Produce Your Own Seeds

This Manual has been written for the peasants.
The aim is to share with them some basic biological knowledge that is useful to understand what the seeds are and how farmers can eventually produce seeds that will give the type of plants that are best suited to their conditions of today and those of tomorrow

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Premise

Three of the global issues most frequently debated today are the decline in agro-biodiversity, i.e. in the number of different types of plants grown in the field, climate changes and hunger: the three problems are connected with each other and as such they should be dealt with. As we will see later, seed is central to all the three issues. Most of our food comes from seeds (even when we eat animals we indirectly eat plants, which are coming from seeds) and food affects our health. Therefore, talking about seeds means talking not only about biodiversity, climate changes and hunger, but also about our health.

Climate change

Today, few scientists question whether climate change is occurring or not and the discussion has shifted from whether they are happening to what to do about them and how to adapt crops to a climate which in many cases will be dryer and warmer than today, and especially more variable. In the coming years climate change will have a profound and direct impact on agricultural systems and/or food (1).

Agro biodiversity

The scientific and industrial agriculture is largely based on monoculture and on a relatively small number of uniform crops (of about 250,000 plant species which is estimated to exist on the planet, of which about 50,000 are edible, we eat only 250 of which 15 provide 90% of calories in our diet, and only three - rice, maize and wheat - 60%). In these three crops genetic improvement - the science with which researchers produce new varieties of plants (see more below) - has dramatically reduced genetic diversity because it has filled the fields with plants that are all the same. Today, for example, 75% of the world area planted with potatoes and 65% of the world area planted to rice is based on only four varieties; for other crops such as maize, soybeans and wheat, the situation is not very different.

The monopoly of seeds

In addition to the gradual reduction of diversity in the most important crops, there has been also a gradual concentration of the control of the seed market: in 2006 private companies globally provided 2/3 of the seed, and between 1994 and 2009, the share of the global seed market in the hands of four industrial corporations has increased from 21 to 54%. In 2009, eight corporations controlled 63.4% of the global seed market and 74.8% of the market of pesticides and herbicides (2). It is obvious that if the seed companies also sells pesticides, and if those who sell seeds and pesticides, also produce varieties, it is hard to imagine that they have a strong interest to produce varieties resistant to diseases and insects. Unfortunately, this was the trend of recent decades with a gradual increase in the genetic improvement made by industrial corporations at the expense of the public interest. However, farmers must remember that is is always the demand and the offer that shape the market; in the case of the seed market they are the demand and if they stop buying because they are able to produce it by themselves, the offer will also need to change.

The monopoly of seeds and farmers' knowledge

One of the less obvious consequences of the privatization of scientific breeding is the lack of recognition and use of traditional farmers' knowledge and consequently its gradual loss. It is useful to keep in mind that the domestication of cultivated plants started in the Neolithic (10,000 years ago) - by domestication we mean the gradual process by which wild plants, which often still exist, were transformed into those that we cultivate today - and then for about 9900 years the whole process of genetic improvement including seed production and the distribution of crops in the world, has been in the hands of illiterate peasants. In these thousands of years, what is known as farmers knowledge has formed based on a daily relationship between humans, plants and animals.

About 100 years ago, what until then had been done by many farmers in many different places, began to be made by a few - the researchers - in relatively few places – the research centers - which in time have come to resemble more and more to each other and less and less to the reality of farmers' fields - the Australians are well aware of this and in fact, even after the privatization of genetic improvement, they make most of the selection in farmers' fields.

During this process, and with very few exceptions, no or very little use was made of that knowledge accumulated over millennia by farmers.

Some Definitions

Biodiversity

Biodiversity is to the set of different biological entities that exist around us. Entity in this context means not only species - a species is defined by many as the set of individuals who can intercross freely and give unlimited fertile offspring - but also varieties within species and individuals within varieties.

Agricultural Biodiversity

Agricultural biodiversity (or agro-biodiversity) is the diversity of species cultivated for food, feed medicine, industrial uses etc. Agricultural biodiversity is the sum of the differences between species, between varieties within species and between individuals within varieties.

Germplasm

Germplasm is the set of varieties, both modern and traditional (indigenous, landraces) of a crop species, including, when still available, their wild progenitors.

Germplasm (or Seed) banks

Many international organizations, recognizing the value and importance of biodiversity in general and of agricultural biodiversity in particular for the future of humankind, have promoted the preservation of old local varieties and their wild progenitors in structures known as germplasm (or seed or gene) banks. These are buildings where the seeds are kept in conditions - low temperature and low humidity - that should ensure the germination of seed for many years. Every few years, depending on the species and the storage conditions, the seed is sown and rejuvenated.

Gene banks are essential as a last resort in case of calamity, but their most important problem is that in addition to freeze the seed they also freeze the evolution.

In the world, there are about 1,700 germplasm banks with 7, 4 million seed samples (accessions). The best-documented collections are those of the International Research Centres (www.cgiar.org) that contain more that 700,000 accessions of more than 3,000 different species; nearly 60% of the 700,000 accessions are landraces, (Table 1).

Table 1. Number of accessions (seed samples) of various crops held in the gene banks of International Research Centres.

International Center	Crop	Number of Accessions
Africa Rice (Benin)	Rice	20,000
Bioversity (Italy)	Banana, Plantain	1,298
CIAT (Colombia)	Beans, Cassava, Tropical Forages	65,635
CIMMYT (Mexico)	Maize, Wheat	155,129
CIP (Peru)	Potato, Sweet Potato, Andean Root and Tubers	16,495
ICARDA (Syria)	Grain Legumes, Wheat, Barley, Forage and Range crops	134,160
ICRAF (Kenya)	Trees	5,144
ICRISAT (India)	Dryland cereals, grain legumes	156,313
IITA (Nigeria)	Banana, Plantain, Maize, Cowpea, Cassava, Yam	28,286
ILRI (Kenya)	Tropical Forages	18,291
IRRI (Philippines)	Rice	110,817
	Total	711,568

There are examples of seed banks managed directly from farmers.

In several countries there are custodians farmers, i.e. farmers who devote their time and resources to the conservation of old varieties. In some cases the custodian farmers are organized in associations.

Variety

The varieties are subgroups within species, which are either the products of natural selection or the selection made by man through genetic improvement. The varieties are usually distinguished in modern varieties (i.e. selected during the breeding programs conducted by the researchers) and ancient and indigenous varieties (i.e. selected and, in many cases, preserved by farmers). Two differences usually observed between ancient and modern varieties are their genetic purity (uniformity) (see also below), in the sense that modern varieties are more uniform than the old ones, and the adaptation in the sense that the old varieties are generally better adapted to more marginal conditions such as less fertile soils, drought etc.

Pure line

Is a variety in which all plants are genetically identical. A pure line produces seeds, which will continue to give the same type of plants, unless the environment modifies them. Pure lines are the modern varieties of cereals such as rice, wheat, barley and of a number of legumes (e.g. lentils, chickpeas, but not alfalfa and clover).

Clone

Like the pure line, the clone is a variety where all plants are genetically identical, but that, unlike the pure line, is obtained by vegetative propagation, i.e. without sexual reproduction. Generally, the clone is obtained by plant parts such as rhizomes, stolons, adventitious buds, bulbs, tubers, etc. The seed produced by a clone does not necessarily reproduce the same type of plant. Examples of crops that are propagated vegetatively are strawberries, potatoes, bananas, fruit trees etc.

F_1 hybrids

F_1 hybrids are varieties obtained by the cross of two pure lines. Like the pure lines and the clones are constituted by all plants genetically identical, but unlike the pure lines, the seeds collected on a F_1 hybrid plant give F_2 plants which are very different from each other for the reasons which we will see below. Note that F stands for **F**ilial generation and 1 indicates the first Filial generation.

F_2

All the plants (population) obtained by sowing the seed harvested on a F_1 hybrid. Contrary to the F_1 hybrid, the F_2 plants are all different from each other. Also in this case, the reasons will be discussed later (see the section "Differences between F_1 and F_2").

Genes and Chromosomes

To explain the difference between pure lines and F_1 hybrids we must remember that all the living beings (we, the plants that we grow and the animals that we breed) have within their cells, and more specifically within the cell nucleus, the chromosomes on which are the genes that determine the characters.

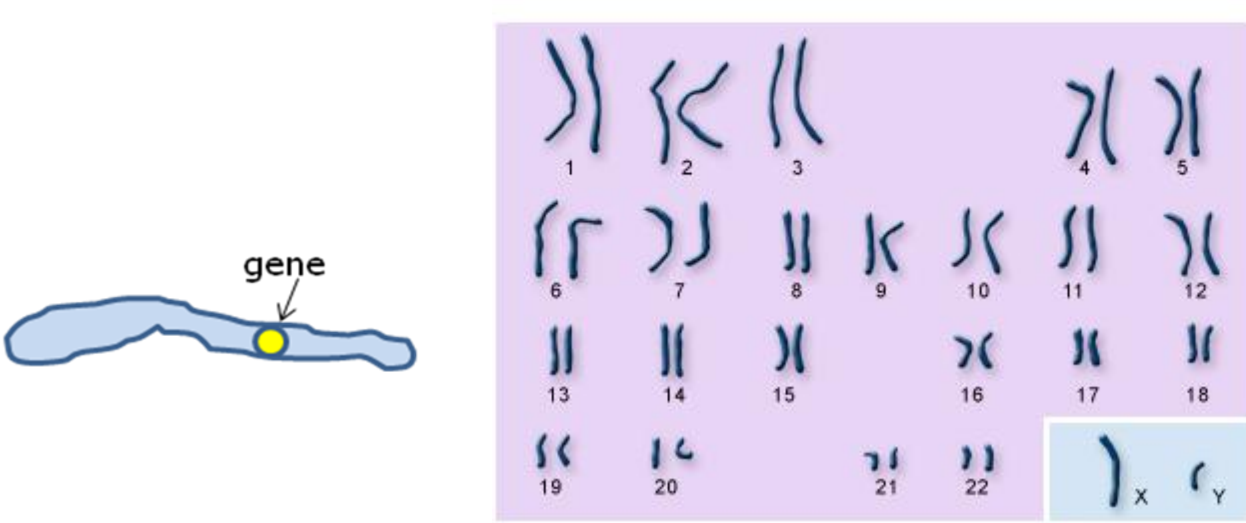

Figure 1 – A schematic representation of a chromosome with one of the several genes (left) and a picture of the 23 pairs of human chromosomes with chromosomes X and Y which determines the sex of the individuals (individuals with two X, namely XX are females; individuals with one X and one Y, namely XY are males).

The number of chromosomes is characteristic of each species and is the same in all individuals of the same species. For example, we have 46 chromosomes, barley 14, maize also 14, durum wheat and spelt 28, bread wheat 42, and so on. Each chromosome is present in pairs, so you can also say that we possess 23 pairs of chromosomes, barley and maize 7 pairs, durum wheat 14 pairs and bread wheat 21. These pairs are separated at the time of the production, in the case of humans, of sperms and eggs that therefore, again in the case of humans, will contain 23 chromosomes, one for each pair. At the time of fertilization, the number of chromosomes returns to be that typical of the species and the children will receive one member of each pair of chromosomes with their genes from the father and one from the mother. This means that also the genes are present in pairs, so for example we have a pair of genes (one on one chromosome and the other on the other chromosome of the same pair) for eye colour and so for all the other characters. The same thing happens in plants and other animals.

Returning to the pure lines and F_1 hybrids, the difference we mentioned earlier is explained by the fact that in the pure lines, and for all pairs of genes, the gene on one chromosome is identical to the gene that is on the other chromosome of the same pair; therefore, the seeds can only give plants that are all the same. In the F_1 hybrid, on the contrary, in all pairs of genes the one which is on one chromosome is different from the one which is on the other chromosome of the same pair, and therefore the seeds which are collected on a F_1 hybrid, and the plants coming from these seeds will have these genes in many new and different combinations. We will come back to this issue later on with the help of a figure.

Genotype
The set of characteristics of a plant or an animal (height, length of the ears, body weight, milk production, etc.) as they are due to the genes that that animal or plant have. Genes are not visible and science can work on them with the help of sophisticated techniques.

Phenotype
The complex of the characteristics of a plant or an animal (height, length of the ears, body weight, milk production, etc.) that is visible to the human eye. The phenotype is the result of the genotype more or less modified by the environment in which the plant has been grown. Different environments (not just location and years, but also agricultural techniques) can greatly modify the same genotype that will show different characteristics (phenotypes) in different environments and cultivation techniques. The phenotype is also determined by the relations between the two genes that control the same character. For example, in the case of eye colour, a person with brown eyes can either have both genes for brown eyes or one gene for dark eyes and one for blue eyes because the gene for brown eyes mask, or more exactly dominates over the blue eye, which is said to be “recessive”. This means that a person with blue eyes has necessarily two genes for blue eyes, and in such a case, the phenotype corresponds exactly to the genotype.

Genetic Improvement
Genetic improvement is the science - some see it as a mixture of science and art - which aims to produce new varieties of crops and new breeds of domestic animals by combining in a single individual favourable characteristics present in different individuals.

Genetic improvement works mainly through the control of the crosses (discussed later) by choosing one or both parents of the crosses based on specifically defined objectives (increased production, improved quality, introduction of a resistance to a disease, etc.).

With the advent of molecular genetics, genetic improvement can now use techniques that allow knowing the genes possessed by individuals (i.e., their genotype) rather than stop at their appearance (i.e. their phenotype that results from the combined effects of genotype and environment). In this way, it is possible to choose the parents and then the individuals obtained by the crosses based on the genes and this greatly increases the effectiveness of selection. Molecular plant improvement - which is often included in the general term of biotechnology - is not different from conventional plant breeding because both operate within the boundaries of the species defined as above but without a manipulation of genes, in other words without changing the DNA.

Sexual reproduction in plants – where do seeds come from?

In the majority of cultivated plants reproduction, i.e. the transition from one generation to the next, takes the form of sexual reproduction. The process is, in substance, similar to that of the animals from which only differs in form.

The first difference is that in animals, the most frequent situation is that the male and female sexes are present in different individuals (with some exceptions such as, for example, fish and snails). In plants, the more common situation is that both sexes are present in the same individual. Here, too, there are some exceptions with in the presence of male and female plants (asparagus, spinach, chicory, kiwi, pistachio).

In plants in which the same individual possesses both sexes (the majority), these may be present in the same flower (Figure 2 left) or in different flowers present at different points in the same plant (Figure 2 right). Among the most important crops, wheat, rice, barley, chickpeas, lentils, belong to the first type while maize to the second. In maize the tassel, on top of the plant, is the male part (being made up of many flowers is actually an inflorescence) and the ear (there may be more than one) is a female inflorescence being also made up of many flowers.

Figure 2. On the left is an example of complete flower (rice) with male (anther) and female (stigma) organs. On the right an example of a plant (maize) with separate male and female flowers.

In the flowers, regardless of the fact that the sexes are separated or not, the male is represented by the anthers, generally but not always, first of green colour and then to maturity of yellow colour (in most cases), that produce pollen that appears as a yellow powder consisting of numerous grains (cells) that can be observed even with a simple microscope. The female (called stigma) can have different aspects from being similar to a small white feather at the base of the anthers (i.e. in barley, wheat and rice) to filaments (silks) of varying lengths such as maize and to more massive structures.

In animals, fertilization occurs when the nucleus, which is present in the head of the sperm produced by the male, fuses with the nucleus of the ovum produced from the female. Fertilization is followed by several multiplications of the cell resulting from the fusion and this will lead to a new individual.

In plants, the process is very similar. Fertilization occurs when a pollen grain fallen from the anthers that open at maturity, or carried by the wind or by insects, is deposited on the stigma. At this point it germinates, producing a tubule that penetrates the interior of the stigma, bringing with it (and this is a first difference with what happens in animals), two nuclei and not just one. One of these nuclei fuses with a nucleus of the egg that is at the bottom of the stigma giving rise to the embryo from which the future plant will originate. A second difference with the animal world is that in plants there is actually a double fertilization because the second nucleus of the tubule produced by the pollen fuses with another nucleus of the female producing the endosperm, which is the mass of starch surrounding the embryo and which serves to feed the embryo until, once sown and germinated, it produces the roots that will allow to absorb water and nutrients from the soil and the first leaf which will start the photosynthesis. In animals, this is not necessary because the embryo develops in the womb that sustains it until birth.

Differences between self-pollinated and cross-pollinated plants

In plants, the different structure of the flowers largely determines whether the pollination and fertilization occur in the same plant or between different plants. In plants such as wheat, barley, rice, lentil, chickpea and many others, where the flower is complete, i.e., contains both the male and the female, pollination and fertilization takes place inside each flower. This is facilitated by the fact that the flower remains closed until the maturation of the anthers (later we will see that this is not always 100% true), and therefore if a seed is formed, it must necessarily come from the pollen produced by the anthers of the same flowers that has been dropped on the stigma of the same flower). The plants that behave this way are called self-pollinated (or autogamous). Therefore, if you are wondering who is the father and the mother of a grain of wheat or rice or barley the answer is that the plant on which you collected the seed is both the mother and the father.

In plants in which the male and female flowers are separated, such as maize, the pollen escapes from the matures anthers, and being very light, it will be very difficult that it will fall vertically on the stigmas of the female flowers of the same plant, also because male and female do not mature at the same time. Therefore, the pollen of a given plant disperses and pollinates the stigmas of the female flowers of other plants. The plants that behave in this way are said to be cross-pollinated (or allogamous). Therefore, the seeds of a maize ears have all the same mother (the plant on which you harvest the ears) but, most likely each a different father.

The structure of the flowers does not always tell us whether the plant is self-pollinated or cross-pollinated. For example, alfalfa and red clover have complete flowers and yet they are cross-pollinated mostly by insects. Also faba bean has complete flowers but is partially cross-pollinated. Finally, autogamy is rarely perfect; therefore, even in wheat, barley and rice it is possible to have a certain percentage, usually no more than 5% of cross-pollination. This depends greatly on the variety and above all by the environmental conditions. Further on we will see how this can be exploited to our advantage.

Making crosses

Making a cross in the plant world means deciding who will be the father and the mother of the seeds that we sow. Therefore, a not too complicated technical operation has a profound significance because is the basis of genetic improvement. If someone makes crosses without involving farmers, in fact decides what those farmers will cultivate in their fields and therefore, ultimately, what we eat.

It is important to notice that in order to regain the control of seeds, making crosses is not essential, but can be very useful.

In the following paragraphs, we will not touch the problem of how to select the parents to cross because this should be evident later from the second part.

Making crosses is extremely easy in species where the male and female flowers are separated as in maize. Once you have chosen the two plants to cross, the process starts with covering with a paper bag the female flower of the plant that will serve as a mother before the stigmas (commonly called silks) appear. One can also remove the male flower from this plant, unless you want to use it as the father in another cross. In the plant that will serve as a father, the male flower also has to be covered with a paper bag a couple of days before the cross: this is because, the pollen produced by other plants could be deposited on the male flower, but such "foreign" pollen will not survive the moisture of the night and therefore you can be sure that the pollen you will find in the paper bag the following day belongs only to the plant chosen as a father.

As soon as the stigmas of the female flower appear at the top of the ear (you can easily check this by touching the top of the paper bag), the male plant will be bended, gently shaken so that the pollen is deposited at the bottom of the paper bag. At this point, and as quickly as possible to avoid uncontrolled pollination, the bag that covers the female flower is replaced by the bag full of pollen, and the cross is done. If the two parents were two pure lines, you have just made an F_1 hybrid.

In species in which the flowers contain both the male and the female organs, making the cross is more laborious, much more laborious when the flowers are small.

Since the plants contain both sexes, to make the cross is necessary to make a plant only female by removing the male organs (emasculation) and then pollinating the female flowers with the pollen from the plant chosen as male. The techniques to do all this vary greatly depending on the species and therefore here we will give only the essential information.

In the plant that will serve as a female, and in every flower, the anthers will be removed when they are still green making sure that they are removed entirely. If at the end of emasculating a flower you have any doubt whether the anthers have been entirely removed, it is advisable to eliminate that particular flower because the pollen of a forgotten half anther is sufficient to fertilize all the flowers of the ear. Once you have completed the emasculation of all the flowers of the plant, the whole inflorescence is covered with a bag to prevent foreign pollen from falling on the stigmas. A couple of days after emasculation, one can assume that the female is mature and then from the plant selected as male mature anthers (again, with technical details that vary from species to species) are taken with which the stigmas of the flowers of the female plant are pollinated. If the operation is well conducted from each flower you will get a seed that, if the two parents were pure lines, will be a F_1 seed

Differences between F_1 and F_2

The difference between F_1 and F_2 can be explained by what has been said about genes and chromosomes. All individuals of the F_1 between two pure lines, which, as defined above, have two identical copies of each gene, will receive one copy of the gene by the father and one copy by the mother. Therefore, they will be all the same, even if very different from their parents, because for all genes for which the father and mother differed, possess different copies.

Consider two maize plants (Figure 3): in red are the chromosomes of the male plant and in green those of the female plant. As can be seen the chromosomes are, two by two, equal.

In Figure 3 both the male and female plant are inbred lines as defined before, and therefore not only the two chromosomes that form a pair are equal in shape and length, but also the genes that they possess are equal. In such a situation, when the male plant produces the pollen and the female produces the eggs, no matter which of the two chromosomes of a pair ends up in the pollen and in the eggs, all the pollen grains are equal to each other as well as all the eggs. Therefore, only one pollen grain-egg combination will be possible and all the F_1 seed, and all the plants derived from them, are identical. This is why the commercial hybrids of our crops are very uniform.

Let's see now what happens if we harvest the seed on an F_1 plant (for example, the plants of a commercial hybrid) and we sow it obtaining F_2 plants. The pollen and eggs produced by the F_1 plant, which has received half of the chromosomes from the father (the red ones) and the other half from the mother (the green ones), will always receive half of the chromosomes, but which half (all red, all green , four red and three green, two greens and five reds, etc.) will depend solely by chance. In other words, the pollen grains and the eggs produced by an F_1plant are of many different types, which in turn can combine at the time of fertilization in many different ways. As a consequence the seeds collected on a F_1 plant and the plants derived from these seeds are all different. As we shall see further on, a phenomenon which at first sight appears undesirable, in reality can offer many opportunities.

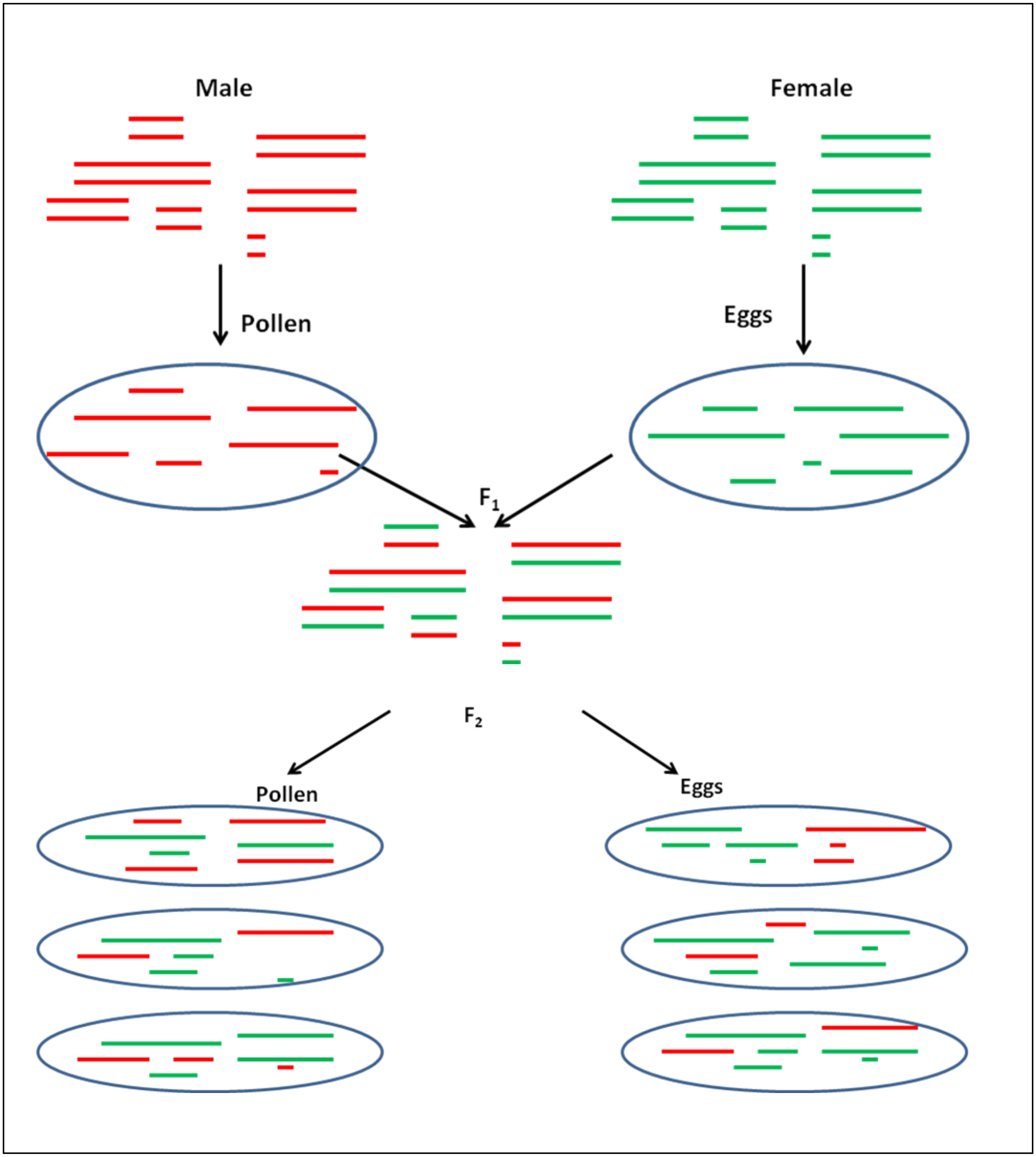

Figure 3. Uniformity of the F_1 hybrids and diversity in the F_2

Participatory Plant Breeding

Participatory research in general and participatory plant breeding (PPB) in particular is considered to be a form of plant breeding that can increase food and feed production at farm level without decreasing, and actually enhancing agro biodiversity. Because it exploits the theoretical proven advantages of selection in the target environment (including low input and organic systems) combined with the participation of farmers (men and women) in all the key decisions, it puts farmers at the centre of the entire process of developing new cultivars including seed production. This matches one of the key recommendations of the interim report of the Special Rapporteur to the United Nations on the right to food (”Put farmers at the centre of research through participatory research schemes such as participatory plant breeding”, pg 22) (3). It also matches article 6c of the International Treaty on Plant Genetic Resources for Food and Agriculture, pg 7 (4): “promoting, as appropriate, plant breeding efforts which, with the participation of farmers, particularly in developing countries, strengthen the capacity to develop varieties particularly adapted to social, economic and ecological conditions, including in marginal areas”.

PPB has been successful in increasing yields, targeting farmers in marginal environments–many of them women’s farmers, and empowering them. Cost benefit analysis of participatory plant breeding revealed highly positive returns.

A PPB program is defined as a breeding program in which selection and testing are conducted in the target environment(s) with the participation of the users (5). This definition includes Participatory Variety Selection (PVS) which consists of the evaluation of a reduced (usually less than 10) varieties in farmers’ fields and with the participation of the users.

The major difference between PPB and conventional plant breeding is that the latter is a process where priorities, objectives and methodologies are decided by one or more scientists with no participation of farmers, while PPB gives equal weight to the opinions of farmers and scientists. It is also important to distinguish between PPB and farmers' breeding (defined as the complex of various breeding activities farmers are conducting on their own), where there is no participation of scientists.

Since the beginning of agriculture and until the rediscovery of Mendel’s laws and the start of scientific plant breeding, farmers planted, harvested, stored and exchanged seeds, continued to modify their crops, moved the crops around the planet (this is how landraces developed), and as a result were able to feed themselves and the rest of the society. In doing all this they also accumulated an immense wealth of knowledge. At the beginning of last century however, plant breeding was gradually removed from farmers’ hands with the consequence that what had previously been done by very many people in very many different places started to be done by relatively few people in relatively few places. This happened without taking into consideration the wealth of knowledge accumulated by farmers during millennia. The difference between traditional knowledge and modern science was probably one of the reasons for this. The first is based on repeated observations over time while the second is based on repeated observations in space (replications). Another difference is the way in which the two types of knowledge are shared: while traditional knowledge is usually shared in an informal, often oral, way, modern science is usually communicated in a written and highly formal manner. It is therefore difficult for scientists to elicit 'traditional knowledge' using the forms of communication of modern science. As a result, farmers' knowledge has often been ignored in conventional plant breeding.

In the implementation of a PPB program, it is worth remembering that there are no fixed models. For the same crop and even within the same country, different models may be required depending, among other factors, on the genetic structure of the varieties and on how farmers used to handle on-farm genetic diversity before they became involved in PPB. A model particularly useful in self-pollinated crops (such a wheat, rice, barley, tef, sorghum, lentil, chickpea, a number of fruit trees, etc.) assumes that the scientists generate genetic diversity (mostly by making crosses, usually between landraces and between improved cultivars and landraces and wild relatives, when available) and grow the first two generations on the research stations to produce enough seed for the trials in farmers' fields. Once the material is grown on farmers' fields, scientists measure traits important to the farmers, as well as analyze the data and keep a safely stored electronic copy of them. The farmers themselves routinely evaluate and score the breeding material, sometimes measure traits, decide what to select and what to discard, adopt and name varieties, and produce and distribute seed of the adopted varieties.

PPB is a dynamic (because it evolves over time) collaboration between institutions doing plant breeding, both national and international and farmers. The collaboration is based on the advantages of the partners, which may change over time, because obviously partners change because of this collaboration.

Farmers have the possibility to take key decisions on a number of aspects of the program, including, for example, what are the important characters to select for, what type of germplasm to use, and in some cases, they even make the crosses.

In the preparatory phase of a participatory program is important to ensure that participation is the most inclusive as possible so that even those traditionally excluded (women and the elderly) are able to express their opinion.

Having decided the structure of the experiments (number of varieties, size of plots, experimental design, etc.), farmers conduct the selection in their fields, where researchers sow experiments with 50, 100, 200 new varieties, depending on the available land and the time that farmers can devote to the selection.

The first selection by farmers is in the field, is visual, and consists in expressing, in numerical form an opinion on each variety in the experiment (Figure 4). In the same experiments researchers measure a series of characters (for example, plant height, the length of the ear, the size of the seed, etc.) that farmers consider to be important (in different countries and crops the characters are different)

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Figure 4. To the left of a field trial with 80 varieties of barley aa right a group of farmers while giving their assessment of the individual parcels.

All these data are analyzed using rigorous statistical methods and the results are tabulated in ways accessible to farmers in special meetings - and this is the second selection (Figure 5) - the farmers consult the results and, based on what they have seen in the field and based on the numerical results, decide autonomously which varieties to select and which to discard.

Selected varieties are sown the following year and the process is repeated for four years at the end of which in each village, only 2 to 5 varieties, that are generally different from village to village, are left. The reason why each selection cycle lasts 4 years is to be sure to find varieties that meet farmers' needs every year; most of the areas where these programs are in progress are characterized by considerable climatic variability from year to year and speeding up the process risks selecting varieties that produce well in one year and poorly in the following year.

Figure 5. The final selection.

From the scientific point of view, a participatory breeding program is the same as a conventional program, with three differences: the experiments are conducted in farmers' fields, rather than in the experimental stations; farmers make decisions jointly with the researchers, the participatory program can be replicated independently in a number of villages, depending on the resources available. The last aspect, the replication of the program in several villages is similar to what in conventional plant breeding are known as Multi Environment Trials (MET). The difference is that in the MET of a conventional program only those varieties performing well across locations are selected (by the researchers) while in a participatory program selection is conducted independently in each village regardless of how the varieties perform in other villages.

The participation of women, which in some cases is spontaneous and independent from religion, is of fundamental importance because often, particularly in developing countries, women have a deep knowledge of production processes, are traditionally involved the preparation of food and therefore often have the last word when it comes to introducing new varieties of crops that provide food. Furthermore, they often grow directly species (at least some) that provide food (sometimes even for the market) and in poor countries are the poorest of the poor and often with greater limitations than men in gaining access to education and information.

The method is flexible, can be adapted to different types of farming - organic farming is considering this method with great interest - produces different types of varieties and has already seen the impacts of varietal type, because we have begun to find varieties adapted to areas where conventional breeding had no impact.

Where participatory plant breeding has been practiced, there has been a big impact in terms of increased agro-biodiversity because, even in the same country where the same (for example, 100) set of varieties of wheat are planted in different villages, in each village different varieties will be selected due to the difference in climate, soil, agronomic practices and preferences of farmers. This is biodiversity in space: since the process of participatory selection is continuous, farmers have the opportunity in a short time to find a new variety, better than those selected few years before: this creates also a remarkable biodiversity in space. Therefore, it is a very dynamic process of varietal replacement which on one side is able to respond quickly to the needs of new varieties, and on the other creates a very difficult environment for diseases and insects, and that projected in time, allows farmers to find varieties adapted to the climate of the future.

We need not to underestimated the human impact of the participatory selection: farmers have acquired a new sense of pride they feel that their knowledge is recognized and appreciated and this was particularly evident in a conference of farmers (www.icarda.org/ farmersconference/) that we held in Syria in 2008, in which the speakers were farmers who were able to express all their feelings and their opinions about the work in the manner just described.

Evolutionary Plant Breeding

The method of participatory breeding described so far, despite having notable successes, has a limitation in that requires the presence of a research institute that accepts this philosophy of research and that provides with continuity the genetic material to star each new cycle.

The need to overcome this limitation combined with the need to find a quick and economical solution to the problem of the adaptation of crops to climate change, has led us to combine participation and evolution reviving the concept of evolutionary genetic improvement proposed in 1956 by the American researcher Suneson (6) and almost never practiced.

The method is based on the creation of large mixtures, mixing both crosses or old varieties or mixing old and new varieties (the composition of the mixture is discussed with farmers) and leaving such mixtures evolve under conditions in which the farmer wishes to cultivate future varieties: in an organic system, in a conventional system, in arid, infertile land in etc (Phillips and Wolfe 2005; Ceccarelli et al., 2010).

In practice, in 2008 we established a population mixing different 1600 crosses of barley. This population was planted in 20 fields in 5 different countries (Algeria, Syria, Jordan, Eritrea and Iran), and is now also grown in 12 Italian regions. The indication that we have given to farmers was: "Do not be afraid to sow these mixtures in the most difficult conditions, because if it dies, it means that we do not have the right material for those conditions and we will start with a new population." Farmers who have planted and observed this population were very satisfied, having never seen so much diversity in such a small space.

Natural selection acts on a population like this by modifying it gradually and continuously making it a source of new types progressively better adapted. In 2009, we established a population of durum wheat by mixing more than 700 different crosses and in 2010, we established a population of common wheat. These mixtures are now grown in various Italian regions.

The results of several experiments conducted with wheat, have shown that some characteristics, such as grain yield, the number of seeds per plant and the weight of the ears, increase in these mixtures over time due to natural selection. However, farmers should be aware that natural selection is not able to improve the quality, for example the bread quality or the malting quality, at least as defined industrially. Therefore, if the quality is important, all the components of the mixture should already possess the desired quality.

The speed of the adaptation, or the evolutionary potential of the population depends on the mating system of the crop (is faster in cross pollinated than in self-pollinated) and on the genetic nature of the starting material (crosses versus fixed lines).

How the evolutionary populations can be developed

Evolutionary populations can be made in a number of ways. The ideal situation is to have the support of a public Research Institute (University or Ministry of Agriculture); in this case, the farmers can request a mix of a large number of F_1 of F_2 derived from the crossing program of self-pollinated crops such as wheat, rice or barley in the cereals, and lentil and chickpea among the legumes. In the case of cross-pollinated crops, farmers can mix a large number of breeding lines donated by the Research Institute.

If farmers do not have the support of a Research Institute, they can buy on the market or obtain from other farmers the seed of as many different varieties as possible, mix the seed, and plant the mixture on about 400 – 500 m^2. In the case of self-pollinated crops, the evolution of the population will rely on the small percent of cross-pollination that occurs in the crops. In the case of self-pollinated horticultural crops where F_1 hybrids are commercially available, it is advisable to mix the seed of as many F_1 hybrids as possible available on the market; for crops like tomato, if the mixture is planted in a plastic house the cross pollination can be encouraged by introducing bumble bees.

Maize and sorghum crops are an example of ideal crops in which to apply evolutionary breeding.

There are a number of ways in which farmers can use an evolutionary population by themselves or in collaboration with scientists.

How the evolutionary populations can be used

The evolutionary population as the farmers' crop

The simplest and cheapest way of implementing evolutionary plant breeding is for the farmers to plant and harvest in the same location (Figure 6 and Figure 7 path 1) without any intervention. The population will be planted and harvested becoming the farmer's crop.

As the population will be planted in locations affected by different stresses or different combinations of stresses (drought, salinity, organic system, and low inputs), the population will become progressively better adapted to those stresses or combinations of stresses.

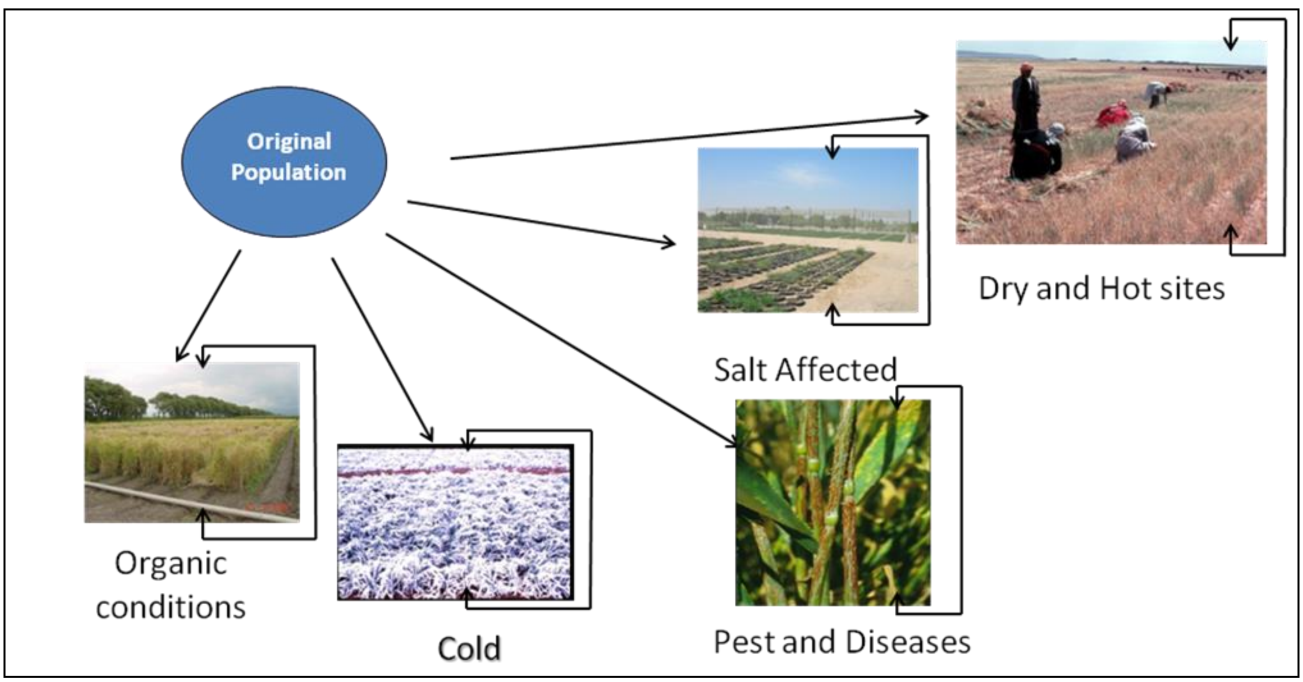

Figure 6. The evolutionary population is planted and harvested in each of many sites (here are shown only five as an example) as the farmer's crop. During the process, farmers can share part of the seed with other farmers who plant the population under their own conditions.

Once the farmer has satisfied his/her needs such as having enough seed for planting the following cropping season, feeding livestock etc, s/he may sell part of the seed to one or more neighbours who can start their own evolutionary population to be handled in the same way.

A suggestion: at each cycle the farmer should store some seed (minimum 4-5 kg) in a dry and cold place and protected from rodents and insects. In the case of events which after x years of evolution lead to the complete loss of the population, using the remnant seed will avoid losing all the benefits of the adaptation accumulated in x years and go back to the population as it was after x-1 years of evolution/adaptation.

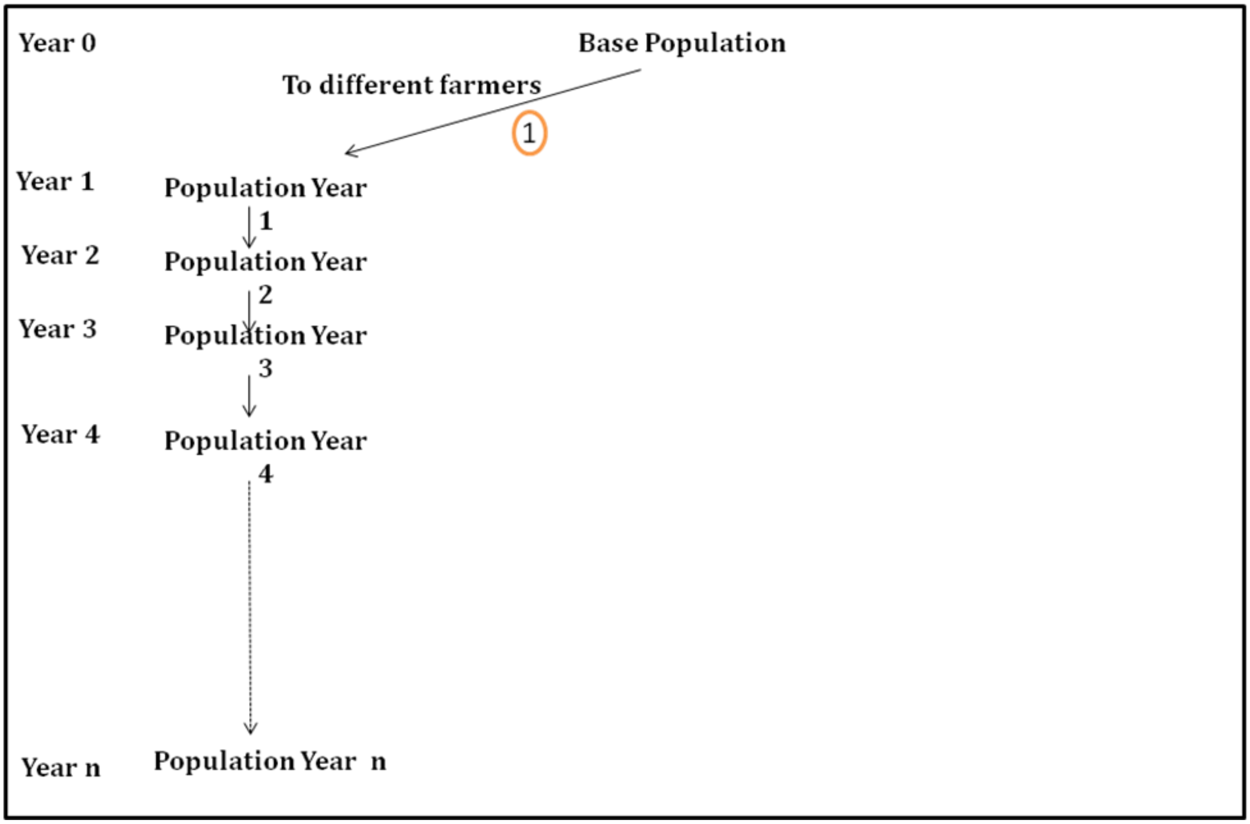

Figure 7. The evolutionary population is planted and harvested by each farmer in his farm and with the techniques he/her considers appropriate. During the process, the individual farmer can share some seeds with other farmers who sow the population under their own conditions.

Selection within the evolutionary population

The breeder and the farmers (both men and women) can superimpose artificial selection with criteria that may change from location to location and with time. While the population is evolving, lines or sub-populations can be derived by collecting spikes, panicles, cuttings etc. depending on the crops. The lines or sub-populations can then be tested as pure lines (in the case of self-pollinated crops), clones (in the case of vegetatively propagated) or populations (in the case of cross-pollinated crops) in the participatory breeding programs, or can be used as multi lines, or a subsample of the population can be directly used for cultivation. The key aspect of the method is that, while the lines are continuously extracted, the population is left evolving for an indefinite amount of time, thus becoming a unique source of continuously better-adapted genetic material directly in the hands of the farmers.

Spike selection

If the evolutionary population is considered as a source population, i.e. to be used for selection, it should be planted in one field, chosen according to the criteria discussed earlier with alleys to avoid damaging the crop and to allow an equal probability of selecting spikes from any plant in the population regardless of its position (Fig. 8).

It is also useful to plant every three or four strips a well-known variety (the black strips in Figure 8) as a reference for the selection.

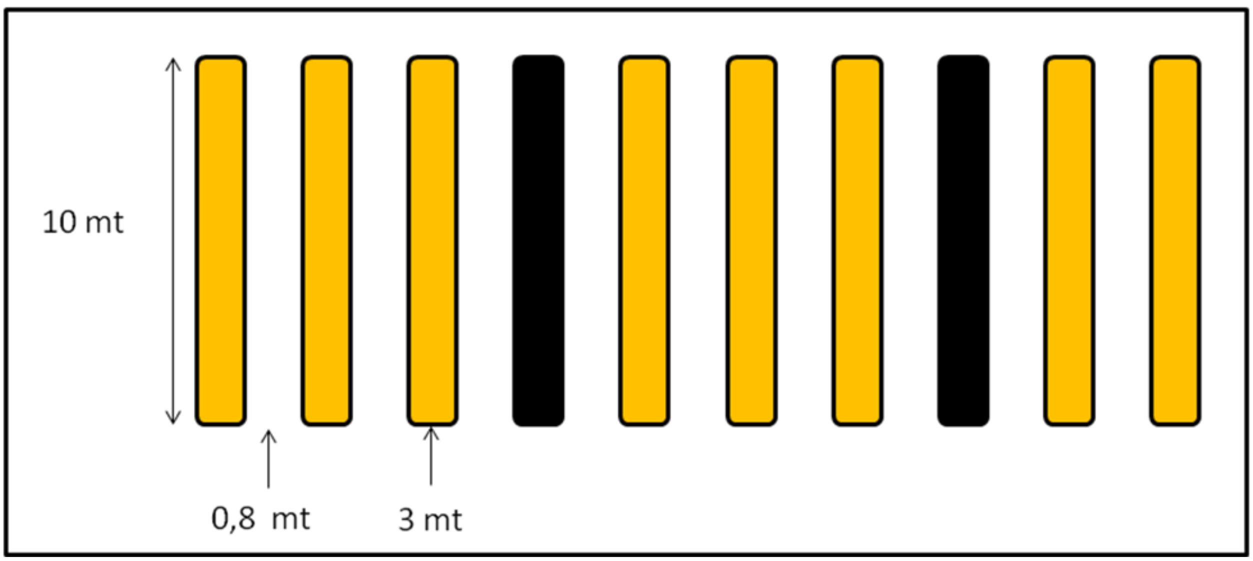

Figure 8. The evolutionary population is planted in strips (the spacing suggested are in the case of a cereal crop such as barley, wheat and rice). The farmers and scientists can walk in the 80 cm path and reach the spikes or the panicles they intend to select within the 3m large plot. The black plots are planted with the farmer's variety as a reference during selection.

Stratified selection: in order to minimize environmental biases spike selection should be done by considering the field as a grid of *x* quadrants and by selecting the best spikes from each quadrant. In this way the danger of selecting all the spikes from that part of the plot/field that has the best environmental conditions will be avoided. The size and the number of quadrants depend on the variability of the soil and other environmental conditions of the plot of land, according to the farmers' knowledge: in general, the higher is the variability in the field the higher should be the number of quadrants and the smaller the size of each.

The number of spikes to be collected from each quadrant depends on the size of the quadrant and the amount of seed that the farmer wants to have in order to start a new sub-population. The following section provides guidelines on this issue.

The spikes selected in any one year can be used in one of the following ways:

Spike selection for row planting (Fig 9, path 2-3 or 2-4)

1. The selected spikes are threshed individually and the seed of each spike will be planted separately in a row. This can be done by the researchers on station or preferably by the farmer. If, because of technical problems, the head-rows are planted on station, they should be only multiplied, and selection should be delayed until the following year in the farmers' field;

2. If the head-rows are planted by farmers they should be planted under the same stressful conditions (e.g. less irrigation) in which they were selected in order to continue the selection.

3. The seed collected on the selected rows can be handled in two different ways (Figure 9 paths 3 and 4)

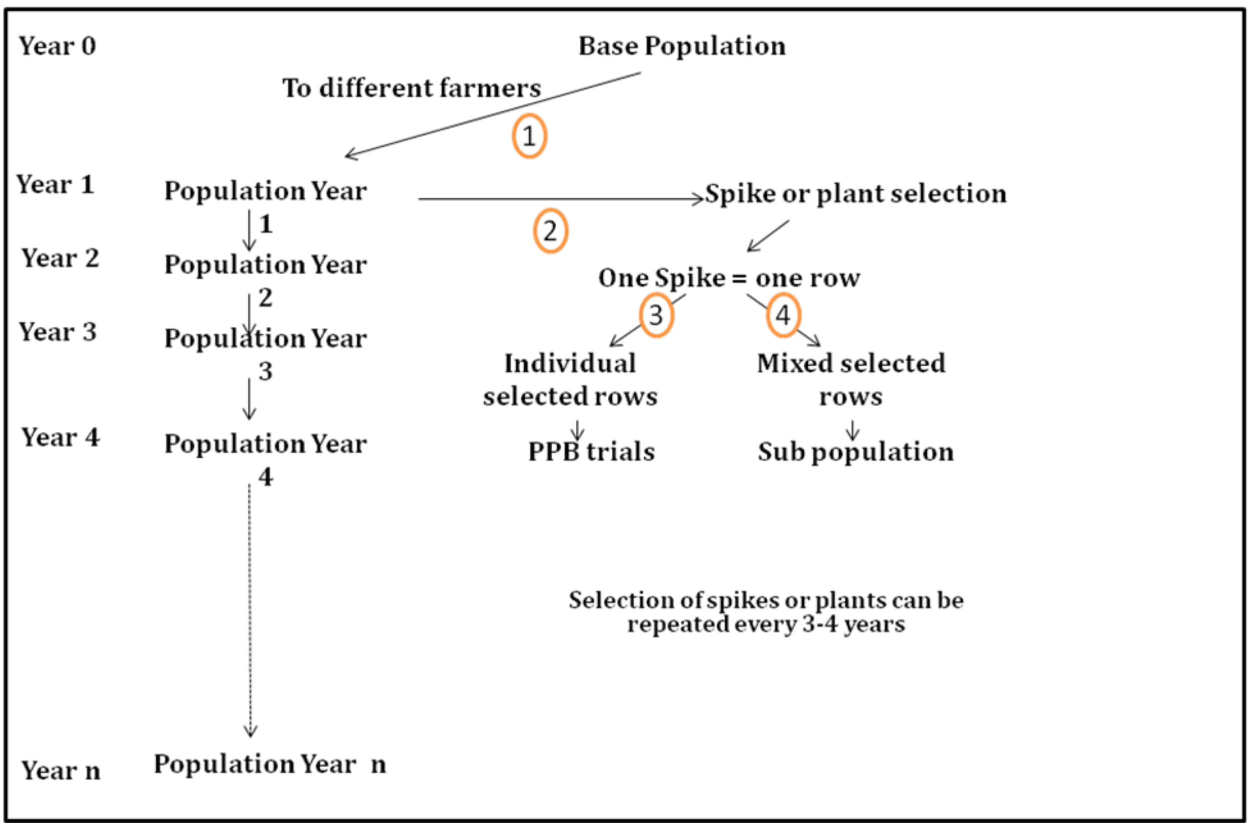

Figure 9. Selection of spikes or plants from an evolutionary population in a cereal crop: path 1 has been described in Figure 7. Path 2 is single spikes (or panicles or plants) selection, which can then be

followed by head rows (paths 3 and 4). Note that the path 1 MUST always be made to enable the population to evolve.

Spike selection to feed the PPB trials (Fig 10, path 2-5)

According to path 3, the seed harvested on the selected head rows will be planted in small plots and further selected according to the scheme of participatory plant breeding described earlier. The seed produced by the small plots should be in sufficient amount to establish a Stage 1 PPB trial as shown in Figure 3) in the sense that each selected rows will be an individual entry in that experiment. Paths 2 and 3 can be repeated every year leading to a situation where in the village there will be short rows, small plots and PPB trials of the various stages. If this is considered difficult to manage, a new cycle of spike selection can be initiated when the material derived from the previous cycle has reached the final stage, i.e. the selection of a new variety.

The seed of the selected file, rather than being sown as small parcels, can be mixed to form a sub-population, and where it is not necessary to have a uniform crop, this can be the new variety. Note that this variety may be replaced by a new, better or simply different variety, every 3-4 years. The farmer can also keep at the same time a range of different varieties.

Spike selection to create sub-populations (Fig 10 path 2-5)

As an alternatively to what described so far, the individual spikes rather than been kept separate and planted as separate rows, can be mixed after harvesting, threshed together and the resulting seed planted as a sub-population. This sub-population can be considered as described above.

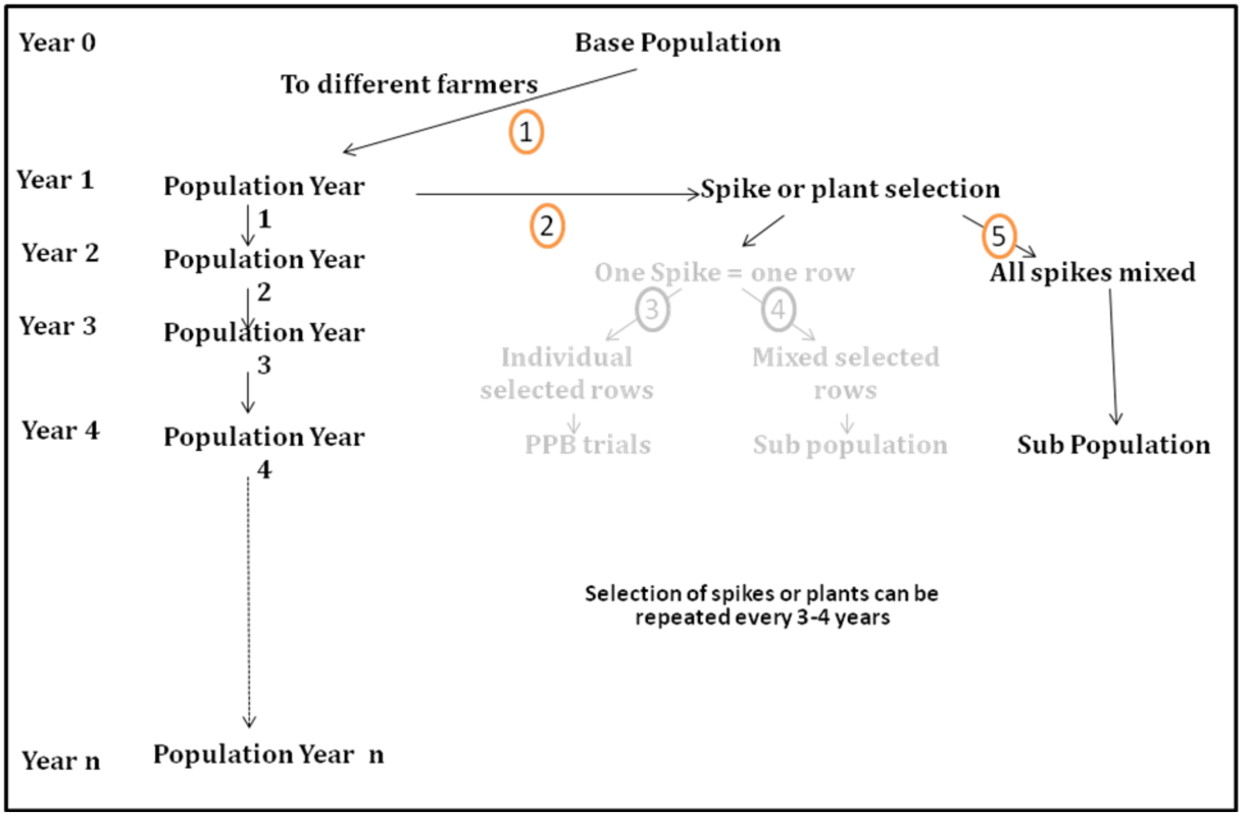

Figure 10. Selection of spikes or of plants from a population evolutionary in a cereal crop: the path 1 has been described in Figure 6. The path 2-5 illustrates the selection of individual ears (or cobs or plants) that can be mixed to make an improved sub-population. Note that path 1 MUST always be made to enable the population to evolve.

The two sub-populations represent a way to accelerate the process of adaptation - the first is expected to be more efficient because the selection is based on families rather than on individuals.

The (improved) subpopulation could eventually gradually become the farmers' crop.

The farmers must keep at least 400 to 500 m2 of the evolutionary population, which has a much broader genetic base and therefore a greater potential for evolution.

Conclusion

In 1908, Herbert J. Webber wrote "Plant-Breeding for Farmers", the Bulletin 251 of the Agricultural Experiment Station of the College of Agriculture at Cornell University (Ithaca, N.Y., USA) (8). In the first page he wrote: "No farmer, however, is so poor but that he can have his breeding patch of maize, wheat or potatoes. Indeed, if they but knew it, they can ill afford not to have such a breeding patch to furnish seed for their own planting"

Article 27 (2) of the Universal Declaration of Human Rights reads “Everyone has the right to the protection of the moral and material interests resulting from any scientific, literary or artistic production of which he is the author.”

This means that the laws prohibiting farmers to sell the seed resulting from their selection and make a profit are detrimental to human rights.

What we have described in this manual is not only a simple and inexpensive way for each farmers of producing his/her own seed, but to produce seed of a crop which is in harmony with the environment, which does not require pesticides because mixtures are very resistant to pests and diseases due to their heterogeneity, and eventually become progressively adapted to climate changes and to any other agronomic change the farmer wants to introduce in his/her field.

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