Chapter 8
Participatory Breeding for Climate Change-Related Traits

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Abstract After a review of the effects of climate changes on food security and agricultural production, the chapter relates modern plant breeding, as opposed to farmers' breeding practiced for millennia, with the decrease of agrobiodiversity. It underlines the contradiction between the unanimous recognition of the importance of biodiversity and the tendency towards uniformity of modern plant breeding, which, combined with the increased consolidation of the seed industry, is causing a dramatic decrease of cultivated biodiversity. This is exactly the opposite of what is required to adapt crops to climate changes. Although a suite of traits play an important role in the adaptation of crops to climate changes, it is also important to recognize that climate changes are a moving target and therefore the emphasis should not be so much on which trait to breed for but rather to adopt breeding strategies that allow a highly dynamic and efficient system of variety deployment in farmers' fields. Participatory plant breeding, whose technical aspects are described in detail, has the capability of increasing agricultural production at farm level by exploiting specific adaptation, thus increasing at the same time agrobiodiversity. Participatory plant breeding, integrated with evolutionary plant breeding, should become the model of plant breeding used by the plant breeding programs of the CGIAR centers.

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8.1 Introduction

Today, nobody questions whether climate changes are occurring or not and the discussion has shifted from whether they are happening to what to do about them.

The most recent evidence from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) indicates that the warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

The report states the following evidence:

- Eleven of the last 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850).
- The temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed faster than the oceans.
- The rising sea level is consistent with warming. The global average sea level has risen since 1961 at an average rate of 1.8 mm per year and since 1993 at 3.1 mm per year, with contributions from thermal expansion, melting glaciers and ice caps and the polar ice sheets.
- Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that the annual average Arctic sea ice extent has shrunk by 2.7 % per decade, with larger decreases in summer of 7.4 % per decade. Mountain glaciers and snow cover on average have declined in both the hemispheres (IPCC 2007).
- It is very probable that over the past 50 years, cold days, cold nights, and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent. Heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea levels has increased worldwide. There is also observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since around 1970, with limited evidence of increases elsewhere.
- There is no clear trend in the annual numbers of tropical cyclones, but there is evidence of increased intensity (IPCC 2007).
- Changes in snow, ice, and frozen ground have resulted in more, and larger, glacial lakes, increased ground instability in mountain and other permafrost regions, and led to changes in some Arctic and Antarctic ecosystems (Walker 2007).

Projections to the year 2100 indicate that CO_2 emissions are expected to increase by 400 % and CO_2 atmospheric concentration is expected to increase by 100 % (Fig. 8.1, modified from Cline 2007).

Some studies have predicted increasingly severe future impacts with potentially high extinction rates in natural ecosystems around the world (Williams et al. 2003; Thomas et al. 2004).

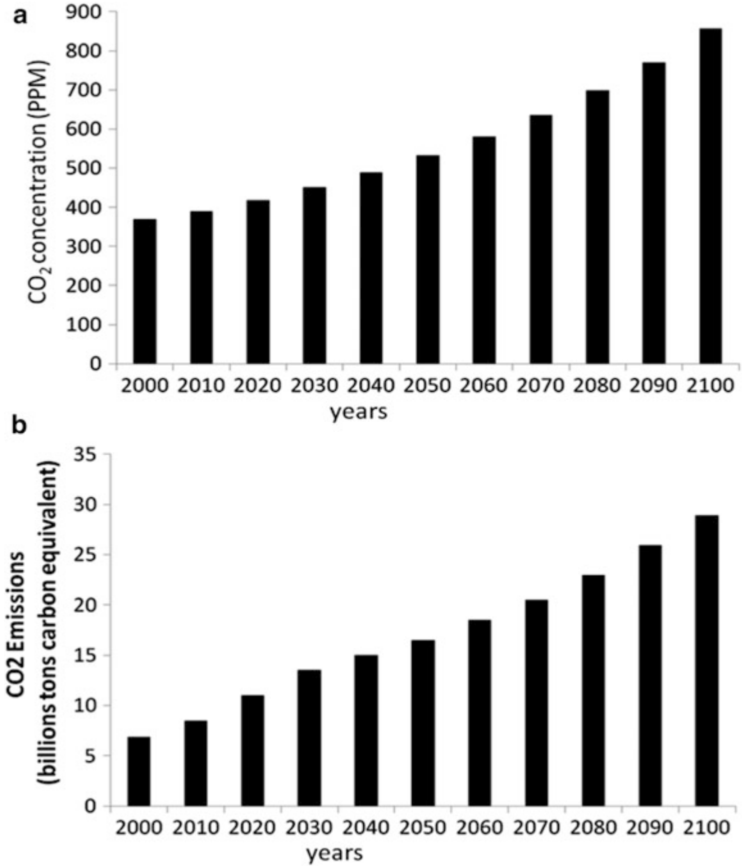

Fig. 8.1 Projected atmospheric CO_2 concentration in parts per million CO_2 (**a**) and projected emission in billion tons carbon equivalent (**b**) (modified from Cline 2007)

More recent evidence (Durack et al. 2012) suggests that dry regions will become drier and wet regions wetter in response to warming. This has been labeled as the “rich get richer” mechanism.

In addition, the IPCC (2007) argues that the impacts of climate change will be distributed differently among regions, generations, age classes, income groups, occupations, and genders (IPCC 2007). Climate change is expected to affect men and women differently because of their different access to assets, opportunities, and decision-making spaces. Gender inequalities, in many developing countries limit rural women’s options of migrating to look for off-farm employment (Aguilar 2009) therefore making their livelihoods dependent on climate-sensitive sectors such as agriculture (Skinner 2011). The feminization of agricultural labor is an increasing phenomenon worldwide (World Bank FAO; IFAD 2009). Yet, the majority of the rural women have limited access to productive resources (e.g., land, water, and seed) to farm (Skinner 2011). The International Assessment of

Agricultural Knowledge, Science, and Technology for Development (IAASTD) argues that the feminization of agriculture can represent a further marginalization of small-scale farms because rural women have mostly limited education and access to resources and opportunities (IAASTD 2009). Poor men, conversely, face greater difficulties in fulfilling their socially assigned roles as breadwinners when agricultural revenues are insecure because they lack the financial capital to diversify their livelihoods (Skinner 2011).

There has always been a considerable interest in understanding whether science can attribute any particular drought or hurricane to climate changes (Schiermeier 2011). Thanks to the advances in statistical tools, climate models and computer power, a link has been found between extreme weather and climate change in at least two instances—the catastrophic flooding in the UK in 2000 (Pall et al. 2011) and the late-twentieth-century increase in intense rainfall across the Northern Hemisphere (Min et al. 2011).

8.2 Climate Changes, Food, and Agriculture

Using the results from formal economic models, it has been estimated that, in the absence of effective counteraction, the overall costs and risks of climate change will be equivalent to a 5 % decrease in global gross domestic product (GDP) each year (Stern 2005). If a wider range of risks and impacts is taken into account, the estimates of damage could rise to a 20 % decrease in GDP or more, with a disproportionate burden and increased risk of famine on the poorest countries (Altieri and Koohafkan 2003).

The majority of the world's rural poor (about 370 million of the poorest people on the planet) live in areas that are resource-poor, highly heterogeneous, and risk-prone. The worst poverty is often located in arid or semiarid zones, and in mountains and hills that are ecologically vulnerable (Conway 1997). In many countries more people, particularly those at lower income levels, are now forced to live in marginal areas (i.e., floodplains, exposed hillsides, arid or semiarid lands), putting them at risk from the negative impacts of climate variability and change.

Climate changes are predicted to have adverse impacts on food production, food quality (Atkinson et al. 2008), and food security. One of the most recent predictions (Tubiello and Fischer 2007) is that the number of undernourished people will have increased by 150 % in the Middle East and North Africa, and by 300 % in Sub-Saharan Africa by the year 2080, compared to 1990 (Table 8.1). Enhancing gender equality is recommended as a key strategy to support women's ability to fulfill their roles in food systems and food cultures vis-à-vis their disadvantaged access to resources and opportunities (Jiggins 2011).

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce crop yields without discouraging weed, disease, and pest challenges. Changes in precipitation patterns increase the likelihood of short-term crop failures and long-term declines in production. Although there will be gains in

Table 8.1 Expected number of undernourished in millions, incorporating the effect of climate (from Tubiello and Fischer 2007)

	1990	2020	2050	2080	2080/1990
Developing countries	885	772	579	554	0.6
Asia, Developing	659	390	123	73	0.1
Sub-Saharan Africa	138	273	359	410	3.0
Latin America	54	53	40	23	0.4
Middle East and North Africa	33	55	56	48	1.5

some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security (Nelson et al. 2009).

Food insecurity will probably increase under climate change, unless early warning systems and development programs are used more effectively (Brown and Funk 2008). Currently, millions of hungry people subsist on what they produce. If climate change reduces production while populations increase, there is likely to be more hunger. Lobell et al. (2008) showed that increasing temperatures and declining precipitation over semiarid regions are likely to reduce yields for maize, wheat, rice, and other primary crops in the next two decades. These changes could have a substantial negative impact on global food security.

In addition, the impacts of climate change include reductions in calories consumption and increases in child malnutrition. Thus, aggressive agricultural productivity investments are needed to raise calories consumption enough to offset the negative impacts of climate change on the health and well-being of children (Nelson et al. 2009).

Foley (2011) proposed five solutions to food and environmental challenges, namely (a) stop the expansion of agriculture, particularly into tropical forests and savannas; (b) close the world's yield gaps between farm's current yield and its higher potential yield; (c) use resources much more efficiently to obtain far more crop output per unit of water, fertilizer, and energy; (d) shift diets away from meat: we can dramatically increase global food availability and environmental sustainability by using more of our crops to feed people directly and less to fatten livestock; and (e) reduce food waste: roughly 30 % of the food produced on the planet is discarded, lost, spoiled, or consumed by pests. For the second of these solutions Foley suggests that the largest and most immediate gain, especially in regions where hunger is most acute are to be expected by improving the yields of the world's least productive farms—a major shift in the research priorities of both national and international agricultural research.

Evidence indicates that if women small-scale farmers had the same access to productive resources—and seed of improved varieties in particular—as men, they could increase yields on their farms by 20–30 %, thereby reducing the number of hungry people in the world by 12–17 % (FAO 2011). Conversely, many have argued that access to food is more related to social marginalization and good governance than to production intensification (Sen 1981; De Schutter 2011;

Tscharntke et al. 2012). Empowering the most marginalized farmers and women farmers in particular, is seen as a means to both improve gender equality and to progress towards hunger and poverty eradication (FAO, IFAD, and WFP 2012).

8.3 How Do People Respond to Climate Changes?

Although the debate about climate changes is relatively recent, people have been adapting to climate changes for thousands of years, for example in Africa. In general, people seem to have adapted best when working as a community rather than as individuals. The four main strategies of adaptation have been (1) changes in agricultural practices, (2) formation of social networks, (3) embarking on commercial projects, such as investing in livestock, and (4) seeking work in distant areas. The first three of these strategies rely on people working together to improve their community (Giles 2007).

In coping continuously with extreme weather events and climate variability, farmers living in harsh environments in Africa, Asia, and Latin America have developed and/or inherited complex farming systems that have the potential to bring solutions to many of the uncertainties facing humanity in an era of climate change (Altieri and Koohafkan 2003). These systems have been managed in ingenious ways, allowing small farming families to meet their subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies (Denevan 1995). The systems can still be found throughout the world, covering some 5 million ha. Such systems are of global importance to agriculture and food production, and are based on the cultivation of a diversity of crops and varieties in time and space that have allowed traditional farmers to avert risks and maximize harvest security in uncertain and marginal environments, under low levels of technology and with limited environmental impact (Altieri and Koohafkan 2003). One of the salient features of traditional farming systems is their high degree of biodiversity, in particular the plant diversity in the form of poly-cultures and/or agroforestry patterns. One example of this traditional farming system is a mixture of barley and wheat known as hanfets, which is practiced since millennia in the Central Highlands of Eritrea and in the northern part of Ethiopia (Woldeamlak and Struik 2000; Woldeamlak 2001; Woldeamlak et al. 2008). Farmers quote yield, yield stability, better resistance to lodging of barley, better resistance to rust of wheat, and better quality of the bread obtained from the mixture as the main reasons for growing this mixture. There are also examples in the same region of more complex mixtures involving bread wheat, durum wheat, six-row barley, and two-row barley. Another famous example is the nine seeds (*Navdanya*) mixture common in some regions of India; the mixture includes barley, little millet, pigeon pea, green gram, chickpea, rice, sesame, black gram, and horse gram.

An additional strategy used in areas with an erratic start of the rainy season, is to have a suite of crops to choose from depending on the timing of the start of the rains. This is, for example, the case in Eritrea where crops such as sorghum, pearl millet, finger millet, teff, and barley are available to farmers (Ceccarelli et al. 2007). In the case of an early start of the rainy season, farmers plant teff and/or barley, while in the case of a late start they plant sorghum and pearl millet.

A careful observation of these systems shows that farmers tend to dilute the risk associated with practicing agriculture in difficult conditions using various combinations of three levels of biodiversity: different crops, different cultivars of the same crop, and/or heterogeneous cultivars to retain adaptability and to maximize adaptation over time (stability or dependability), rather than adaptation over space. Diversity and heterogeneity serve to disperse or buffer the risk of total crop failure due to unpredictable environmental variation. As we will see later, this is in sharp contrast with the trend of modern plant breeding towards uniformity over space and uniform cultivars.

These strategies of minimizing risk by planting several species and varieties of crops makes the system more resilient to weather events, climate variability and change, and is more resistant to the adverse effects of pests and diseases (Newton et al. 2011), while at the same time stabilizing yields over the long term, promoting diet diversity and maximizing returns even with low levels of technology and limited resources (Altieri and Koohafkan 2003). As we will see later, these strategies are an important lesson to breeding for adaptation to climate changes.

The term "autonomous adaptation" has been used to define responses that will be implemented by individual farmers, rural communities, and/or farmers' organizations, depending on perceived or real climate change in the coming decades, and without intervention and/or coordination by regional and national governments and international agreements. To this end, pressure to cultivate marginal land, or to adopt unsustainable cultivation practices as yields drop, may increase land degradation and endanger the biodiversity of both wild and domestic species, possibly jeopardizing future ability to respond to increasing climate risk later in the century.

One of the options for autonomous adaptation includes the adoption of varieties/ species with, for example, increased resistance to heat shock and drought (Bates et al. 2008).

8.4 How Do Crops Cope with Climate Changes?

Adapting crops to climate changes has become an urgent challenge, which requires some knowledge on how crops respond to those changes. In fact plants have responded to increasing CO_2 concentration from preindustrial to modern times by decreasing stomatal density—reversing the change which occurred about 350 million years ago and that led to the appearance of leaves (Beerling et al. 2001; Beerling 2007; Ceccarelli et al. 2010)—as shown by the analysis of specimens collected from herbaria over the past 200 years (Woodward 1987). In *Arabidopsis thaliana*, the ability to respond to increasing CO_2 concentration with a decrease in the number of stomata is under genetic control (Gray et al. 2000); with the dominant allele (*HIC* = high carbon dioxide) preventing changes in the number of stomata. In the presence of the recessive *hic* allele, there is an increase of up to 42 % in stomatal density in response to a doubling of CO_2. Stomatal density varies widely within species: for example in barley stomatal density varies from 39 to 98 stomata/mm^2 (Miskin and Rasmusson 1970) suggesting that the crop has the capacity to adapt.

We know now fairly well how plants respond to an increase in CO_2 concentration, which has both direct and indirect effects on crops. Direct effects (also known as CO_2-fertilization effects) are those affecting crops by the presence of CO_2 in ambient air, which is currently sub-optimal for C_3 type plants like wheat, rice, and barley. In fact, in C_3 plants, mesophyll cells containing ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) are in direct contact with the intercellular air space that is connected to the atmosphere via stomatal pores in the epidermis. Hence, in C_3 crops, rising CO_2 increases net photosynthetic CO_2 uptake because RuBisCO is not CO_2-saturated in today's atmosphere and because CO_2 inhibits the competing oxygenation reaction, leading to photorespiration. CO_2-fertilization effects can include an increase in photosynthetic rate, reduction of transpiration rate through decreased stomatal conductance, higher water use efficiency (WUE), and lower probability of water stress occurrence. Consequently, crop growth and biomass production may increase by up to 30 % for C_3 plants at doubled ambient CO_2. However, other experiments show biomass increases of only 10–20 % under doubled CO_2 conditions. In theory, at 25 °C, an increase in CO_2 from the current 380 to the 550 ppm (air dry mole fraction), projected for the year 2050, would increase photosynthesis by 38 % in C_3 plants. In contrast, in C_4 plants (e.g., maize and sorghum) RuBisCO is localized in the bundle sheath cells in which CO_2 concentration is three to six times higher than atmospheric CO_2. This concentration is sufficient to saturate RuBisCO and in theory would prevent any increase in CO_2 uptake with rising CO_2. However, even in C_4 plants, an increase in WUE via a reduction in stomatal conductance caused by an increase in CO_2 may still increase yield (Long et al. 2006).

However, the estimates of the CO_2-fertilization effects have been derived from enclosure studies conducted in the 1980s (Kimball 1983; Cure and Acock 1986; Allen et al. 1987), and currently they appear to be overestimated (Long et al. 2006).

In fact free-air concentration enrichment (FACE) experiments, representing the best simulation of elevated CO_2 concentrations in the future, give much lower ca. half) estimates of increased yields due to CO_2-fertilization (Table 8.2).

Indirect effects (also known as weather effects) are the effects of solar radiation, precipitation, and air temperature. Keeping management the same, cereal yields typically decrease with increasing temperatures and increase with increased solar radiation. If water supply is limited, yields eventually decrease because of higher evapotranspiration. Precipitation will obviously have a positive effect when it reduces water stress but can also have a negative effect when, for example, it causes waterlogging.

In addition to CO_2, nitrogen (N) deposition is also expected to increase further (IPCC 2007) and it is known that increasing N supply frequently results in declining species diversity (Clark and Tilman 2008). In a long-term open-air experiment,

Table 8.2 Percentage increases in yield, biomass, and photosynthesis of crops grown at elevated CO_2 (550) in enclosure studies versus FACE (Free-air concentration enrichment) experiments (Long et al. 2006)

Source	Rice	Wheat	Soybean	C_4 crops
	Yield			
Kimball (1983)	19	28	21	–
Cure and Acock (1986)	11	19	22	27
Allen et al. (1987)	–	–	26	–
Enclosure studies	–	31	32	18
FACE studies	12	13	14	0[a]
	Biomass			
Cure and Acock (1986)	21	24	30	8
Allen et al. (1987)	–	–	35	–
FACE studies	13	10	25	0[a]
	Photosynthesis			
Cure and Acock (1986)	35	21	32	4
FACE studies	9	13	19	6

[a] Data from only 1 year (Leakey et al. 2006)

grassland assemblages planted with 16 species were grown under all combinations of ambient and elevated CO_2 and ambient and elevated N. Over 10 years, elevated N reduced species diversity by 16 % at ambient CO_2 but by just 8 % at elevated CO_2. Although the projected increase in atmospheric CO_2 and global warming may enhance food production to some extent in the temperate developed countries, it is likely to reduce both arable area and yield per crop in many less developed ones (Evans 2005).

The most likely scenario within which plant breeding targets need to be established, is the following:

- Higher temperatures, which will reduce crop productivity, are certain
- Increasing CO_2 concentration is certain with both direct and indirect effects
- Increasing frequency of drought is highly probable
- Increase in the areas affected by salinity is highly probable
- Increasing frequency of biotic stress is also highly probable

Given this scenario, and given that plant breeding has been a success story in increasing yield (Dixon et al. 2006), plant breeding may help in developing new cultivars with enhanced traits better suited to adapt to climate change conditions. These traits include field drought and temperature stress resistance—defined as higher and stable performance (=grain yield, forage yield, tuber yield, etc.) under below optimal moisture availability and above optimal temperature, resistance to pests and disease—which will increasingly cause crop losses (Oerke 2006; Newton et al. 2011), salinity, and waterlogging (Humphreys 2005).

Breeding for drought resistance has historically been one of the most important and common objectives of several breeding programs for all the major food crops in most countries (Ceccarelli et al. 2004, 2007, 2010). It has also been a major investment, yet with no improved varieties developed, of molecular breeding and genomic technologies (Morrell et al. 2012).

As we will discuss in the second part of the chapter, breeding for the adaptation to climate changes will be fruitless if farmers do not adopt the varieties with the desirable traits, regardless of whether these traits have been assembled using conventional or DNA-based technologies.

One of the main opportunities for new cultivars with increased drought tolerance includes changes in phenology or enhanced responses to elevated CO_2.

Phenology is known to be a major determinant in drought tolerance allowing crops to complete the life cycle before the onset of drought (Baum et al. 2003) and therefore this will be one of the main traits in breeding for adaptation to climate changes.

Phenology has been shown in recent studies to be associated with yield under drought (Lakew et al. 2011, 2013), and it has been shown to have been modified in wild relatives of wheat and barley collected in Israel over a period of 28 years (Nevo et al. 2012). Genes controlling flowering time are among the top candidates controlling local adaptation in *Arabidopsis thaliana* (Gaut 2012).

Recent data based on a large number of studies (Wolkovich et al. 2012) show that warming experiments under-predict advances in the timing of flowering by 8.5-fold, compared with long-term observations and the experimental results did not match with the observational data in sign or magnitude. The observational data also showed that the species that flower earliest in the spring have the highest temperature sensitivities, but this trend was not reflected in the experimental data.

Root characteristics, generally poorly known, are expected to become more and more important as water availability becomes the main limiting factor.

With respect to water, a number of studies have documented genetic modifications in major crop species (e.g., maize and soybeans) that have increased their water-deficit tolerance (Drennen et al. 1993; Kishor et al. 1995; Pilon-Smits et al. 1995; Cheikh et al. 2000), although this may not extend to a wide range of crops. In general, too little is known currently about how the desired traits achieved by genetic modification perform in real farming and forestry applications (Sinclair and Purcell 2005).

Thermal tolerances of many organisms have been shown to be proportional to the magnitude of temperature variation they experience: lower thermal limits differ more among species than upper thermal limits (Addo-Bediako et al. 2000). A crop such as barley, for example, which has colonized a wide diversity of thermal climates, may harbor enough genetic diversity to breed successfully for enhanced thermal tolerance.

Soil moisture reduction due to precipitation changes could affect natural systems in several ways and therefore, indirectly, also the agricultural systems. There are projections of significant extinctions in both plant and animal species. Over 5,000 plant species could be impacted by climate change, mainly due to the loss of suitable habitats. By 2050, the extent of the Fynbos Biome (Ericaceae-dominated ecosystem of South Africa, which is an International Union for the Conservation of Nature and Natural Resources (IUCN) “hotspot”) is projected to decrease by

51–61 % due to decreased winter precipitation. The succulent Karoo Biome, which includes 2,800 plant species at increased risk of extinction, is projected to expand south-eastwards, and about 2 % of the family *Proteaceae* is projected to become extinct. These plants are closely associated with birds that have specialized in feeding on them. Some mammal species, such as the zebra and nyala, which have been shown to be vulnerable to drought-induced changes in food availability, are widely projected to suffer losses. In some wildlife management areas, such as the Kruger and Hwange National Parks, wildlife populations are already dependent on water supplies supplemented by borehole water (Bates et al. 2008).

With the gradual reduction in rainfall during the growing season, aridity in Central and West Asia has increased in recent years, reducing the growth of grasslands and ground cover (Bou-Zeid and El-Fadel 2002). The reduction of ground cover has led to increased reflection of solar radiation, such that more soil moisture evaporates and the ground becomes increasingly drier in a feedback process, thus adding to the acceleration of grassland degradation (Zhang et al. 2003). Recently, it has been reported that the Yangtze river basin has become hotter and it is expected that the temperature will increase by up to 2 °C by 2050 relative to 1950 (Ming 2009). This temperature increase will reduce rice production by up to 41 % by the end of the twenty-first century and maize production by up to 50 % by 2080.

The negative impact of climate changes on agriculture and therefore on food production is aggravated by the greater uniformity that exists now compared to 150–200 years ago, particularly in the agricultural crops of developed countries. The decline in agricultural biodiversity can be quantified. While it is estimated that there are ca. 250,000 plant species, of which about 50,000 are edible, in fact no more than 250 are used—out of which 15 crops provide 90 % of the calories in the human diet and three of them, namely wheat, rice and maize, provide 60 %. In these three crops, modern plant breeding has been particularly successful and movement towards genetic uniformity has been rapid—the most widely grown varieties of these three crops are closely related and genetically uniform (pure lines in wheat and rice and hybrids in maize—but hybrids are being promoted also in rice (Jahaiah 2002)).

The number of varieties covering large areas for the major crops is frighteningly small: 71 % of the area planted with maize is planted with 6 varieties, 75 % of the area planted with potato is planted with 4 varieties, 65 % of the area planted with rice is planted with 4 varieties, and so on (Secretariat of the Convention on Biological Diversity 2010).

The major consequence of the dependence of modern agriculture on a small number of varieties for the major crops (Altieri 1995) is that the main sources of food are more genetically vulnerable than ever before, i.e., food security is in danger. A number of plant breeders have warned that conventional plant breeding by continuously crossing between elite germplasm lines would lead to the extinction of diverse cultivars and nondomesticated plants (Vavilov 1992; Flora 2001; Gepts 2006; Mendum and Glenna 2010) and climate change may exacerbate the crisis. Gepts (2006) claims that the current industrial agriculture system is "the single most important threat to biodiversity." Historically, there are several examples of the devastating effects of a narrow genetic base (Keneni et al. 2012). A recent example of this danger is the rapid spreading of diseases such as UG99 (a new race of stem rust of wheat caused by *Puccinia graminis triticii*, detected for the first time in Uganda in 1999). The new race is virulent to most wheat varieties and can cause complete loss of the crop (Pretorius et al. 2000; Singh et al. 2006). The danger of a narrow genetic base applies equally well to climate changes as the current predominant uniformity does not allow the crops to evolve and adapt to the new environmental conditions (see also Chapter 9). The expected increase of biofuel monoculture production may lead to increased rates of biodiversity loss and genetic erosion. Another serious consequence of the loss of biodiversity has been the displacement of locally adapted varieties, which may hold the secret of adaptation to the future climate (Ceccarelli and Grando 2000; Ceccarelli et al. 1992; Grando et al. 2001; Sarker and Erskine 2006; Rodriguez et al. 2008; Abay and Bjørnstad 2009; Ceccarelli 2012a).

One aspect of modern plant breeding in relation to traits important for adaptation to climate changes has been its reductionist approach in searching, for example, genes for drought resistance. Only recently it has been recognized that one of the key traits in relation to climate changes, namely drought resistance is too complex to be manipulated with biotechnological methods. In fact, those methods have so far failed to increase farmers yield in dry years or dry locations.

8.5 Agrobiodiversity and Plant Breeding

Plant breeding is one of the main causes for the reduction of agrobiodiversity quantified earlier and the evolution of plant breeding helps explain the progression of genetic erosion.

Selection started at the same time as domestication when the Neolithic men and women started intentional sowing, which applies strong, unconscious selection pressure (Zohary 2004). Alleles for nonshattering, lack of dormancy, reproductive determinacy, and increased fertility of formerly sterile florets are all favored by the sowing–harvesting–sowing cycle (Harlan et al. 1973). After domestication, farmers have continued to modify crops for millennia and have been largely responsible for the spreading of crops across the planet (Gepts 2002). As they migrated across continents, they brought with them their seeds and their animals, which both needed to adapt to the new environments, the new soil types and possibly to new uses. In the plant breeding done by farmers there was an emphasis on specific adaptation not only to the environment (climate and soil) but also to the uses so that it was obvious that the same farmer will select more than one variety of the same crop and that different farmers will select different varieties. An important aspect of farmers' breeding was that the selection environment and the target environment was the same, a situation that avoids the negative consequences of Genotype × Location interaction on response to selection (Falconer 1981). Over thousands of years this process (farmers' breeding) led to the formation of landraces.

Therefore, long before Mendel and long before plant breeding as we know it today, farmers planted, harvested, stored, and exchanged seeds, and fed themselves and others, and in doing all this they built a considerable amount of knowledge about the crops, their characteristics and possible uses, and their interactions with the surrounding environment.

With the rediscovery of Mendel's work, two major changes took place, which profoundly affected the evolution of plants, particularly of domesticated crops and of their evolutionary potential (Ceccarelli 2009b). Firstly, plant breeding was moved from farmers' fields to research stations and from farmers to scientists. What was done by very many farmers in very many different places started to be done by relatively few scientists in a relatively few places (the research stations), which with time became more and more similar to each other. Secondly, selection for specific adaptation was replaced by selection for wide adaptation because of aiming at several target environments from few selection environments. Thirdly, plant breeding gradually went from publicly to privately funded—today even the CGIAR,[1] which were publicly funded till recently, have opened the door to private donors: as a consequence not all crops were treated equally, and some became "orphan crops," neglected by science. They include some important food crops such as banana, cassava, and yam that are central in the livelihoods of the poorest farmers (Bellon 2006) and of women farmers in particular (Howard 2003). In these changes, there is no evidence that any use was made of, or any attention was paid to, the local knowledge accumulated over thousands of years.

It is interesting to note that in the early part of the twentieth century a number of scientists were actually advocating an environmentally friendly type of plant breeding. In 1923, H. K. Hayes wrote, "The importance of plant breeding as a means of obtaining varieties which are adapted to particular environmental conditions is becoming more generally recognized." In 1925, F. L Engledow added, "We can no longer hope, as breeders once did, for the new form which everywhere and in all years will excel. Our hope is of breeding for every locality the form best adapted to the environment it offers."

However, the dominant breeding philosophy which eventually emerged as a consequence of what is known as the "Green Revolution" was based on "wide adaptation," i.e., the selection of varieties able to perform well in many different locations and countries, having lost photoperiod sensitivity and vernalization requirement.

The term Green Revolution was coined in March 1968 by William S. Gaud, the then director of the US Agency for International Development (USAID) to indicate the outcome of a development strategy based on (a) new crop cultivars, (b) irrigation, (c) fertilizers, (d) pesticides, and (e) mechanization. Within that strategy, the

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[1] CGIAR is the new brand name of the Consultative Group of International Agricultural Research Center.

new varieties obtained by shuttle breeding were, as a collateral and unplanned effect, photoperiod insensitive and without vernalization requirement, hence widely adapted (Salvi et al. 2013). Not only was this exactly the opposite of what farmers had done for millennia, but the term wide adaptation was somewhat misleading because it indicates wide "geographical" adaptation rather than wide "environmental" adaptation (Ceccarelli 1989). In fact the agricultural environments in which these "widely adapted" varieties were successful were actually very similar (high rainfall and good soil fertility) or were made similar by adding irrigation water, fertilizers, and pesticides when farmers can afford them. This caused three major problems. First, the heavy use of chemicals soon began affecting the environment. Today it is estimated that about 25 % of N applied particularly in developing countries does not provide any additional yield increase but only increased pollution (Good and Beatty 2011). Second, the poorest farmers and particularly those living in marginal environments were bypassed because they could not afford to purchase the chemicals needed to create the right environments for the new varieties—not all scientists agree on this, but most of the poor farmers do. The father of the Green Revolution, Norman Borlaug, pointed out a few years ago, "despite the successes of the Green Revolution, about two billion people still lack reliable access to safe, nutritious food, and 800 million of them are chronically malnourished" (Reynolds and Borlaug 2006); these figures may well increase because of climate changes. Third, there was a dramatic decline in agricultural biodiversity because on one hand hundreds of genetically diverse local varieties selected by farmers over millennia for specific adaptation to their own environment and uses were displaced, and on the other hand the new varieties (despite having different names) were all very similar in their genetic constitution.

The trends towards uniformity has continued and today we see a dramatic contrast between, on one hand, the scientific literature showing how vital is biodiversity for our future on this planet and, on the other, the dramatic decrease of agrobiodiversity which is made even worse by the ever-increasing concentration of the seed market in the hands of a few seed industries (Fuglie et al. 2011).

A key issue in breeding for climate changes is to recognize that climate changes are a moving target and therefore the emphasis should not be so much on which trait to breed for but rather a drastic change in breeding strategies to have a highly dynamic and efficient system of variety deployment in farmers' fields.

8.6 Genotype × Environment Interactions and Breeding Strategies

One of the main consequences of the separation between the selection environment (the research station) and the target environments (the farmers' fields) is that a large amount of breeding material is discarded before knowing whether it could have been useful in the real conditions of farmers' fields, and the one which is selected is likely to perform well in environments similar to the research stations, but not in environments which are very different. This is because of Genotype × Environment (GE) interactions which are one of the major factors limiting the efficiency of breeding programs when they cause a change of ranking between genotypes in different environments (crossover interaction).

Studies conducted in Australia (Pederson and Rathjen 1981; Cooper et al. 1997) to evaluate the relevance of research stations for their suitability as selection environments have found that, in many cases, the genetic correlations between the yield of breeding lines on the research station and yield under on-farm conditions were low in comparison with the genetic correlations between different on-farm experiments.

An example of crossover GE interactions between research stations and farmers fields is given in Fig. 8.2. In both cases there was much more similarity between research stations than between farmers' fields, and low or negative correlations between research stations and most of the farmers' fields. Another case is shown in Fig. 8.3. The five highest yielding barley lines in a farmer's field in Senafe (Eritrea) had a yield advantage over the local check of between 27 % and 30 %. However, when tested on-station the same lines showed a yield disadvantage of between 15 % and 87 % except entry 95 which had a yield advantage of only 4 %. Therefore, most probably they would have been discarded had the evaluation been done only in the research station.

In general, when different lines or cultivars of a given crop are evaluated in a sufficiently wide range of environments, GE interactions of crossover type seem to be very common (Ceccarelli 1996). We have argued (Ceccarelli 1989) that for crops grown in environments poorly represented by the research stations, this often results in useful breeding materials being discarded.

When GE interactions are significantly large, it is not possible to ignore them and the two remaining strategies are (1) to avoid them by selecting material that is broadly adapted to the entire range of target environments, or (2) to exploit them by selecting a range of material, each adapted to a specific environment (Ceccarelli 1989). The choice is based on a separate analysis of the two components of GE interactions, namely Genotype × Years (GY) and Genotype × Locations (GL), the first of which is largely unpredictable, while the second, if repeatable over time, identifies distinct target environments (Annicchiarico et al. 2005, 2006).

Selection for specific adaptation to each of the target environments is particularly important in breeding crops predominantly grown in unfavorable conditions such as those that will increasingly become more common with climate changes, because unfavorable environments tend to be more different from each other than favorable environments (Ceccarelli and Grando 1997). An example is shown in Fig. 8.4 where the total GE in the case of the two dry locations (left) was nearly 90 %, while in the case of the two high rainfall locations was less than 50 %.

Selecting for specific adaptation has the advantage of adapting cultivars to the physical environment where they are meant to be cultivated, and hence is more sustainable than other strategies, which rely on modifying the environment to fit new cultivars adapted to more favorable conditions (Ceccarelli and Grando 2002).

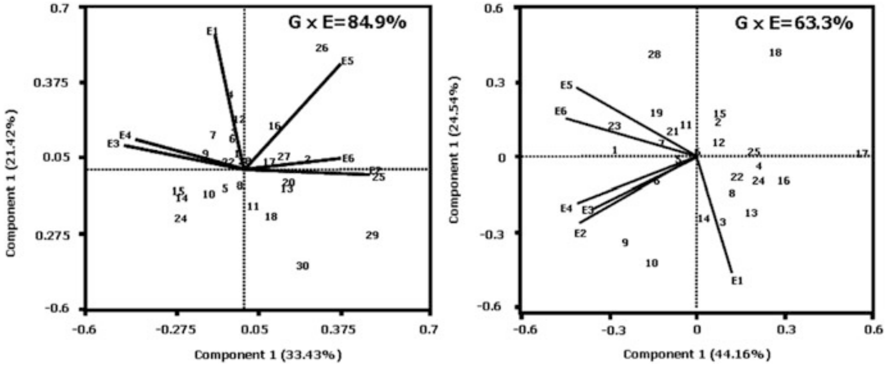

Fig. 8.2 Biplots of 30 barley genotypes grown in six locations in Morocco (*left*) including two research stations (E3 and E4) and four farmers' fields (E1, E2, E5, and E6) and of 25 barley genotypes in six locations in Tunisia (*right*) including two research stations (E5 and E6) and four farmers' fields (E1, E2, E3, and E4)

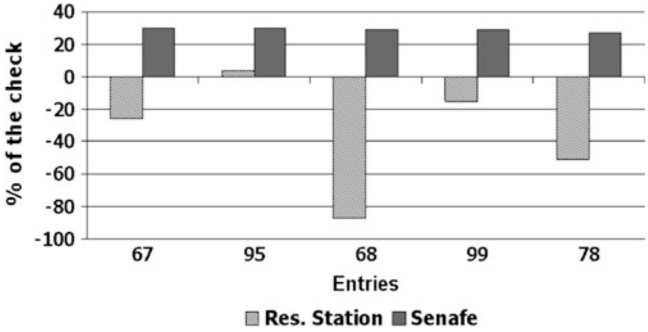

Fig. 8.3 Yield (in percent of the local check) of five barley lines in a farmer's field in Senafe (Eritrea) and in the research station at Halale (40 km south of Asmara)

Selection theory and experimental data (Annicchiarico et al. 2005) shows that selection for specific adaptation is more efficient because it exploits the larger heritabilities within each specific target environment.

The similarity between research stations observed in Fig. 8.2 and between high rainfall locations and years observed in Fig. 8.4 are likely to be also associated with the larger use of inputs (fertilizers, weed control, etc.) common to both research stations and high rainfall areas, which tend to smooth out differences between locations and years.

Selection for specific adaptation is based on direct selection in the target environment as farmers' did for millennia, which has also been defined as decentralized selection (Falconer 1981; Simmonds 1984, 1991). Murphy et al. (2007) have shown that selection for specific adaptation is important in organic agriculture (van Bueren Lammerts and Myers 2012).

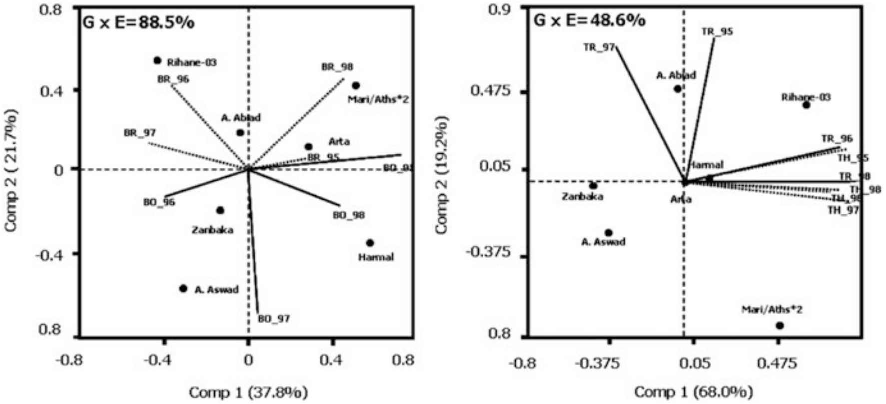

Fig. 8.4 Biplots of grain yield of seven barley cultivars grown for 4 years (1995–1998) in two dry locations, Bouider (BO) and Breda (BR) with a grand mean of 1.3 t/ha (*left*) and in two locations, Tel Hadya (TH) and Terbol (TR) with a grand mean of 3.5 t/ha (*right*)

Direct selection in the target environments is particularly important in the case of a moving target such as a gradual increase in temperature and a gradual decrease in rainfall, their interactions, and the interaction with biotic stresses and agronomic management, the likely scenario of climate changes. The advantages of selecting for specific adaptation to climate changes are the holistic approach and the fact that phenology, the plant attribute that we have seen as one of the major factors involved in adaptation to climate changes, is highly heritable. This should allow a cycle of selection for earliness on-station, which leaves enough genetic variability in the breeding material for adaptation to specific environmental conditions in the subsequent cycles of selection.

8.7 A New Paradigm

At this point, a number of questions can be asked such as:

- Would it have been possible to feed the world without depleting the resources of the planet?
- Given that plant breeding has been defined as “guided evolution,” could we have “guided” the evolution of crops in a different direction?
- Would it be possible to harmonize the increase of agricultural production with agrobiodiversity conservation?
- In summary, would it be possible to organize agricultural research in general and plant breeding in particular, in such a way to increase agricultural production while at the same time respecting biodiversity, gender equity, the environment, and ultimately safeguarding human health?

Participatory research and participatory plant breeding (PPB) are addressing these specific questions while at the same time addressing some of the major global problems such as climate changes, biodiversity, and hunger.

8.8 Participatory Plant Breeding

In recent years, there has been an increasing interest towards participatory research in general, and towards participatory plant breeding in particular. Following the early work of Rhoades and Booth (1982), scientists have become increasingly aware that users' participation in technology development may in fact increase the probability of success for the technology.

The interest is partly associated with the perception that the impact of agricultural research, including plant breeding, particularly in developing countries and for marginal environments and poor farmers has been below expectations.

Three common characteristics of most agricultural research, which might help to explain its limited impact in marginal areas, are:

The research agenda is usually decided unilaterally by the scientists and is not discussed with the users;

Agricultural research is typically organized in compartments, i.e., disciplines and/or commodities, and seldom uses an integrated approach; this contrasts with the integration existing at farm level. The different technology needs of the users (influenced for example by socioeconomic, gender and cultural factors that might affect their agronomic practices, food preferences, crops and variety priorities) and their knowledge are rarely taken into account;

There is a disproportion between the large number of technologies generated by agricultural scientists and the relatively small number of them actually adopted and used by the farmers.

When one looks at these characteristics as applied to plant breeding programs, most scientists would agree that:

- Plant breeding has not been very successful in marginal environments and for poor farmers and has generally overlooked gender-based differences in crop and variety preferences and needs;
- It still takes a long time (about 15 years) to release a new variety as reported in the recommendations of Interdrought, Rome (2005) "While the support for and the capacity of plant biotechnology increased, the collaboration with plant breeding has been insufficient (with the exception of the private sector). This lack of collaboration resulted in slow delivery of biotechnology solutions to the user in the field. There is an explosive growth of information in genomics with a proportionally minute rate of application of this information to problem solving in farming under water-limited conditions"
- Many varieties are officially released, but few are adopted by farmers; by contrast farmers often grow varieties, which were not officially released

- Even when new varieties are acceptable to farmers, their seed is either not available or too expensive
- There is a widespread perception of a decrease of biodiversity associated with conventional plant breeding.

Conventional plant breeding seems therefore ill-suited to provide a dynamic and rapid adaptation to climate changes matched by a prompt adoption by farmers.

Participatory research, in general, defined as that type of research in which users are involved in the design—and not merely in the final testing—of a new technology, is now seen by many as a way to address the problems discussed in the first part of this chapter. PPB in particular, is defined as that type of plant breeding in which farmers, as well as other partners, such as extension staff, seed producers, traders, NGOs, etc., participate in the development of a new variety. PPB is expected to produce varieties, which are targeted (focused on the right farmers), relevant (responding to real needs, concerns, and preferences) and appropriate (able to produce results that can be adopted) (Bellon 2006).

In the next sections we will illustrate some of the characteristics of PPB using examples from projects implemented by the International Center for Agricultural Research in the Dry Areas (ICARDA) in a number of countries (Ceccarelli 2012b), from experiences in participatory plant breeding applied to organic agriculture (Desclaux et al. 2011) with an emphasis on the beneficial effects of PPB in relation to climate changes.

8.9 Plant Breeding and Plant Breeders

Plant breeding is an applied, multidisciplinary science based on the application of genetic principles and practices for the development of cultivars more suited to the needs of people; it uses knowledge from agronomy, botany, genetics, cytogenetics, molecular genetics, physiology, pathology, entomology, biochemistry, bioinformatics, and statistics (Schlegel 2003). The ultimate outcome of plant breeding is mainly improved cultivars. Therefore, plant breeding is primarily a science, which looks at the organism as a whole even though it is also suited to translate information at the molecular level (DNA sequences, protein products) into economically important phenotypes (Gepts and Hancock 2006).

As a science, plant breeding started soon after the rediscovery of Mendel's Laws at the beginning of the twentieth century. Before that, plant improvement had been done for several thousand years by farmers as described earlier.

There is evidence that hybridization also started before 1900 (as discussed by, for example, Strampelli 1944). Since then, plant breeding has evolved by absorbing approaches from different areas of science, allowing breeders to increase their efficiency and exploit genetic resources more thoroughly (Gepts and Hancock 2006). Over the years, it has put to productive use the progress in crop evolution, population and quantitative genetics, statistical genetics and biometry, molecular biology, and genomics. Thus, plant breeding has remained a vibrant science, with continued success in developing and deploying new cultivars on a worldwide basis. On average, around 50 % of productivity increases can be attributed to genetic improvement (Fehr 1984). Despite differences between crops and between breeders, in all breeding programs it is possible to identify three main stages (Schnell 1982; Ceccarelli 2009a):

- Generating genetic variability. This includes making crosses (selection of parents, crossing techniques, and type of crosses), inducing mutation, and introducing exotic germplasm.
- Selection of the best genetic material within the genetic variability created in the first stage. In self-pollinated crops, this includes primarily the implementation of various methods, such as classical pedigree, bulk pedigree, backcross, hybridization, recurrent selection, or the F_2 progeny method. In self-pollinated tree crops, this includes progressive evaluation of individual plants. In cross-pollinated crops, synthetic varieties, open-pollinated varieties and hybrids are used, and in vegetatively propagated crops there are clones and hybrids. Marker-assisted selection (MAS) could be used in this stage.
- Testing of breeding lines. This includes comparisons between existing cultivars and the breeding lines emerging from Stage 2, and the appropriate methodologies to conduct such comparisons. These comparisons take place partly on-station (on-station trials) and partly in farmers' fields (on-farm trials).

As a consequence of Stage 1 and partly also due to selection during the first part of Stage 2, the amount of breeding materials generated is very large (from a few to several thousands). During Stages 2 and 3 the number of breeding lines decreases, the amount of seed per line increases and so does the number of locations where the material can be tested.

There are two other important stages in a breeding program: setting priorities; and dissemination of cultivars. These two steps have been discussed in detail by Weltzien and Christinck (2009) and by Bishaw and van Gastel (2009).

In a nonparticipatory program, all the decisions are taken by the breeder and by the breeding team, even in the case of on-farm trials.

An important characteristic of a breeding program is that it is a cyclic process in which each step feeds information and material into the subsequent step, and each breeding cycle feeds information into the next cycle (Fig. 8.5).

By breeding cycle we mean the period of time, usually 10–15 cropping seasons (assuming one generation per year), from making a cross to obtaining advanced lines or varieties, which in turn are used as parental material in the crossing program to start a new cycle, i.e., from cross to cross. In a breeding program, where crosses are made every year, several breeding cycles co-exist, each one year ahead of its successor. During this process, a tremendous amount of information is generated, and one of the major challenges in a breeding program is how to capture and store this information in a way that is sufficiently transparent for others (scientists and nonprofessionals) to use. In conventional (nonparticipatory) breeding programs (CPB), most of this information represents the "cumulative experience" or the

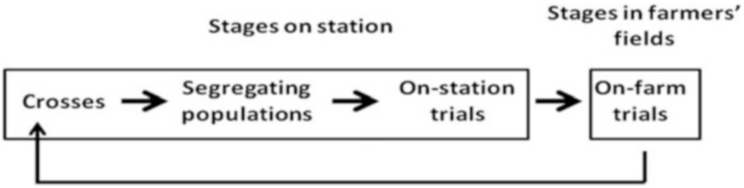

Fig. 8.5 Schematic representation of a typical centralized, nonparticipatory plant breeding (CPB) program that mostly takes place within a research station (the first three stages, which usually last more than 10 years), with all the decisions being taken by the breeder's team

"knowledge of the germplasm" that the breeder slowly accumulates over the years. Examples of the three main stages of a breeding program can be easily identified in the three major groups of crops, namely self-pollinated, cross-pollinated, and vegetatively (or clonally) propagated, and in the most common breeding methods used (Ceccarelli 2012b).

Alongside a definition of plant breeding it is also important to define who is a plant breeder.

The traditional definition of a plant breeder includes only those persons who have the full responsibility of a breeding program, made up of progressive cycles, as described earlier, to develop new cultivars and improved germplasm. However, many feel this definition should be expanded to include persons who contribute to crop improvement through breeding research (Ransom et al. 2006).

In this chapter, we will use the traditional definition of a plant breeder because we believe that only scientists who have the full responsibility for a breeding program can be successful partners of farmers in PPB programs.

8.10 Defining Participatory Plant Breeding

We define PPB as a dynamic and permanent collaboration that exploits the comparative advantages both of plant breeding institutions (national or international) that have the institutional responsibility for plant breeding, and of farmers and possibly other partners, as noted earlier. The definition does not imply preassigned roles, or a given amount of collaborative work (at one extreme, scientists may only supply germplasm, while at the other partners may only do field selection), nor imply that farmers and breeding institutions are the ONLY partners. This is because field experience in practicing PPB tells us that a true PPB program is a dynamic process in which both the roles of partners and the extent and the manner in which they collaborate change with time. Implicit in this definition is that farmer breeding, in which scientists or other stakeholders have no part, is not considered as a PPB program. This of course should not be interpreted as an underestimation of its value and importance. It is also important to mention that a truly participatory program is

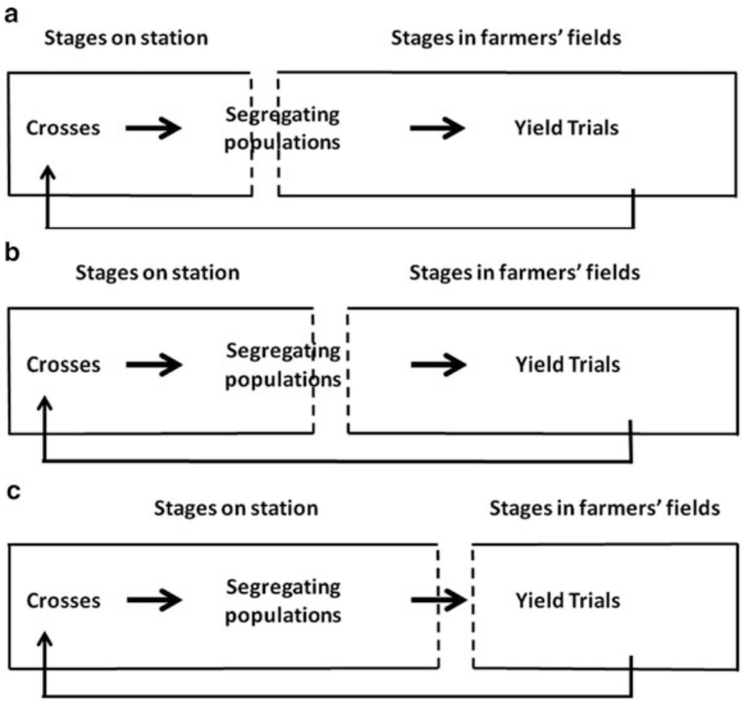

Fig. 8.6 Schematic representation of two types (A and B) of PPB program: the stages that take place within a research station are much less (the first and part of the second in A and the first and most of the second in B) than in a CPB program, with all the decisions being taken by the breeder's team together with the farmer community. If the decentralization takes place in the third stage (as in C) with a small number of lines the program becomes a Participatory Variety Selection program (discussed later)

necessarily inclusive in relation to gender and has, as we also see later, an empowering effect on the participants.

With regards to gender, while it is possible to conduct gender analysis and gender studies in a nonparticipatory context, the contrary is not true: in other words, a program that is not gender inclusive does not deserve to be defined as participatory.

A PPB program (Fig. 8.6) is similar to a CPB program in that it maintains the typical cyclic structure of a breeding program, but with three important organizational differences (Ceccarelli 2009c):

- Most of the program takes place in farmers' fields (i.e., is decentralized)
- The decisions are taken jointly by the breeder and the farmers and other partners
- The program, being decentralized, can be replicated in several locations with different methodologies and types of germplasm (Fig. 8.7)

Comparing Fig. 8.6 with Fig. 8.5, it will be noticed that there are no differences in the case of Stage 1; in Stage 2, the CPB program is conducted on-station, while in

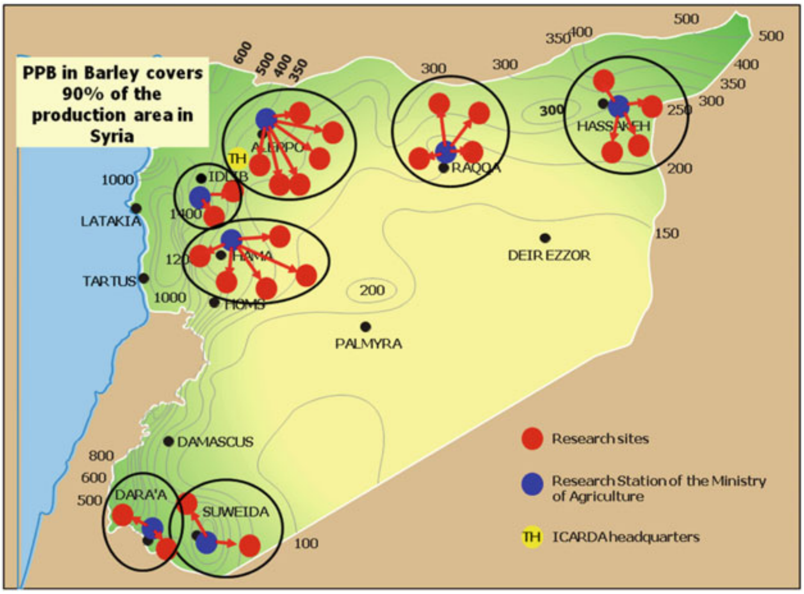

Fig. 8.7 The organization of a PPB program using the example of the barley PPB program in Syria

a PPB program it is conducted partly on-station and partly in farmers' fields; while in Stage 3, which in CPB programs is partly conducted on-station and partly conducted on-farm, in the case of a PPB program it is confined to farmers' fields. Figure 8.6C also represents the case of crops grown for the market (malting barley, wheat for industrial transformation, canola, groundnut, cassava, etc.), which need to possess a given expression of a suite of traits to be accepted by the market. These traits can be fixed, when possible with MAS, on-station, while traits associated with adaptation to different environments will be selected on-farm with the participation of farmers and other partners.

It is also possible for farmers to make crosses on-farm with the technical assistance of breeders. In these cases, the entire process takes place on-farm and the amount of variability can be increased by crosses coming from the station. These cases are not very frequent, as they require special skills and dedication.

8.11 Participatory Variety Selection

Participatory Variety (or Varietal) Selection (PVS) is a process by which the field testing of finished or nearly finished varieties, usually only a limited number, is done with the participation of the partners. Therefore, PVS is always an integral part of PPB, representing its final stages, but can also stand alone in an otherwise nonparticipatory breeding program if, using Fig. 8.5 as an example, partners' opinion is collected and used during the final stage, i.e., the on-farm trials.

Involvement of partners during the last stage of an otherwise nonparticipatory breeding program has one major advantage and one major disadvantage: the advantage is that, if the partners' opinion becomes part of the release process which follows the on-farm trials, only the variety(ies) that partners like will be proposed for release, thus increasing enormously the speed and the rate of adoption; the major disadvantage is that because partners' opinion is sought at the very last stage of the breeding program there may be nothing left among the varieties tested in the on-farm trials that meets partner expectations. This disadvantage may induce the breeder to seek partner participation at an earlier stage of the breeding program, hence moving from PVS to PPB. PVS may also be used as a starting point, a sort of exploratory trial, to help partners in assessing properly the amount of commitment in land and time that a full-fledged PPB program requires.

8.12 A General Model of Participatory Plant Breeding

A general model of PPB as defined above is shown in Fig. 8.8a. In this model, the first step (generation of genetic variability) is often, but not necessarily always, the responsibility of the research institution. It should be noted that when the genetic variability is created by making crosses, there is a substantial difference between making crosses, choosing the parents, and designing the crosses. Making a cross is a purely technical operation, while choosing the parents and designing the crosses is a key decision in a breeding program. In a breeding program, a large part of the parental material used in crosses is represented by the best breeding material selected from the previous breeding cycle, and because in PPB the selection is done by both breeders and farmers, farmers do in fact participate in the choice of the parents to begin a new breeding cycle. Farmers may also explicitly choose parents by suggesting crosses to the research institution or learning to perform crosses themselves.

A number of stages of selection (four in this hypothetical example) are conducted in each farmers' field with the participation of men and women farmers and other stakeholders, with continuous interaction with the research institute (for example for the choice of appropriate experimental designs, data analysis, seed production, etc.) and with other farmers involved in the PPB program. The selection is conducted independently in each location. This generally leads to the selection of different entries in different locations but does not exclude selecting the same material (see for example in Fig. 8.8b variety A being selected in locations 1 and 3 and variety B being selected in locations 2 and 3).

The best breeding material produced after the four stages of selection can be used by farmers as varieties and by the research institute as parental material for crosses to begin a new breeding cycle. It is important to notice that different locations may receive different types of germplasm of the same crop and select

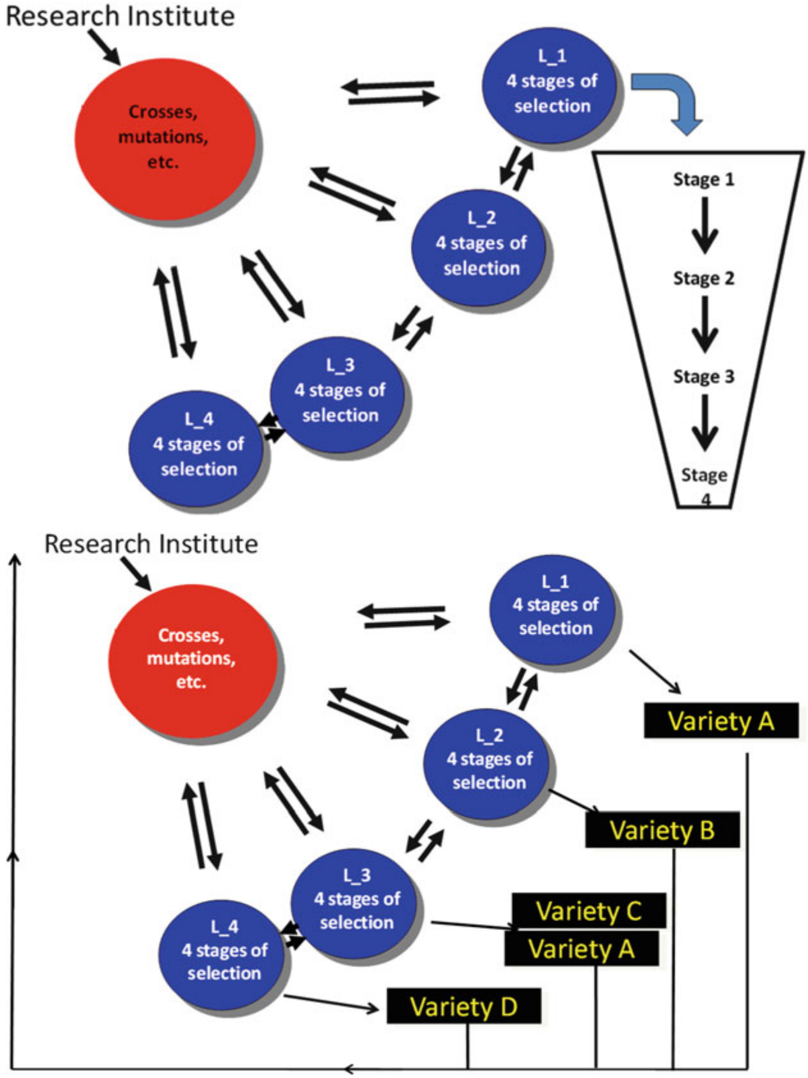

Fig. 8.8 (**a**) A schematic model of participatory plant breeding in four villages: from stage 1, grown by one farmer, participatory selection identifies the lines to be grown in the stage 2 trials by more farmers. The process is repeated to identify lines to be grown in stage 3 trials and in the stage 4 trials. The key aspect is that selection is conducted independently in each village. (**b**) As a result of the process described in (**a**), similar but more often different varieties are selected in each village. The varieties can go directly into cultivation, can be shared among farmers and go back to the research center for further cycles of recombination and selection. Hence, a participatory breeding program maintains the cyclic aspect of a breeding program

different varieties and that interaction among farmers may depend on their geographical location as well as communication technologies, language differences, etc.

A PPB program may lose a great deal of its potential effectiveness if the sample of both environments and users in which the program is implemented does not represent both the target environments and the target users. In order to do that, setting the criteria for identification of the target environments and users is a critically important step. This is even more important if one of the objectives of the program is to generate a continuous flow of varieties and/or population adapted to a moving target such as climate changes.

The most obvious criterion for the choice of the target physical environments is the representativeness of the combination of stresses, both biotic and abiotic the crops are likely to meet in the future. PPB has evolved mainly to address the difficulties of poor farmers in developing countries (Ashby and Lilja 2004), which have been largely bypassed by the products of CPB.

Once the target environments have been selected, the choice of which farmers in the communities and within the households to collaborate with is a key factor that affects the relevance of the improved varieties at ground level (Cornwall 2003; Guijt and Shah 2006). Targeting the right users is particularly critical for marginal areas where agriculture is characterized by wide spatial and temporal variability of agroecological conditions and by diverse socioeconomic needs resulting in complex stresses and high production risks (Aw-Hassan et al. 2008; Bellon 2006). Gender-sensitive targeting is important wherever socioeconomic needs vary within the community and the household. It is particularly critical in cases when men and women perform different agronomic activities that entail gender-differentiated skills, knowledge, needs, and trait preferences (Farnworth and Jiggins 2003; Pimbert 2006). For instance, those in charge of food processing might have preferences related to cooking quality that are different from those in charge of marketing who might prioritize customers' product requirements. Gender sensitive analysis and a careful and systematic observation in the field might help reveal gender-based agronomic roles, crop and variety preferences and overcome gender biases in the identification of farmers to collaborate with (Galiè et al. 2012). In cases when agricultural labor is not divided on the basis of gender, it might be worth assessing empirically how gender affects the preferences relative to farm activities. In Syria, for example, both men and older women are in charge of marketing the seed and straw (younger women are not involved in marketing). However, gender was found to affect their performance of marketing activities: men access more formal and wider markets than older women who mainly sell to other women in the village. This has consequences on their customers' requirements and therefore variety preferences (Galiè 2013c). Finally, the inclusion of gender concerns in PPB might also help identify crops that are considered important by farmers for their food security but usually neglected by crop improvement because they are considered less economically valuable.

Paris et al. (2008) argue that who participates in decision-making about crop improvement affects both the resulting varieties—because of the breeding priorities that are taken into account—and variety adoption—because involvement in variety trials and evaluations might affect final adoption. Effort to involve all household decision-makers in PPB seems a good strategy to ensure that the portfolio of PPB varieties reflects the breeding priorities of all members, and are evaluated by them, all (Galiè et al. 2012). Also, selecting farmers who have knowledge, status, and decision-making power, and are well placed within the seed distribution network is helpful to increase the out-scaling of PPB varieties to villages not directly involved in the program. However, Farnworth and Jiggins (2003) argue that participants selected because of efficiency criteria only, might not be representative of the intended target group and most marginal individuals in the communities are likely to be excluded.

Empowerment of farmers is considered an important means to increase the participation of the most marginal farmers in agricultural research, to support their capacity to benefit from research results and to enhance locally adapted practices (De Schutter 2009; Skinner 2011). Research shows that PPB can have positive effects on the empowerment of farmers by, for example, enhancing their access to information, seed, and decision-making opportunities (Galiè 2013a). Equity concerns need to be taken into account when selecting the target farmers to ensure that the less vocal and more marginalized farmers are not excluded from opportunities for empowerment provided by the participation in PPB. In the case of Syria, for example, women's involvement in the participatory barley breeding program was discouraged at village level because barley was considered a male crop. Yet, when a gender-balanced participation of farmers was actively supported in the program, the sale of good PPB seed became an important income-generating activity for some women (as for the men) who had fewer opportunities than men to engage in nonagricultural paid work and mostly worked as on-farm unpaid labor (Galiè 2013b).

In the case of self-pollinated crops and when the breeding method is the pedigree method, the selection in farmers fields can start with the segregating populations (for example, F_2-derived F_3 families) after their number is reduced by selection (including MAS) on-station for disease resistance, for traits with high heritability (for example phenology), or for quality traits such as malting or culinary qualities. Distributing different segregating populations to different locations according to farmer preferences is an additional strategy to further reduce the amount of breeding material in any one farmer's field. When the breeding program uses the bulk-pedigree method, it is possible to start the field testing as early as the F_3 bulks. In both cases, the yield testing should continue for at least four consecutive cropping seasons to generate sufficient information on the stability and performance of the breeding material for farmers to make a decision about adoption and for the variety release process.

In the case of population improvement of cross-pollinated crops, the recombination phase corresponds with the creation of genetic variability, which can be done on-station while the selection and testing can be done in farmers' fields. In the case of hybrid development, the creation and enrichment of breeding populations can be done—and in fact is being done, for example in China—in farmers' fields (Song et al. 2006). The production of uniform inbred lines to use as parents of hybrid cultivars can equally well be done on-station or in farmers' fields. In the latter case, because of the lower yield of inbred lines, a farmer compensation scheme should be envisaged. The advantage of developing inbreds in farmers' fields is that selection during the inbreeding process is done in the real production environment, making sure that field heterogeneity does not bias the selection. Similarly, in the case of test crosses, they can be more efficiently evaluated in farmers' fields. While the actual production of the hybrid seed can be done both on-station and in farmers' fields, the former has the advantage of not using farmers' land and farmers' labor. The field testing of the experimental hybrids has to be done for at least four cropping seasons, for the reasons given earlier. As in the case of self-pollinated crops, targeting germplasm to farmer preferences is an additional strategy to reduce the amount of breeding material under selection and testing at any one site.

In the case of vegetatively propagated crops after the initial crosses, all the subsequent generations are suitable for testing and selection in farmers' fields. As in the case of the pedigree method for self-pollinated crops, the number of clones can be reduced on-station by selecting for traits such as disease and or pest resistance, for traits with high heritability, and quality traits.

Other important features of the general model are summarized below.

- From Stage 1 to Stage 4 there is a progressive decrease in the amount of breeding material (entries) and an increase in the amount of seed available for each entry. This, as we will see later, affects the choice of the experimental design and the number of locations where the entries are tested.
- The decision on what to promote from one stage to the next is taken by the farmers in ad hoc meetings held between harvesting and planting, and is based on both farmers' visual selection during the cropping season and on the data collected by the researchers or by the farmers, or by both, after proper statistical analysis—as described later.
- In general, researchers have the primary responsibility for designing, planting and harvesting the trials, data collection, and data analysis. Farmers are responsible for everything else and make all the agronomic management decisions. However, as the program evolves, farmers can become responsible for planting, harvesting, and data collection.
- In terms of the farmer's time, the cost of participation ranges from 2 days to 2 weeks annually, depending on the level of participation.
- A back-up set of all the materials tested in Stages 1 to 4 is also planted at the research station to purify the bulks if pure lines are required in the case of self-pollinated crops, but, more importantly, to produce the seed needed for the trials and to insure against the risk of losing the trials to drought or other climatic events.
- In some countries, the farmers who are hosting trials are compensated (in kind) for the area used for the trials with an amount of seed equivalent to the production expected in an average year.

Seed cleaning machinery is supplied to some villages to assist in the multiplication and dissemination of selected varieties following the fourth year of farmer selection.

Screening for diseases and insect pests is carried out on-station before the first stage of yield testing on farmers' fields to avoid the spreading of new diseases or pests, as PPB has been criticized (for example, in Syria) for the danger of spreading new diseases, yet interestingly in Syria, most of the wheat and barley varieties released through CPB are disease susceptible.

The approach is flexible enough to accommodate biotechnological techniques, specifically MAS, after the first year of farmer selection (PPB should be able to provide reliable information on desirable traits that could later be evaluated via MAS should this be available and deemed desirable by farmers).

One of the consequences of a PPB program is that the number of varieties it generates and the turnover of varieties are both higher than with CPB, thus increasing both spatial and temporal agrobiodiversity.

Also, it is not unusual that more varieties are adopted and cultivated within a region at any given time. While this is of course highly positive in terms of both agricultural biodiversity conservation and enhancement, and of protection against pests and diseases, it poses a number of challenges to seed production and for studies on the impact of PPB programs.

8.13 Farmers' Selection, Selection Criteria, and Data Collection

At the time of selection, farmers are provided with field books to register both qualitative and quantitative observations. Farmers' preferences are usually recorded from 0 (discarded) to 4 (most preferred plots) by between 10 and 30 farmers including (in some countries) women, occasionally assisted by scientists (or literate farmers) to record their scores. Breeders collect quantitative data on a number of traits indicated by farmers as important selection criteria (such as growth vigor, plant height, spike length, grain size, tillering, grain yield, biomass yield, harvest index, resistance to lodging and to diseases and pests, cold damage, etc.), as usually done in the MET in a CPB. If the testing environment has been properly chosen, these data will provide information on differences in adaptation to abiotic stresses together with farmers' preferences.

It is at this stage that a PPB program can accommodate the collection of data on those traits that could be associated with adaptation to climate changes and discussed earlier in this chapter.

The data are processed (see under Sect. 8.14) and the final decision of which breeding lines to retain for the following season is made jointly by breeders and farmers in a special meeting and is based on both quantitative data and visual scores.

The process is repeated at each stage and in each cycle of selection, and this continuous association with the breeding material has both an enormous empowering effect and is what it is driving adoption.

8.14 Experimental Designs and Statistical Analysis

One widespread criticism towards PPB is that it is not science-based, and in fact several PPB programs do suffer from lack of suitable experimental designs and of statistical analysis.

Two experimental designs which are suitable in the first stage, where there is only one host farmer in each location, are (a) the unreplicated design with systematic checks every ten or every five entries arranged in rows and columns or (b) the partially replicated design in which about 20–25 % of the entries are replicated twice and all the others are present once. In Stage 1, when the total number of new entries tested vary (in our projects) between as few as 50 to as many as 160 at each location, a compromise must be sought between the plot size and the number of locations. This compromise is reached by sacrificing replications in favor of locations, as done in most CPB in the initial stages (Portmann and Ketata 1997) in recognition that in this stage of the breeding program ranking of genotypes is more important than predicting their yields (Kempton and Gleeson 1997) and the G×E variance is larger than the experimental error variance.

In the second, third, and fourth stages of the PPB program, as in CPB, the number of lines progressively decreases because of the selection, while the amount of seed available for each entry increases. Another characteristic of the second, third, and fourth stage of trials is that they usually contain different entries in each of the different locations in which the PPB program is conducted and in which the Stage 1 trials were planted. This is a consequence of the selection being conducted independently at each location, which usually results in different Stage 1 entries being selected in different locations. Another difference is that, while there is usually only one Stage 1 trial in each location, it is advisable to have at least three Stage 2, 3, and 4 trials at each location. This allows capturing differences within each location between agronomic practices, soil physical characteristics, uses of the crops, farmers' preferences, etc., and allows genotype × farmer interaction analysis. In stages 2, 3, and 4 seed is usually nonlimiting and therefore it is possible to use progressively larger plot size; this has the additional advantage of providing a large seed supply of the lines that will eventually be adopted at the end of the cycle.

The data are subjected to different types of analysis such as the spatial analysis of unreplicated or replicated trials (Singh et al. 2003). The environmentally standardized Best Lineal Unbiased Predictors (BLUPs) obtained from the analysis are then used to analyze Genotype × Environment Interactions (GE) using the GGEbiplot software (Yan et al. 2000).

Therefore, the PPB trials generate the same quantity and quality of data as that generated by the MET in a CPB with the additional information on farmers' preferences usually not available in the conventional MET. As a consequence, varieties produced by PPB are eligible for submission to the official variety release process that in several countries, including many in the developing world, is the legal prerequisite for commercial seed production.

8.15 Time to Variety Release

In a typical breeding program of a self-pollinated crop and following a classical pedigree method, it takes normally about 15 years to release a variety. With the method described in the previous section the time is reduced by half and this advantage is particularly important in the case of climate changes, because it assures a dynamic turnover of progressively better adapted varieties. However, the comparison is biased because of the difference in the genetic structure of the material being generated, i.e., pure lines in one case and populations in the second.

If populations are not acceptable by the variety release authorities, and the model includes pure line selection within the superior bulks, it can be shown that the time to variety release in the PPB program is still 3–4 years shorter than the CPB based on the pedigree method, and again the comparison is biased because the CPB does not generate the information on farmers' preferences which is one of the main characteristics of a PPB program.

This characteristic of a PPB program is important to cope with climate changes because it ensures a rapid and continuous turnover of varieties.

The method is therefore very flexible because it can generate populations, pure lines, and eventually mixtures of pure lines. Similarly, when applied to cross-pollinated crops, PPB can be used to produce hybrids, populations, and synthetics.

8.16 Effect on Biodiversity

One of the main benefits expected from PPB, of particular importance to maintain and improve adaptation to climate changes, is an increase in crop biodiversity because of the joint effect of decentralized selection and of the farmers' participation. The effect on biodiversity is illustrated using the data of the 2001–2004 breeding cycle in Syria (Table 8.3). As indicated earlier, in each village the starting point of the breeding cycle in farmers' fields are the initial yield trials with 165 genetically different entries: the number of entries tested in the subsequent trials decreases to about 17 in Stage 2, to 7 in Stage 3, and to 3 in Stage 4. The number of trials per village varies from 1 in the case of Stage 1, to about 3 in the case of the other trials. The number of lines selected by between 8 to 10 farmers per village was on average 17, 8, 3.5, and between 1 and 2.

Because different germplasm is tested in different villages, the total number of genetically different entries tested in the various trials was 412 in Stage 1, 238 in Stage 2, 51 in Stage 3, and 19 in Stage 4. In the case of Syria, the number of different entries at the end of a breeding cycle in farmers fields is higher than the number of lines the Syrian National Program tests at the beginning of its on-farm testing which usually ends with one or two recommended varieties across the country (Ceccarelli et al. 2013).

Table 8.3 Flow of germplasm, selection pressure, number of farmers participating in the selection, and number of lines in initial adoption in one cycle of participatory plant breeding on barley in Syria

	Stage 1	Stage 2	Stage 3	Stage 4
Entries tested per village	165	17.3	7	3
Trials per village	1	3.2	3.4	2.8
Entries selected per village	17	8	3.5	1–2
Farmers selecting	9–10	8–9	8–9	8–9
No. of different entries per village	412	238	51	19

8.17 Variety Release and Seed Production

The potential advantages of PPB, such as the speed with which new varieties reach the farmers helping them face the challenges of climate changes, the ability to address gender-based crop and variety preferences vis-à-vis climate change and the increasing feminization of agricultural labor, the increased adoption rate and the increased biodiversity within the crop due to the selection of different varieties in different areas, will not be achieved if the seed of the new varieties does not become available in sufficient amounts to the entire farmer community. In many countries this is associated with, and depends on, the official recognition of the new varieties. This process, called variety release, is usually the responsibility of a committee (the variety release committee) nominated by the Minister of Agriculture, which decides whether to release varieties based on a scientific report on the performance, agronomic characteristics, resistance to pests and diseases, and quality characteristics of the new variety. The process suffers from several drawbacks: (1) it takes a long time, (2) testing sites are poorly chosen, (3) the trial management is often not representative, (4) the trial analysis is biased against poor environments, (5) traits important to the farmers are not included, (6) farmers' opinion is not considered, (7) there is often lack of transparency in sharing the information, and (8) the trials are often conducted using obsolete experimental design and statistical analysis.

As a consequence there are several cases of varieties released which have never been grown by any farmer and also of varieties grown by farmers without being released. In these cases, the considerable investment made in developing the new variety and in producing its seed has no benefits.

One of the most important advantages of PPB is associated with reversing the delivery phase of a plant breeding program (Fig. 8.9). In a CBP, the most promising lines are released as varieties, their seed is produced under controlled conditions (certified seed) and only then do farmers decide whether to adopt them or not; therefore the entire process is supply-driven. In many developing countries the fact that very few of the varieties released by conventional breeding are actually adopted by farmers is explained with the reluctance of farmers to change. As breeders are rewarded based on the number of varieties released, they have no reason to test the hypothesis that lack of adoption may have different reasons. With

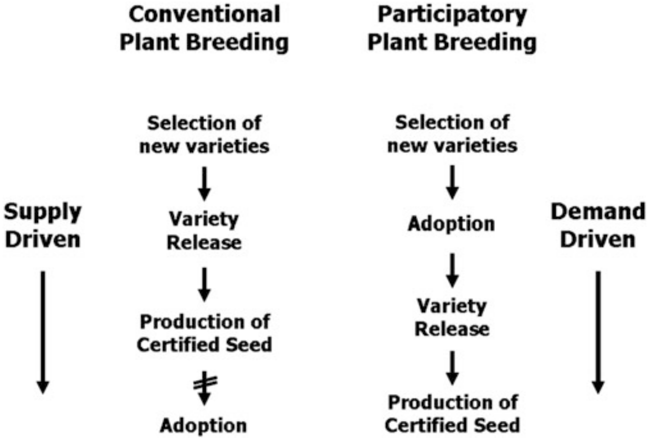

Fig. 8.9 In conventional plant breeding new varieties are released before knowing whether the farmers like them or not and the process is typically supply-driven. In participatory plant breeding the delivery phase is turned upside down because the process is driven by the initial adoption by farmers at the end of a full cycle of selection and is therefore demand-driven

PPB, it is the initial farmers' adoption which drives the decision of which variety to release, and therefore the process is demand-driven. Adoption rates are higher (showing that farmers are not reluctant to changes), and risks are minimized, as an intimate knowledge of varietal performance is gained by farmers as part of the selection process. Last but not least, the institutional investment in seed production is nearly always paid off by farmers' adoption.

The implementation of a PPB program implies not only a change in the process of variety release but also assumes changes in the seed sector. CPB and the formal seed sector have been successful in providing seeds of improved varieties of some important staple or cash crops to farmers in favorable areas of developing countries. However, the policy, regulatory, technical, and institutional environment under which these institutions operate limits their ability to serve the diverse needs of the small-scale farmers in marginal environments and remote regions. In other words, to capture the potential benefits of PPB in relation to climate changes the seed legislation needs to be changed also because it does not have any biological justification.

Gender concerns also need to be included in systems for seed delivery that take into account gender-based restrictions on seed access. For example, informal seed distribution channels might be supported to provide seed to women farmers—given that the presence of women in public agricultural spaces (e.g., agricultural retailers, or extensions) is often discouraged—and to farmers who are located in areas not reached by the formal system (Galiè 2013b).

The full advantages of PPB could be captured and scaled up with the inclusion of small seed companies as participants in the process. Small seed companies can cover a limited area and within that area they could be instrumental in spreading the continuous flow of PPB varieties of various crops to a wider community of farmers sharing the benefits with those farmers participating in the selection process.

In those countries where most of the seed used is produced by the informal seed system, the model can provide the informal system with quality seed of improved varieties.

8.18 An International Decentralized Participatory Plant Breeding

International plant breeding programs such as those of the CGIAR aim to assist national programs to increase agricultural production by developing superior cultivars. This is traditionally done through very large breeding programs, which develop fixed or semifixed lines with an average good performance across many environments (often high input research stations).

This type of interaction between international and national plant breeding programs has been largely a one way, "top-down" process (Simmonds and Talbot 1992) where international programs develop germplasm, distribute it as "international nurseries," and national programs test it, and eventually release selections as cultivars. This "top-down" approach has often excluded the use of locally adapted germplasm, which is specifically adapted to particular conditions and often performs poorly in the favorable conditions of research stations, and has, in fact encouraged its displacement.

The distribution of germplasm from CGIAR centers to national breeding programs has indeed historically also included segregating populations. However, such segregating populations, obtained from crosses designed by the international breeders, are the same for all the countries, and they are not usually targeted to a specific environment.

To exploit specific adaptation fully and make positive use of GE interactions, international breeding programs can decentralize most of the selection work to national programs by gradually replacing the traditional international nurseries with targeted segregating populations with the possible addition of specific genetic stocks. The distribution of segregating populations reduces the danger of useful lines being discarded because of their relatively poor performance at some selection sites (Ceccarelli et al. 1994). It also a way to capitalize from the extensive training programs on plant breeding conducted by CGIAR.

An example of what CGIAR centers could do to contribute to biodiversity is the decentralization of the ICARDA's barley breeding program, which started in 1991 with the distribution of targeted segregating populations first to Morocco, Algeria, Tunisia, and Libya (Ceccarelli et al. 1994), and later to Iraq in 1992, to Egypt in 1995, and gradually to other countries.

The term decentralization is used here to mean decentralized selection, i.e., selection in the target environment(s).

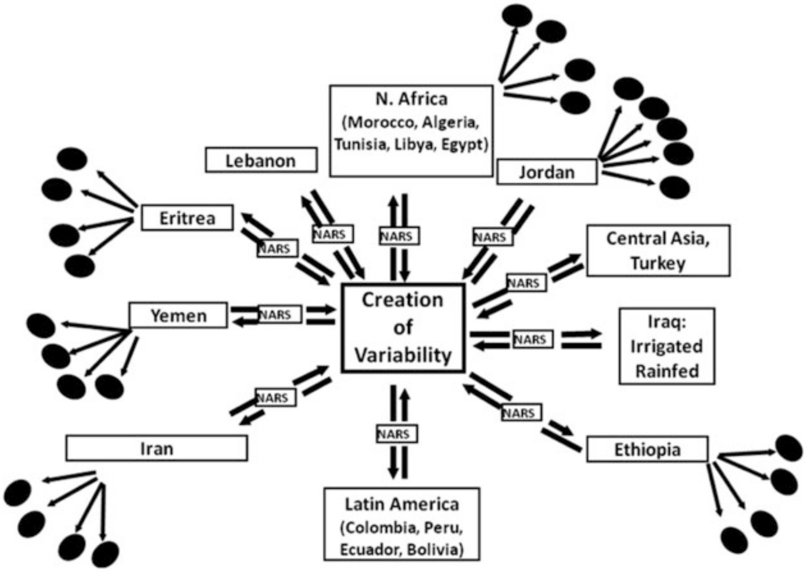

Fig. 8.10 An example of an international decentralized participatory breeding program: an international breeding program such as those of the CGIAR Center creates genetic variability in the form of targeted segregating populations which are distributed to specific National Agricultural Research Systems (NARS). NARS multiply the material to have sufficient seed to test the material in farmers' (*filled ovals*) fields with farmers' participation. The model is based on an efficient feedback process (*bidirectional arrow*) between farmers and NARS and NARS and CG centers

While the national programs accepted decentralization very positively, we started recognizing that decentralization per se will not necessarily respond to the needs of resource-poor farmers in less favored areas, if it is only a decentralization from the research station(s) of a CG center to the research stations of a national program, and if the research stations of the national programs do not represent, as is often the case, the environments where the crop is predominantly grown. To exploit the potential gains from specific adaptation to low input conditions, breeding must be decentralized from research stations to farmers' fields (Fig. 8.10) following the methodology described earlier. An essential component of the system is the continuous feedback that could allow breeders in the CGIAR centers to continuously improve the targeting of the germplasm.

Although decentralization and farmer participation are unrelated concepts, decentralization to farmers' fields almost inevitably (except in Australia, where decentralization has not been followed up by participation) leads to the participation of farmers in the selection process.

A scheme such as the one shown in Fig. 8.10, integrated with the development of evolutionary populations, if applied by all CGIAR centers to the main food crops and in the poorest countries, could provide a major contribution to the enhancement of biodiversity and therefore to adaptation to climate changes and to food security.

Table 8.4 Number of varieties selected and adopted by farmers in the PPB programs in five countries

Country	Crop(s)	Varieties
Syria	Barley	93
Jordan	Barley	1 (submitted)
Egypt	Barley	5
Eritrea	Barley	3
Yemen	Barley	2
	Lentil	2
Ethiopia	Barley	3

8.19 Impact of Participatory Plant Breeding

By 2011 the model shown in Fig. 8.8a, b was fully implemented in Syria, Jordan, Algeria, Egypt, Ethiopia, Eritrea, and in Iran. PPB programs based on the methodology described above have also been implemented in Tunisia and Morocco (Ceccarelli et al. 2001), and Yemen. These PPB projects had four main types of impact

Variety development: a number of varieties have already been adopted by farmers even though the program is relatively young in breeding terms (Table 8.4). In Syria adoption is taking place for the first time in low rainfall areas (<250 mm annual rainfall) (Table 8.5).

Institutional: in several countries, the interest of policy-makers and scientists in PPB as an approach, which is expected to generate quicker and more relevant results, has considerably increased.

Farmers' skills and empowerment: the cyclic nature of the PPB programs has considerably enriched farmers' knowledge, improved their negotiation capability, and enhanced their dignity (Soleri et al. 2002); PPB affected positively the recognition of women as farmers; their access to and control of relevant seed; and their decision-making about variety development (Galiè 2013a).

Enhancement of biodiversity: different varieties have been selected in different areas within the same country, in response to different environmental constraints and users' needs. In Syria, where this type of impact has been measured more carefully, the number of varieties selected after three cycles of selection is 4–5 times higher than the number of varieties entering the on-farm trials in the CBP.

An economic analysis of the PPB barley breeding program in Syria shows that PPB increases the benefits to resource-poor farmers. The total estimated discounted research induced benefits to Syrian agriculture were estimated at US$21.9 million for conventional breeding and US$42.7 million to US$113.9 million for three different PPB approaches (Lilja and Aw-Hassan 2003).

Using case studies on different crops, Ashby and Lilja (2004) have shown that:

- The use of participatory approaches improves the acceptability of varieties to disadvantaged farmers by including their preferences as criteria for developing, testing, and releasing new varieties. A survey conducted on over 150 PPB

Table 8.5 Varieties adopted from the PPB program by farmers in Syria in various rainfall zones

Pedigree	Name	Location	Rainfall[a]
H.spont.41-1/Tadmor	Raqqa-1	Bylounan	212.4
Arta//H.spont.41-5/Tadmor	Raqqa-2	Bylounan	“
Zanbaka/JLB37-064	Karim	Bylounan	“
Tadmor/3/Moroc9-75/ArabiAswad//H.spont.41-4	Akram	Bylounan	“
Mo.B1337/WI2291//Moroc9-75/3/SLB31-24	Suran-1	Suran	383.7
ChiCm/An57//Albert/3/Alger/Ceres.362-1-1/4/Arta	Suran-2	Suran	383.7
ER/Apm//Lignee131/3/Lignee131/ArabiAbiad/4/Arta	Suran-3	Suran	383.7
Hml-02/5/..Alger/Ceres362-1-1/4/Hml	Nawair-1	Suran	“
Hml-02/5/..Giza 134-2L/6/Tadmor	Nawair-2	Suran	“
SLB03-10/Zanbaka	Yazem	J. Aswad	226.4
Tadmor//Roho/Mazurka/3/Tadmor	Salam	J. Aswad	“
ArabiAswad/WI2269/3/ArabiAbiad/WI2291//Tadmor/4/Akrash//WI2291/WI2269	Ethiad	J. Aswad	“

[a] Annual rainfall in mm in the period 2000–2005

projects showed that (a) PPB improved program’s effectiveness in targeting the poor, (b) by consulting women and involving them in varietal evaluation, there was a better acceptability and faster adoption of the varieties, and (c) involvement of women farmers in the development of maize seed systems in China resulted in a broadened national maize genetic base, improved maize yield, and strengthened women’s organizations.

- PPB improves research efficiency. A case study conducted using the PPB program in Syria (Ceccarelli et al. 2000, 2003) found that farmers’ selections are as high yielding as breeders’ selections. Another study found that by introducing farmer participation at the design stage, a 3-year reduction was achieved in the time taken from initial crosses to release. In another example, breeders concluded that it was faster, less expensive, and more reliable to involve farmers directly in the identification of promising accessions for use in the breeding program. Efficiency gains depend also on the extent to which farmer involvement enables the breeding program to minimize its investment in the development of varieties, which, after release, turn out to be of little if any interest to farmers.
- PPB accelerates adoption. The incorporation of participatory approaches consistently enables breeding programs to “break through” adoption bottlenecks caused by low levels of acceptability of new varieties by poor farmers. In addition to the examples given in Table 8.4, other examples are Ethiopia, where out of over 122 varieties of cereals, legumes, and vegetables which had been released, only 12 were adopted by farmers, Brazil, where after years of nonadoption, the implementation of PPB led to the adoption of several clones of cassava which were both resistant to root rot and highly acceptable to farmers,

and Ghana, where maize breeders had released several modern varieties (MVs) which had poor acceptability and poor adoption, while with farmers' participation the overall adoption of MVs increased to over two-thirds.

- Finally, there is increasing evidence that one of the most widespread impacts of participatory plant breeding, and possibly of participatory research in general, is of a psychological and ethical nature: when farmers are asked which benefits they believe they receive from PPB, they state that their quality of life has improved, that they feel happier as a consequence of changing their role from passive receivers to active protagonists, that their opinion is valued, and that, as an Eritrean farmer said, they have taken science back into their own hands.

8.20 Conclusions

The results presented in this chapter indicate that it is possible to organize a plant breeding program in a way that addresses not only those plant characteristics that maximize yield and stability over time in a given physical environment, but also the preferences of the users, by developing varieties, which are specifically adapted to different physical and socioeconomic environments and gender needs. Such an objective can be achieved by using a decentralized participatory approach, which needs to be extended also to seed production aspects. A breeding program organized according to these principles will have the advantages of producing environmentally friendly varieties and of maintaining or even enhancing biodiversity.

The main objections to participatory plant breeding are usually that (1) plant breeding is "plant breeders' business," and if plant breeders do their job properly there should not be the need for participatory plant breeding, (2) it is not possible for seed companies to cope with the multitude of varieties generated by participatory plant breeding, and (3) varieties bred through participatory plant breeding do not meet the requirements for official variety release (Ceccarelli and Grando 2007).

With regard to the first objection, circumstantial evidence suggests that while plant breeding has been a success story in climatically, agronomically and economically favorable areas, and in areas where the agronomic environment could be modified to create near-optimum growing conditions, it has been much less successful in less-favorable areas. In those areas where it has been successful, plant breeding has raised both environmental concerns due to high levels of chemical inputs required by modern varieties, and biodiversity concerns because of the narrowing of the genetic basis of agricultural crops. More recently, there is widespread concern about the use of the improperly called genetically modified organisms (GMOs) which, regardless of other considerations, represent yet another type of top-down technology. For these reasons, it may be useful to explore alternative avenues of plant breeding where the same science can be used in a different way.

The second objection assumes implicitly the need to breed taking into account the requirements of the seed companies rather than the interest of the farmers, the consumers, and society at large. It also ignores the fact that in the case of the major food crops and in developing countries, farmers and not seed companies are the main suppliers of seed with over 90 % of the seed, which is currently planted: participatory plant breeding can introduce new varieties directly into the most efficient seed system currently operating.

Against the third objection, the chapter has shown that it is possible to organize a participatory breeding program in such a way that it generates the same quantity of information of the same (or even better) quality than a conventional breeding program. In addition to the usual data set on agronomic characteristics, a participatory breeding program also generates information on farmers preferences (which is missing in the data set generated in a conventional breeding program), and therefore it makes the process of variety release more efficient and effective.

The third objection usually addresses also the genetic structure of the varieties produced by PPB. It assumes that varieties produced by PPB are inevitably genetically heterogeneous, unstable and not distinct and therefore not suited for release. On this issue there are three points to make. Firstly, the majority of cultivars still grown in marginal environments are genetically heterogeneous, and in several cases their seed is multiplied officially by the same authorities which deny the right of populations to be released; secondly, it is disputable how wise it is to replace them with genetically uniform material and it has been recently shown (Di Falco and Chavas 2006) that crop genetic diversity can increase farm productivity and can reduce the risk of crop failure; thirdly, we have shown that PPB, like conventional plant breeding, is flexible and can be used to produce varieties with different genetic structure including pure lines and hybrids.

Therefore, the most frequent objections to PPB are unfounded; they ignore the fact that farmers have domesticated the crops that feed the world, and that they have continued to modify these crops for millennia. In this process they have planted, harvested, exchanged seed, introduced new crops and new varieties, fed themselves and others and in so doing they have accumulated a wealth of knowledge that modern science tends to ignore. Participatory plant breeding is one way of recognizing farmers' knowledge and to merge it with modern science.

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