Chapter 13
Health, Seeds, Diversity and Terraces

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Abstract Modern plant breeding has moved towards uniformity, while the increasing demand for nutritious and safe food would require the maintenance and enhancement of biodiversity to respond to climate changes, to improve resilience at farm level and to improve health through a diversified diet. Thus, a change in the way new varieties are produced is necessary, and this is offered by participatory plant breeding, which combines modern science with farmers' knowledge and emphasizes specific adaptation. This is particularly relevant for remote, difficult to access agricultural landscapes such as terraced agriculture. Yemen, a typical country with large areas covered by terraces, offers an example that participatory plant breeding can be successfully implemented even in these challenging situations: in a three years programme, new varieties of barley and lentil, two key food crops in Yemen, were obtained. A methodology, which can be even more suitable to terraced agriculture, is evolutionary plant breeding through which farmers can manage independently a large and evolving genetic diversity. This allows them to quickly respond to climate changes and associated new pests, to be the owner of their own seed, to diversify their agricultural systems and increase their resilience and, more importantly, to improve their nutritional status with a more diversified diet without depending on external inputs.

13.1 Nutrition and Diseases

Farming and livestock production, along with the food industry that transforms and transports the products to where they are consumed, not only does not make available to the world nutritious and healthy food but at the same time has negative impacts on the environment and on the most vulnerable people (Sukhdev et al. 2016).

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The food systems are currently the cause of 60% of terrestrial biodiversity loss, 24% of greenhouse gas emissions, 33% of land degradation and 61% of the decline in commercial fish stocks (Hajer et al. 2016).

The reduced crop diversity and the consequent homogenization of food sources around the world on the one hand are reducing the capacity to cope with climate change and on the other hand are reducing our immunitary defences (von Hertzen et al. 2011) thus undermining human health around the world.

According to the report on global nutrition, malnutrition and diet are by far the major risk factors for diseases at the global level (International Food Policy Research Institute 2016).

Currently, about 800 million people worldwide suffer from hunger, two billion are malnourished, and another about two billion are overweight or obese. People suffering from diabetes are so many that if they live in the same country, that country would be the third most populated country in the world after China and India: the number of people with diabetes has quadrupled between 1980 and 2014 (Krug 2016), and in 2012, diabetes only caused a half million deaths (WHO 2015) with a global cost of 1.31 trillion dollars (Bommer et al. 2017).

13.2 Climate Change and Health

Climate change represents an intriguing research problem because, firstly, of the uncertainty of the expected changes (Nelson et al. 2009; Trenberth et al. 2015), which makes difficult predicting the increase in temperature and the decrease in rainfall anywhere on the planet with an acceptable degree of accuracy, and, secondly, because the decrease in rainfall and the increase in temperature are likely to be different according to, among others, elevation and slope. Therefore, agroecologies such as the terraces, which represent the dominant agricultural landscape in countries such as Yemen, Nepal, Bhutan and are also widespread in Ethiopia, Eritrea, Vietnam, China and in a number of countries in South America, are particularly vulnerable because of the large differences in elevation, slope and exposure. Therefore, particularly in these areas, plant breeding programmes to improve crop adaptation to climate change are likely to face a moving target and probably a different target in different areas (Ceccarelli 2014a, 2017). Thirdly, adaptation to climate change implies also adaptation (resistance or tolerance) to new insect pests and diseases, which have been shown to have altered their latitudinal ranges in response to global warming (Bebbe et al. 2013).

Climate change is also expected to have an impact on crops with a direct consequence on health: a simulation study showed that the increase in CO_2 is expected to decrease the content of iron and zinc in crops such as rice, bread wheat, maize, soybeans, field peas and sorghum (Myers et al. 2014). This is a serious problem as the deficiency of these two microelements is already causing the death of 63 million people annually. According to the World Health Organization

(WHO), there are two billion people with anaemia in the world and half of the anaemia is due to iron deficiency (WHO, UNICEF, UNU 2001).

Therefore, adapting crops to climate change represents a complex research objective.

13.3 Can We Have Both Cheap and Healthy Food?

It seems that now we must resign to a choice between these two options that reflect the dilemma between feeding and nourishing. However, there is nothing preventing us to strive for affordable healthy food.

In an attempt to get out of this dilemma, the concept of smart food is emerging, as the type of food that is good to the consumer, to the planet and to the farmer. Is good to the consumer because derived from crops rich in antioxidants, proteins, vitamins and micronutrients such as iron, calcium and zinc and are easy to digest; they do not contain gluten and prevent cancer, diabetes and cardiovascular disease; are good to the planet because are more resistant than others to high temperatures and drought and therefore are able to adapt to climate change and need less water; are good to farmers because increasing agrobiodiversity does increase the resilience of the farm, are easy to grow and can open up new markets. Examples of smart foods are those derived from legumes and from grains such as sorghum and millet, common in Asia and Africa. Sorghum has been recently defined as the new quinoa (http://www.icrisat.org/smartfood/).

Even if so far we have discussed only health and food, implicitly, we have been discussing about seed, because all our food derives from seed and our health depends largely from food; therefore, the seeds are at the root of many of the current problems.

13.4 Where the Seed Comes from?

Plant breeding is the science that produces new crop varieties, many of which give the food that ends up on our table. For millennia, it has been done by farmers and only in the last hundred plus years has been done by researchers in research centres or research stations.

During the millennia before modern plant breeding began, farmers were moving around with seeds and livestock, and because neither were uniform, they could gradually adapt to different climates, soils and uses. Whenever farmers settled, they continued to improve crops and livestock. In the case of crops, the way they did it can still be seen today in a number of countries and consists of selecting the best plants that give the seed to be used for the following season. Therefore, the selection was done in the same place where the crops were grown and the seed of the selected plants was *mixed* before planting. This process was highly location-specific in the sense that each farmer did it independently from other farmers and for his/her own conditions of soil, climate and uses. What we call ancient, old, heirloom varieties originated through this process (Ceccarelli 2017) which generated diversity both within and between farmers' fields.

With time, modern plant breeding took a different approach: being done in a research station, moved the selection away from the place where the crop was grown, thus creating a gap between the "selection environment" and the "target environment". It also moved the selection away from the people who did it for millennia, thus ignoring all the knowledge generated by that process.

As the target environment is actually represented by several locations outside the research station, it is more appropriate to talk about a "target population of environments". Hence the problem of whether the research station is representative of any of the locations it is supposed to serve. This is a particularly serious problem because, to the best of my knowledge, there are no research stations located on terraces, and one may wonder how relevant could be the research—the selection—in the specific case of plant breeding, done in a station situated in an entirely different environment, not only in a geographical sense but in a agroecological sense.

The problem of addressing a number of heterogeneous environments outside the research station was solved by smoothing the differences between the target environments with external (mostly chemical) inputs, namely fertilizers, pesticides and irrigation water. In such a way, those environments became from an agronomic point of view very similar even if geographically distant and therefore one or few varieties could be grown across all of them: these varieties were defined as "widely adapted" and the breeding philosophy that produced them "wide adaptation".

The Green Revolution (Baranski 2015) adopted the "wide adaptation" philosophy in the 1960s wheat programme in India avoiding, in the short term, the incipient danger of a famine, but causing, on the long term, penalties such as the leaching into the groundwater of fertilizers residues due to the overuse of fertilizers above the amount that plants can utilize (Good et al. 2011), the water shortage, the emergence of pesticide resistance (Gassmann et al. 2014), the increase in the population of harmful insects (Lu et al. 2013), the bypassing of farmers in marginal areas (Baranski 2015) and the loss of crop diversity by displacing or even replacing landraces (Frison et al. 2011).

As a result of this change in breeding philosophy, there has been (1) a progressive emphasis on genetic uniformity both in the self-pollinated crops (such as wheat, barley and rice) and in cross-pollinated crops (such as corn), and in the latter through the use of hybrids, and (2) the use of production per unit area as the predominant breeding objective, with the result that the quality progressively declined: in fact, globally, crops contain today less protein (−4%), less iron (−19%) and less zinc (−5%) than in the 1960s (De Fries et al. 2015). In USA, while grain yield of bread wheat has increased over time, the concentrations of copper, iron, magnesium, manganese, phosphorus, selenium and zinc have decreased (Garvin et al. 2006; Murphy et al. 2008). A similar trend has been observed in fruits and vegetables (Davis 2009).

The two developments of modern plant breeding mentioned earlier, together with (1) a growing concentration of the seed and of the pesticides markets in the hands of few large corporations, and (2) a similar concentration in few hands of the food industry, have had, have and, in a scenario of business as usual, will continue to have some negative effects on our health. The increasing uniformity of what is grown inevitably entails increasing uniformity of what we eat, and this has been put in relation with a reduction of our immunitary defence system and the consequent rise of a whole range of diseases including cancers (Khamsi 2015). Also, since modern varieties, particularly cereals, are generally less nutritious, we must eat more to meet the daily requirements, thus contributing to the increase, now endemic, of obesity.

Because food is derived from seeds, it is at the way in which the seeds are produced and made available to farmers that we have to look for the solution to environmental problems including climate change and to our and future generations' health. One solution is to change the way we select new varieties by moving back the process in farmers' fields and by making farmers equal partners in the selection process, in a model known as participatory plant breeding (Ceccarelli et al. 2009). This genetic improvement model has several advantages such as an increase in agrobiodiversity, reduction of chemical inputs because it adapts crops to the environment rather than changing the environment, a higher benefit/cost ratio (Mustafa et al. 2006) and finally the recognition that farmers can play a key role in plant breeding by combining their traditional knowledge with that of the scientists (Halewood et al. 2007; Ceccarelli et al. 2000, 2009). This model of plant breeding has been implemented in a number of countries, in different agroecologies and with various crops (Ceccarelli 2015) including the terraced agriculture in Yemen (Ceccarelli et al. 2003).

13.5 The Case of Yemen

The project, which allowed implementing participatory plant breeding (PPB) on the terraced agriculture of Yemen, was supported by the then System-Wide Program of Participatory Research and Gender Analysis (PRGA, later dismantled). The project was implemented in the Kuhlan Affar area, a steep mountain slope that descends from about 3000 m asl to about 800 m asl towards Wadi Sharis and addressed the terraced mountain slopes that range from 1700 m asl to 2800 m asl approximately, where 90% of the agriculture is located. The area is supported by traditional methods of water harvesting mainly terracing of mountain slopes. Most farming families still grow landraces and save part of their harvest as seed source for the subsequent year (Fig. 13.1).

The villages of the research area are very small in terms of population numbers. The villages of Kuhlan Affar are in Hajjah province, 123 km northwest of the capital Sana'a. The study area lies within the two districts of Sharis and Kuhlan in Hajjah province, which is located in the western escarpments of Yemen. At the time the

Fig. 13.1 A typical village in Yemen with the terraces in the background. *Photo* S. Ceccarelli

project was implemented, the total population of this province was estimated at about 1.5 million, which represented 7.8% of the total population of Yemen, and was growing at a rate of 3% annually. They produced about 5% of the total agricultural crop production of the country. Most people of Hajjah province worked in agriculture and cattle breeding. The total agricultural area in Hajjah province was estimated at about 124,600 ha, of which 36% or 46,000 ha is predominantly cultivated terraces and Wadi banks, and rangelands cover about 63% of the province or 78,000 ha. The area is famous for its coffee beans, fruit and cereals production. Tobacco and palm trees are also common in the plains. Kuhlan Affar is a remote area, on mountains, where living conditions and access to cities are difficult, and was chosen because the province represented the traditional dry lands farming systems in the country's northwestern highlands; it was a typical example of areas neglected by agricultural research, and the area was characterized by subsistence agriculture.

The size of the terraces varies, mostly in relation to the slope—the steeper the slope the smaller the terrace. Each farming family usually owns more than one terrace, with an average farm size of only about 1.4 ha; usually, only one crop is planted in each terrace, but it is not uncommon to see terraces divided between lentil and barley or between sorghum and faba bean or even between all four crops. Agriculture is mainly rainfed with an annual average rainfall of 300–500 mm, falling in two seasons: March to April and August to September. It is the principal economic activity in the area and engages 80% of the population (Aw-Hassan et al. 2000). The most important crops are sorghum, wheat, lentil, barley, dry peas, maize, millet, beans, fenugreek, coffee and qat (Ceccarelli et al. 2003). Mainly, local varieties dominate in these farming systems, and women and men farmers save part of their harvests as seed for next year planting and sometimes exchange it with neighbours under the assumption that this will improve productivity, but the seed quality is generally poor. For these reasons, we started a PPB programme in collaboration with the Agricultural Research and Extension Authority (AREA). Women started to be involved gradually into the PPB programme, especially when men farmers started to gain confidence in the project.

Three villages (Hasn Azam, Beit Al-Wali, and Al-Ashmor) were selected by the local breeders based on the importance of barley and lentil cropped in the area. The project was discussed with farmers in these villages through meetings where the objectives of collaborative research and its potential benefits for rural communities were discussed, and the responsibilities in terms of project implementation and evaluation defined.

The implementation of the project was challenging because we did not have any previous experience of working in the limited physical space offered by terraces.

The participatory barley and lentil selection in the Kuhlan Affar areas was conducted for three years with the objectives of:

(1) testing the methodology in remote locations characterized by traditional agricultural systems and difficult environments
(2) identifying improved cultivars of barley and lentil.

The initial experiments were conducted in the three villages in the Kuhlan Affar area mentioned earlier and in the research station of the Agricultural Research and Extension Authority (AREA) at Al-Erra, near Sana'a. In each of the four locations, the trial consisted of the same fifty genotypes in both barley and lentil. The 50 barleys included six landraces, collected from different areas in the Northern Highlands of Yemen and obtained from the national Gene bank of Yemen, and improved lines from the Arab Centre for Studies in Arid Dry Lands (ACSAD). The 50 lentil entries included 15 local land races, also obtained from the national Gene bank of Yemen, and 35 entries from the International Centre for Agricultural Research in the Dry Areas (ICARDA) lentil breeding programme. In both crops, one local cultivar was used as a common check in each location.

Planting of the barley and lentil trials occurred in June 1999 in Bit Al–Wali (BA) and Hasn Azam (HA), and in July in Al-Ashmor (AA) and Al-Erra (AE) research station (Fig. 13.2). Plots consisted of four rows 2.5 m long and 25 cm apart. The experimental design was the randomized complete block design with two replications hosted in two adjacent terraces. The farmers' cultural practices were followed. Both planting and harvesting were organized by the AREA researchers and done manually by the host farmer and his family. Planting was done in furrows opened by one-stilted plough pulled by a donkey in the direction of the maximum length of the terrace. This was actually suggested by the farmers and resulted in the plots being oriented as the surrounding farmer's crop. Harvesting was done by hand.

Fig. 13.2 Research station at Al-Erra and the village of Al-Ashmor at about 3000 m elevation with the participatory barley and lentil breeding experiments. *Photo* S. Ceccarelli

At the end of the first year, the farmers selected 19, 16 and 21 barley lines in Hasn Azam, Bit Al-Wali and Al-Ashmor, respectively. In lentil, the number of lines selected was 23 in both Hasn Azam and Bit Al-Wali and 21 in Al-Ashmor, respectively. During the second year, the selected lines were evaluated in the same location in which they had been selected, in two replications and in plots of 10 rows at 25 cm distance and 5 m long. The experimental design, field layout, cultural practices, planting and harvesting were as described for the first-year trials.

At the end of the second year, six barley lines were selected in each of the three locations and were tested for a third year in the three villages. The total number of different lines was 12 including 2 of the six landraces. Only one line was commonly selected in all three villages, three lines were common to two villages, and the others two were unique to a specific village. In lentil, the number of lines selected in the second year was 7 in Hasn Azam, 8 in Al-Ashmor and 11 in Bit Al-Wali. The total number of different lines was 17 out of the initial 50 with 6 lines common to two locations. The 17 lines included 8 landraces (or 53% of those present in the first year) and 9 breeding lines (or 26% of those present in the first year). All trials were planted in two replications and in plots of 10 rows at 25 cm distance and 5 m long.

The third-year trials were sufficiently small for both replications to be accommodated on the same terrace.

As this was the first time farmers (both men and women) were involved in evaluating a relatively a large number of lines, the evaluation was initially done through consensus by the group of farmers and resulted for each plot in either discarding or selecting. In the second and third years, the selection procedure was changed at the request of the farmers, since they felt more confident in their individual opinion. This eventually allowed to disaggregate the data according to men and women preferences.

The three years of participatory plant breeding in Yemen ended with the identification of two high yielding barley varieties and three high yielding lentil varieties, which were adopted and cultivated by most of the farmers in locations where in the past centralized and non-participatory breeding was not capable of introducing any new variety (Ceccarelli 2002). As a consequence, there were seed production skills emerging among the farmers which were translated into a functional and efficient seed production system.

There were much more differences between farmers' and breeder's selection in the first and second year when the diversity was higher than in the third year when the number of lines was nearly 1/10th of the initial population. This was particularly true in barley where also genotype x locations interactions played a greater role than in lentil. This suggests that if farmers do participate in the selection process during the initial phases of a breeding programme, the differences in selection by farmers and breeder may determine the final outcome of a participatory breeding programme as compared with a non-participatory programme. An additional implication is that participatory programmes based on a small number of lines, such a participatory variety selection (PVS), are neither likely to exploit the full potential of farmer participation nor can be taken as example of lack of differences in selection criteria of the various participants.

This work demonstrates that with the participation of farmers, it was possible to implement a research programme in remote and difficult to access areas where conventional research did not have any impact. This demonstration affected the policy-makers to the point that participatory research has become part of the strategy of agricultural research in Yemen.

13.6 Evolutionary–Participatory Plant Breeding (EPB)

There are several other examples of successful PPB programmes, but despite these successes, PPB has a weakness in requiring the collaboration of a research institute to provide breeding materials and technical support such as experimental designs and statistical analysis. Therefore, the sustainability of a participatory programme depends on the long-term commitment of a research institution, and this is the main weakness of the PPB because it is not possible to count on the participation of an institution on a lasting basis.

An interesting alternative is offered by evolutionary (participatory) plant breeding—participatory is in parenthesis because, though desirable, the participation of an institution is not indispensable. The idea is not new as it was proposed back in 1956 (Suneson 1956). The method consists in planting in farmers' field's mixtures of many different genotypes of the same crop, or populations built using early segregating generations, namely materials obtained from crosses. Mixtures and populations will be planted and harvested year after year, and due to the natural crossing (higher in cross-pollinated and lower in self-pollinated crops), the genetic composition of the seed that is harvested is never the same as the genetic composition of the seed that was planted. In other words, the population evolves to become progressively better adapted to the environment (soil type, soil fertility, agronomic practices including organic systems, rainfall, temperature) in which is grown. As the climatic conditions vary from one year to the next, the genetic makeup of the population will fluctuate, but if the tendency is towards hotter and drier climatic conditions as expected in view of climate changes, the genotypes better adapted to those conditions will gradually become more frequent (Ceccarelli 2014b).

An evolutionary population, which can be made by the farmers themselves by buying and mixing seed of as many different varieties (including hybrids) of a given crop, can be used by the farmers (and by the researchers if they are willing to participate) as a source of genetic diversity from which to select. When this is done, it is expected that, based on selection theory (Falconer 1981), response to selection will increase because of the large population size of an evolutionary population leading therefore to a greater selection efficiency.

This has been done in Italy (data not published) using a zucchini (summer squash) evolutionary population obtained by letting 11 commercial hybrids to freely intercross. After only two cycles of visual selection, as in the case of tomato as described in Campanelli et al. (2015), the farmer selected two varieties, differing in colour, yielding as much as the commercial hybrids. He has already started selling the two new varieties in local markets.

Evolutionary populations of different crops (Fig. 13.3) are currently grown by farmers in Jordan, Ethiopia (as part of the Bioversity International project "Strengthening cultivar diversity of barley and durum wheat to manage climate-related risks and foster food and nutritional security in marginal areas of Ethiopia" supported by GIZ), Iran, Italy, France, Portugal and India for cereal crops (maize, barley, bread and durum wheat and rice), grain legumes (common bean) and horticultural crops (tomato and summer squash). Farmers growing these populations report higher yields, lower weed infestation and disease presence and lower insect damages. The use of pesticides has consequently been reduced.

Because of their continuous evolving, evolutionary populations cannot be patented or protected by IP. According to the Commission Implementing Decision of 18 March 2014 pursuant to Council Directive 66/402/EEC, in Europe, it is currently possible to market experimentally heterogeneous materials of wheat, maize, oats and barley up to 31 December 2018 (Official Journal of the European Union 2014).

Fig. 13.3 An evolutionary population of bread wheat (left) and one of zucchini (right). *Photos* S. Ceccarelli, at the left; courtesy of Dr. Campanelli on the right

Iranian farmers growing an evolutionary population of wheat have marketed the bread obtained from the flour of the evolutionary population in local artisanal bakeries. The bread can be consumed also by customers intolerant to gluten (Rahmanian et al. 2014). Farmers growing wheat evolutionary populations in France and Italy confirmed that creating mixtures brings not only greater yield stability but also greater aroma and quality to the bread (Fig. 13.4).

Thus, evolutionary (participatory) plant breeding, being a relatively inexpensive and highly dynamic strategy to adapt crops to a number of combinations of both abiotic and biotic stresses and to organic agriculture, seems to be a suitable method to generate, directly in farmers' hands, the varieties that will feed the current and the future populations. Indeed, experimental evidence shows that with evolutionary breeding it is possible to combine high yield and stability (Raggi et al. 2017).

Combining seed saving with evolution and bringing back the control of seed production in the hands of farmers can produce better and more diversified varieties that can contribute to help millions of farmers to reduce the dependence from external inputs and the vulnerability to disease, insects and climate change and ultimately contribute to food security and food safety for all. Being simpler to implement and to manage, evolutionary plant breeding seems particularly suited to terraced agriculture.

Participatory plant breeding and evolutionary plant breeding, while benefiting from advances in molecular genetics, reconcile increased production of more readily available and accessible food, with increased agrobiodiversity while maintaining the evolutionary potential of our crops needed to cope with climate change.

Fig. 13.4 Traditional bread making in Iran with the flour of a bread wheat evolutionary population (left) and a shop selling the same bread (right). *Photos* courtesy of Ms. Maede Salimi

13.7 Conclusions

In discussing the global problems including the pandemic of obesity and diabetes, seldom it is recognized that the solution of these problems requires a change in the way seed is produced, because seed is related to all these problems. Conventional plant breeding conducted by large private seed companies needs to generate profit and is difficult to change it from the current emphasis on wide adaptation supported by a consolidation of the seed industry (Howard 2009; Fuglie et al. 2011) to an emphasis on specific adaptation. This could be conveniently done, to some an extent, by small seed companies, but mostly by public breeding such as the breeding programmes conducted by CGIAR using their large germplasm collections amounting to about 710,000 seed samples (http://www.cgiar.org/consortium-news/genebanks-investing-in-biodiversity-for-future-generations/) which include all the most important staple food crops.

However, there are three reasons to be worried about the future of seed. First is the increasing trend towards public–private collaboration, which is leading to the creation of private–public breeding activities with some parts of the public breeding programmes executed by large seed companies which derive royalties from the final products; second is the transfer of former top managers of some of the largest seed companied into top-management positions in the CGIAR and vice versa; and third is the increasing role of private foundations' support to public research (Martens and Seitz 2015). All this is made worse by the progressive consolidation of the seed market (MacDonald 2017). These three recent developments raise questions on weather in a not too distant future we may witness a, at least partial, privatization of the CGIAR gene banks. Whether this will happen or not, the evolutionary populations may play two important roles: firstly, in the hands of developing countries may represent a continuous, independent from CGIAR centres and not patentable source of better adapted genetic material for their breeding programme as an addition to or a replacement for the genetic material they usually receive from the CGIAR; secondly, in the hands of the farmers, and being non-patentable for their continuing evolving nature, they will remain as publicly available genetic resources. Once the farmers have the seed, they have the solution (Gilbert 2016).

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