://spcri.org/en/Pages/SeedandPlantPolicy.aspx*

Special Rapporteur on the Right to Food (2013), *Seed policies and the right to food: enhancing agrobiodiversity and encouraging innovation.*

Suneson, C.A. (1956) An Evolutionary Plant Breeding Method. Agronomy

IFAD
Enabling the rural poor
to overcome poverty

The International Treaty
ON PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

drynet

U N
D P

gef

SGP The GEF Small Grants Programme

گروه توسعه پایدار
کشاورزان دشت گرمسار

معاونت موسسه تحقیقات کشاورزی دیم

همه باهم
جهاد
کشاورزی

سازمان جهاد کشاورزی استان فارس

Cenesta

Cenesta (Centre for Sustainable Development)

108 Azerbaijan Avenue 13169- Tehran, Iran

Tel: 00982166452741   E-mail: cenesta@cenesta.org
Fax: 00982166400811   Website:http://www.cenesta.org