Participatory Plant Breeding: Concept and Applications
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Long back, we had been greatly touched by Rudyard Kipling’s literary work, *The Masque of Plenty*.

His speech is of mortgaged bedding,
On his kine he borrows yet,
At his heart is his daughter’s wedding,
In his eye foreknowledge of debt.
He eats and hath indigestion,
He toils and he may not stop;
His life is a long-drawn question
Between a crop and a crop

In this materialistic world, the plight of the poor farmer is often lost. The small and the marginal farmers constitute a large chunk of the farming community and are dispersed in most agricultural areas with bulk of them concentrated in the sub-Saharan Africa and South Asia. In many cases, the feeders of the world are themselves impoverished. It was in consideration of these poor farmers that the present work took shape.

Conventional plant breeding has significantly improved the living conditions of the well-off farmers but has often been criticized for ignoring indigenous germplasm and failing to address the needs of the poor farmers. Participatory plant breeding (PPB) is the process by which the producers and other stakeholders are actively involved in a plant breeding program with opportunities to make decisions throughout. Research in PPB can promote informed participation and trust in research among consumers and producers. In recent years, a lot of research has been conducted in PPB which offers significant advantages relevant to the developing countries where large investments in plant breeding have not resulted in production increases, especially in the marginal environments. In addition to the economic benefits, participatory research has a number of psychological, moral, and ethical benefits which are the consequence of a progressive empowerment of the farmer’s communities. Looking at the potential of PPB in the coming decades, the present book was conceptualized. The topic is more relevant since international breeding efforts for major crops are aimed at decentralizing local breeding programs to better incorporate the perspective of end users into the varietal development process.
The book reviews the important tools and applications of PPB in an easy-to-read, succinct format. The present work describes the novelty and complexity of the topic; the chapters are straightforward, with illustrations to make the topics simple, and provide additional help and clarity. The book provides readers with a basic idea of participatory plant breeding that presents advancements in the field and insights on the future. This book has especially been contemplated to cater the needs of breeders and researchers and tries to provide a simple yet comprehensive coverage of those recent updates in the field of PPB which have not yet been discussed together. The book provides an overview of the development of participatory plant breeding development, discusses the current and future considerations, and aims at facilitating successful integration of farmer in the breeding programs. A highlight of the present work is the in-depth application of PPB in different categories of crops like cereals, fruits, vegetables, and miscellaneous crops.

This reference work will be valuable for agriculturists, agricultural advisers, policy-makers, NGOs, postdoctoral students, and scientists in agriculture, horticulture, forestry, and botany.

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Abstract

Human beings have existed on this earth for about 250,000 years initially as foragers or hunter-gatherers for thousands of years gathering wild plants and hunting animals. The earliest fossils of *Homo sapiens* are located in Africa and dated to the late Middle Pleistocene. The hunter-gatherers dominated the scene across all continents until the end of the Pleistocene. Thereafter, food production based on domestication of relatively few wild species (both plant and animal) took the center stage. Agriculture was thought to be a significant improvement over the hunter-gatherer mode of living since it was more convenient to grow a dependable food source rather than collect plants from the wild. Domestication, an accelerated evolutionary process driven by human intervention and natural selection, was a unique form of mutualism that developed between humans and the target plant or animal population and had strong selective advantages for both the partners. During the domestication process, many traits in plants underwent dramatic modifications to meet the fastidious requirement of humans. After domestication, only favorable haplotypes were retained around selected genes leading to the creation of a valley with extremely low genetic diversity.

1.1 Introduction

Mankind has come a long way from the beginning of the concept of heliocentrism to a thorough understanding of the universe and the solar system. The nebular hypothesis, formulated by Emanuel Swedenborg, Immanuel Kant, and Pierre-Simon Laplace, is the most accepted hypothesis with respect to the origin of our solar system. According to this, the solar system formed about 4.5–4.6 billion years ago with the gravitational collapse of a small part of a giant molecular cloud of gas and dust. Most of the collapsing mass collected in the center and formed the sun, while the rest flattened into a protoplanetary disk that gave rise to other celestial
structures like the planets, moon, and asteroids. In 1905, Thomas Chrowder Chamberlin, a geologist, and Forest Ray Moulton, an astronomer, propounded the planetesimal hypothesis according to which a wandering star approached the sun and exerted its gravitational pull on the sun resulting in the separation of cigar-shaped material from the sun which started revolving around the sun and condensed into numerous small bodies that they termed planetesimals and a few larger protoplanets. The planetesimal hypothesis is no longer accepted, but the idea of planetesimals remains in modern theory. However, the most popular theory regarding the origin of the universe is the Big Bang Theory, also referred to as the expanding universe hypothesis put forward by Edwin Hubble. This theory envisages that everything in the world emerged from a point known as singularity (of indefinite mass and density) about 13.7 billion years ago. At the “big bang,” the tiny ball exploded violently leading to a huge expansion that continues till the present day. Within the first 3 min from the big bang, the first atoms began to form. Within a span of 300,000 years from the big bang, temperature dropped to as much as 4500 K and gave rise to atomic matter. As the universe expanded, hot radiation cooled down leading to the formation of galaxies which further broke into stars, and finally stars broke to form planets.

1.2 *Homo sapiens*: Origin and Spread

*Homo sapiens* are unique among the known humans since they possess numerous small-scale cranial characteristics like a short, tall, and more or less globular braincase, beneath the front of which a small, anteroposteriorly short and delicately built face is distinctly retracted. Other unique features of *H. sapiens* include the following:

(i) Complex chin in the form of an inverted “T,” in which a vertical keel bounded by lateral depressions meets a basal transverse bar running between lateral tubercles
(ii) Slender and delicately built skeleton
(iii) Barrel-shaped thorax that is relatively narrow and tapers inward at the bottom and at the top, while the relatively delicate pelvis below it lacks lateral flare and has notably more vertical iliac blades

The earliest fossils of *H. sapiens* are located in Africa and dated to the late Middle Pleistocene. The “Out of Africa” hypothesis of modern human origins was propounded by paleoanthropologists such as Günter Bräuer (Germany) and Chris Stringer (the United Kingdom) in the mid-1980s which posits that *H. sapiens* arose as a new species in Africa and subsequently spread, leading to the extinction of other archaic human species. This hypothesis was based on the fact that the earliest fossils that resembled *H. sapiens* came from southern and eastern Africa. It is
assumed that the first groups of *H. sapiens* left Africa via the Middle East and had reached Australia at least 40,000 years ago (Fig. 1.1). Although the single African origin hypothesis received an enormous boost from molecular systematics studies based on protein and DNA sequence data, recent discoveries from archaeology, hominin paleontology, geochronology, genetics, and paleoenvironmental studies hint at revision of the traditional “Out of Africa” model.

### 1.3 The Hunter-Gatherers

Human beings have existed on this earth for about 250,000 years initially as foragers or hunter-gatherers for approximately 84,000 generations gathering wild plants and hunting animals. They were organized in small nomadic groups of around 20–30 people since they were incapable of sustaining large populations because of limited food supply and needed to keep moving. In this mode man survived by hunting animals and eating vegetation and would stay in one place only as long as they could forage food from that area. During the Paleolithic (Old Stone Age – before 10,000 BC), all humans were nomadic hunter-gatherers. While procuring food from the surrounding resources, man developed adequate knowledge about the resources and learnt the means to effectively exploit them. During this time, he competed for food with other surrounding animals and gradually got adapted to this mode of living. The knowledge of the hunter-gatherer societies led to the beginning of a new window into understanding early human cultures. It was as hunters and gatherers that man developed the crucial physical and mental capacities that are shared by all
humans to this day. The main features of a hunting and gathering society have been provided below:

(i) Ties of kinship with defined role for most members.
(ii) Communities were small with low population growth and delayed marriages. Increased mobility for food provided a lower return and poorer diet that led to increase in infanticide. Societies which depended on hunting and gathering were comparatively smaller than those that incorporated other means of subsistence.
(iii) Hunting and gathering societies were usually nomadic and moved in search of food supplies, to obtain a large kill, due to seasonal changes and as a result of conflict within the group.
(iv) Education was an informal process in which children learnt both through their actions and through observing and imitating their elders.

Wild plants contributed about 50–75% of their calorie intake. Survival within the hunter-gatherer niche required enormous amount of utilization of energy on a daily basis in activities such as food and water procurement, social interaction, escape from predators, and maintenance of shelter and clothing. Natural selection endowed human beings with the genetic makeup that allowed our ancestors to survive the physical work and daily rigors required of the hunter-gatherer and concomitantly thrive in response to these demands. Pastoralists and cultivators differed from hunter-gatherers in their reliance on a limited range of food sources by following intensive husbandry.

Humans were hunters and gatherers for the major part of human evolutionary history with diversification beginning about 100,000 years ago. Virtually all humanity lived as hunters and gatherers until 12,000 years ago. Many of the worlds’ hunting and gathering groups like the Arctic Inuit (inhabiting a long arc from eastern Siberia, through northern North America to Greenland), Aboriginal Australians, San (Bushmen) of Kalahari region in southern Africa, and various such groups in East Africa, the Americas, Siberia, India, and Southeast Asia represent the oldest and possibly the most successful human adaptation. Some of the hunter-gatherer tribes have managed to maintain much of their independence as hunter-gatherers and are mentioned below:

(i) Kalahari Bushmen of the Kalahari Desert of Africa
(ii) Spinifex people or Pila Nguru of the Great Victoria Desert, situated in Western Australia
(iii) Sentinelese of the Andaman Islands of India
(iv) Pirahã of Brazil’s Maici River
(v) Batak of northern Palawan in western Philippines

These ancient societies hold the key to some of the central questions about the human being, viz., social life, diet and nutrition, healthy association with nature, living without accumulated technology, and the possibility of living in nature without harming it.
1.4 The Beginning of Settled Life and Agricultural Revolution

The hunter-gatherers dominated the scene across all continents until the end of the Pleistocene. Thereafter, food production based on domestication of relatively few wild species (both plant and animal) arose independently. It is estimated that between about 8500 and 2500 B.C., almost nine homelands of agriculture and herding were scattered over all inhabited continents except Australia at different subsequent times. The initial theories described the transition from foraging to agriculture as “agricultural revolution” wherein the discovery of agricultural is attributed to a brilliant sage who realized that the crops will grow on sowing of seeds. However, by the 1960s archaeologists brewed the idea that the origin of agriculture was not a revolution but the result of a gradual cultural evolution. The hunter-gatherers knew the art of growing wild plants and utilized farming along with foraging as an overall food-collection strategy when necessary. It was stated that some aboriginal groups on the Peruvian coastland abandoned their farming practices whenever fish became plentiful.

1.5 Origin of Agriculture

Angiosperms, the first plants to have double fertilization and the enclosure of seeds in fruit, appeared in the early Mesozoic or late Paleozoic era about 200–250 million years ago. The paleontological evidence of angiosperms is extremely limited until their sudden and widespread in the Cretaceous (136–190 million years ago). The angiosperms set the stage for the development of our human ancestors since they provided us with most of our crops, and their emergence predated the appearance of human beings. Agriculture was thought to be a significant improvement over the hunter-gatherer mode of living in that a dependable food source could be easily grown rather than collected from the wild. There were three major advantages that agriculture offered over hunting-gathering mode:

(a) Agriculture facilitated higher population densities as compared to hunting-gathering due to higher food yields per area of productive land.
(b) Accumulation of large food surpluses by sedentary food-producing societies that helped the development of complex technology, social stratification, and formation of centralized states having large standing armies.
(c) Development of resistance among the farming community against epidemic infectious diseases of crowded populations, such as smallpox and measles that probably originated from the epidemic infectious diseases of domestic animals.

A wide range of hypotheses are available that shed light on the rapid emergence and diversification of the angiosperms. The most accepted of these explained the
powerful divergent selection as foragers and hosts developed complex relationships due to a concomitant rise of pollinating insects. Takhtajan (1969), Proctor and Yeo (1973), Faegri and van der Pijl (1979), and Armstrong et al. (1982) were the chief proponents of this hypothesis. It was also proposed that the appearance of closed carpels and self-incompatibility increased chances of cross-pollination, which led to increase in genetic diversity and the potential for divergence. Other hypotheses are as under:

(a) Stress-induced selection.
(b) Closed carpels induced enhanced competitive ability against predation.
(c) Significance of endosperm in successful establishment of seedling.
(d) Improved water conduction by vessel elements.
(e) The defensive nature of secondary metabolites especially the alkaloids.
(f) The wide dispersal of fruits.

Agriculture began independently in several parts of the world at about the same time. These include:

(i) Mesoamerica: maize
(ii) Yangtze region of Southeast Asia: rice
(iii) Lowland and highland regions of South America: potato, peanut, and manioc
(iv) “Fertile Crescent” (a region of Southwest Asia comprising the valleys of the Tigris, Euphrates, and Jordan rivers and their adjacent hilly flanks): einkorn wheat, emmer wheat, barley, lentil, pea, flax, bitter vetch, and chickpea

The inception of agriculture has been a major turning point in both environmental and cultural history of human beings. The origins and evolution of agriculture show us how human food-procurement methods have changed drastically resulting in evolution of plant populations. The initiation of food production represents a major shift in human methods toward the manipulation of the soil environment (clearance, tillage) and through an influence on the composition of plant populations in that soil (via preferential seeding and tending of one or a few species). Agriculture facilitates the increasing ability of humankind to manipulate other organisms and modify trophic energy flows for their selective advantage. This ability of humans to channel food energy paved the way for numerous technological and cultural innovations along with sweeping changes in the structure and organization of human communities. However human interference in the environment has resulted in undesirable changes like soil erosion, desertification, water pollution, and soil degradation which are intimately associated with development of agriculture. The most significant impact of agriculture has been its power to destroy germplasm through extinction which is irreversible as compared to the ills like soil erosion and desertification. Thus, our quest for the generation of a reliable food supply has also destroyed opportunities through extinction.
1.6 Center of Origin of Crops

Knowledge of the origins of crop plants is of immense importance in avoiding the genetic erosion of crops, depletion of germplasm due to the loss of ecotypes and landraces, loss of habitat, and increased urbanization. Vavilov (Box 1.1) postulated the existence of eight centers of origin and diversity of crops which had important factors in common (ancient agriculture and an old civilization; distributed in the tropical and subtropical regions; diverse eco-topographic conditions).

Box 1.1: Nikolai Ivanovich Vavilov (1887–1943)
Vavilov, a prominent Soviet botanist, geneticist, and plant breeder, was born in 1887 in Moscow to a wealthy textile merchant and went on to study graduation from the Moscow Agricultural Institute. Vavilov was deeply interested in Mendelian genetics and undertook a 2-year official trip to visit the main biological laboratories in Europe, especially those of England, France, and Germany in 1913–1914 wherein he studied plant immunity, in collaboration with the British biologist William Bateson. He was the professor of the agronomy department of the Saratov University from 1917 to 1921. From 1924 to 1935, he held the prestigious position of the director of the Lenin All-Union Academy of Agricultural Sciences at Leningrad. Vavilov was the founder of the Academy of Agricultural Sciences, 1929, and its first president; head of the Genetics Laboratory, later Institute of Genetics, of the Academy of Sciences of USSR (1930–1940); and an active member of the Geographical Society of USSR, serving as President, 1931–1940. He was a member of the USSR Central Executive Committee, President of All-Union Geographical Society and a recipient of the Lenin Prize.

Vavilov is best known for having identified the centers of origin of cultivated plants. While developing this theory, he organized a series of botanical-agronomic expeditions for seed collection from every corner of the globe and created the world’s largest collection of plant seeds in Leningrad. By the end of 1924, his seed collection had grown to almost 60,000 acquisitions from 5 continents of which 7000 came from Afghanistan. For his expedition to Afghanistan, the Russian Geographic Society awarded Vavilov a special gold medal “For Exploits in Geography.” Such was the enormity of his germplasm collection that about 26,000 varieties of wheat alone were kept in cultivation at Leningrad.

Vavilov’s criticism of the non-Mendelian approach of Trofim Lysenko earned him the ire of Joseph Stalin. Lysenko began a campaign against Mendelian genetics and attacked Vavilov as a “reactionary, bourgeois, idealist, and formalist.” He was removed as president of the All-Union Academy of Agricultural Sciences and later falsely accused of working for the American government. Vavilov was arrested on August 6, 1940, on charges of being a traitor and British spy and sentenced to death in July 1941 which was later commuted to 20 years of imprisonment. He died of starvation in prison in Saratov on January 26, 1943. Even during his imprisonment, Vavilov read lectures in genetics to his cellmates and wrote a book called “The History of World Agriculture,” which was never published.
According to Vavilov the distribution of the genetic diversity followed certain patterns.

The eight Vavilovian centers of origin have been described above (Fig. 1.2):

I. **Chinese Center**: The largest independent center which includes the mountainous regions of central and western China and adjacent lowlands.

II. **Indian Center**: This area has two subcenters.

   A. **Main Center (Hindustan)**: Includes Assam and Burma, but not Northwest India, Punjab, nor Northwest Frontier Provinces. In this area, 117 plants were considered to be endemic.

   B. **Indo-Malayan Center**: Includes Indochina and the Malay Archipelago. Fifty-five plants have been listed here.

III. **Central Asiatic Center**: Includes Northwest India (Punjab, Northwest Frontier Provinces and Kashmir), Afghanistan, Tadzikistan, Uzbekistan, and western Tian Shan. Forty-three species are listed for this center.

IV. **Near-Eastern Center**: Includes interior of Asia Minor, all of Transcaucasia, Iran, and the highlands of Turkmenistan. Eighty-three species of plants are listed.

V. **Mediterranean Center**: Includes the borders of the Mediterranean Sea. Eighty-four plants are listed for this region.
VI. **Abyssinian Center**: Includes Abyssinia, Eritrea, and part of Somaliland. Thirty-eight species have been listed in this center.

VII. **South Mexican and Central American Center**: Includes southern sections of Mexico, Guatemala, Honduras, and Costa Rica.

VIII. **South American Center**: (62 plants listed) Three subcenters have been described:

A. **Peruvian, Ecuadorean, and Bolivian Center**: Comprised mainly of the high mountainous areas, formerly the center of the megalithic or pre-Inca civilization.

B. **Chile Center (Island near the coast of southern Chile)**.

C. **Brazilian-Paraguayan Center**.

The centers of origin described by Vavilov are of critical importance for current and future breeding programs since they harbor major parts of the genetic diversity of a given gene pool that include both the domesticated species and their wild and weedy relatives. Adaptation and selection processes in the crop gene pools are still continuing in these centers, especially in traditional agricultural production systems, where farmers continue to play an important role in the management and maintenance of this genetic diversity. Diverse cultivation practices are followed in many parts of these centers since commercial agriculture has not yet been adopted. Cultivation in these areas is usually based on traditional knowledge that has evolved over centuries and is passed on to the coming generation. Most of the crops produced in these regions are consumed locally, and traditional seed systems are an important component of these agricultural practices. However, these traditional systems are extremely vulnerable, and specific care is needed to avoid that their built-in strength is undermined through outside interventions. Jack Harlan (Box 1.2), another botanist and agronomist, was in consonance with Vavilov but preferred the term center of diversity to Vavilov’s term center of origin.

**Box 1.2: J.R. Harlan (1917–1998)**

Jack Rodney Harlan, a botanist, agronomist, and plant collector, was born on June 7, 1917, in Washington, DC. Harlan developed a deep passion for plants under the influence of his father Harry V. Harlan who worked at the US Department of Agriculture (USDA) and worked on barley genetics. Jack came under the influence of the famous Russian plant breeding expert Nikolai Vavilov, who was a friend of Harry and often had long discussions with him. Jack completed his BS from George Washington University in 1938 and thereafter moved to the University of California at Berkeley for his doctorate under the famous botanist and evolutionist G. Ledyard Stebbins. From 1942 to 1951, he worked at the US Department of Agriculture and thereafter moved to Oklahoma State University, Stillwater, as a professor and later as a (continued)
professor of plant genetics at the University of Illinois Urbana-Champaign where he co-founded the Crop Evolution Laboratory in 1966. The Crop Evolution Laboratory was a cosmopolitan place that harbored graduate students, postgraduate students, and visiting scholars from all over the world. It was estimated that 19 different languages were spoken in the lab. In 1984 he became Professor Emeritus as he ended his formal professional career.

He developed a deeper understanding of the domestication of many crops through his extensive plant exploration work and astute observations in some 45 countries on all of the continents over a period of 35 years. He undertook extensive archaeobotanical work which shaped his views on the origins of agriculture. Being a keen student of Vavilov’s work, Harlan agreed broadly with Vavilov’s idea that just a few geographical locations are crucial for generating much of the biodiversity on which plant breeders depend. However Harlan challenged Vavilov’s concept and preferred the use of the term center of diversity to Vavilov’s term center of origin, because while the centers of crop diversity are known and mapped, the origins of crops cannot be definitely pinned down. In his classic paper *Agricultural Origins: Centers and Noncenters* (1971), Jack introduced the concept of “noncenters” as a complement and refinement of Vavilovian theories of crop origins and diversity wherein he observed that the centers of crop origins described by Vavilov were centers of diversity and centers of long-standing agricultural activity, which may or may not represent centers of crop evolution or domestication. He emphasized on the need for conservation of wild species in a post-Green Revolution paper, *Genetics of Disaster* (1972), in which he formulated his concerns about “genetic vulnerability” and “genetic wipeout.”

During his illustrious career, Jack was conferred with numerous prestigious awards, namely, John Simon Guggenheim Memorial Fellowship (1959), American Grassland Council Merit Award (1962), Frank N. Meyer Memorial Medal for Plant Genetic Resources (1971) (awarded by the Crop Science Society of America), International Service in Agronomy Award (1976), Distinguished Botanist Award (1986) (awarded by the Society for Economic Botany), and Vavilov Medal (1987), awarded during the Vavilov Centennial Celebration in Moscow and St. Petersburg.

Harlan was of the firm opinion that education should be a continual process throughout one’s life and should not end with a PhD. Thus, apart from making contributions in wide areas of science like agronomy, genetics, botany, archeology, anthropology, and history, Harlan was also interested in music, art, history, sailing, languages, birds, museums, and libraries.
1.7  Plant Domestication

Domestication is a unique form of mutualism that develops between humans and a target plant or animal population and has strong selective advantages for both the partners. In this mutualistic association, humans increase the genetic fitness of the target populations by modifying their life cycles and enabling them to increase in numbers and to expand their range and habitat far beyond that of their wild progenitors. Domestication is the outcome of a selection process that leads to plants adapted to cultivation and utilization by human beings. Domestication is not an instantaneous event but is an accelerated evolutionary process driven both by human intervention and natural selection, in which a wild plant or animal is suddenly transformed into a domesticated one. This cumulative process is marked by changes on both sides of the mutualistic relationship, as both partner populations, over time, become increasingly interdependent. The domesticates acquire improved fitness for human purpose which often occurs at the expense of survival in nature. Domesticated species are the ones that have been altered through human selection to such an extent that their existence depends on human intervention. Although it is perceived that certain plant species were “preadapted” for domestication, early breeders selected traits that improved the species suitability for food and decreased the ability of crops to survive in the wild. Thus, crop domestication led to a dramatically reduced genetic diversity, known as a genetic bottleneck. It is estimated that of more than 275,000 species of flowering plants, less than 1% have been domesticated. Forty percent of the domesticated species belong to four families, viz., Poaceae, Solanaceae, Fabaceae, and Rosaceae. It is interesting to note the reliance of humans on a handful of plants like wheat, rice, and corn which provide about 61% of the world’s calories. Domestication was at the core of Charles Darwin’s thoughts when he formulated the theory on the origin of species through natural selection.

According to Harris (1989), domestication is a four-step process:

(i) Collection of wild plants for food (true hunting and gathering)
(ii) Production of wild plants for food production (the origin of cultivation)
(iii) Systematic cultivation (of morphologically wild plants)
(iv) Cultivation of plants after selection, viz., agriculture based on domesticated plants

Zohary (2004) describes two types of selection that seem to be associated with domestication of crops operating and complementing each other. These are.

(1) **Conscious or intentional selection**: Intentional selection is carried out deliberately by the producers for certain traits of interest. In this process, the farmers intentionally preserve what they consider the most valued plants and utilize them for raising the next generation. This results in gradual elimination of the less valued plants since they are denied reproduction.

(2) **Unconscious, unintentional, or automatic selection**: Many botanists like Vavilov and Engelbrecht viewed the initial stages of domestication largely
determined by unconscious selection. This occurs when the plants are moved from their original wild habitat to a different habitat which is often human-made or human-managed. This shift in the ecology of the plant leads to drastic changes in selection pressures. Due to introduction of the plants into the anthropogenic environments, numerous adaptations vital for survival in the wild lost their fitness and were gradually eliminated. Automatic selection took place for new traits that facilitated the plant to fit into the new environments, resulting in the buildup of the characteristic “domestication syndrome.”

### 1.8 The Domestication Syndrome

The domestication syndrome is the set of characters that distinguishes the crop plant from its wild ancestors (Table 1.1).

During the domestication process, many traits in plants underwent dramatic modifications to meet the fastidious requirement of humans (Fig. 1.3).

Some of these modifications were necessary to enable efficient cultivation, while others were brought about to enhance the culinary or aesthetic preferences. The characters arise at least in part from human selection and hence relate to ways in which the plants are cultivated and harvested. The domestication syndrome in grain crops usually includes the following criteria.

#### 1.8.1 Elimination/Reduction Seed Shattering

Seed shattering or fruit shedding, the detachment of the fruit from the pedicel in cereals and fleshy fruit species, is essential for the propagation and survival of the offspring in wild plants. The phenomenon occurs either by seed abscission and/or by spikelet disarticulation. The evolutionary success of wild plant species depends essentially on their capacity to scatter their offspring. Mature grains of several plants detach easily by wind or animals due to which their seeds can be dispersed promptly. The easy shattering of wild plants, however, makes grain harvest difficult especially when they mature over a relatively long period of time during which substantial grain loss occurs as a result of strong wind or storms. Thus the reduction of grain shattering was necessary for effective harvest.

This is one of the most important traits altered during domestication. Loss of seed shattering means that instead of shedding seeds on maturity, the plant retains them. These seeds need to be separated by threshing and winnowing, and then the seeds are dispersed by the farmer. Thus, the farmer gets higher yields since he can wait until most of the grains have matured. It makes a species dependent upon the human for survival i.e., a means of mutualism. For example, non-shattering rachis in cereals, non-dehiscent pod in pulses. In Triticeae the most important traits modified during domestication were the free-threshing state (release of seeds from the rachis at threshing) and brittle rachis (dried inflorescence does not disarticulate at maturity) (Fig. 1.4).
### Table 1.1 Commonly observed traits in crops accompanying domestication (Stage 1) and diversification (Stages 2–4)

<table>
<thead>
<tr>
<th>Seed crop</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed size</td>
<td>Larger seeds</td>
<td>More seeds</td>
<td>Reduced vernalization</td>
<td>Increased yield</td>
</tr>
<tr>
<td>Resource allocation</td>
<td>Increased seed size variation</td>
<td>Reduced photoperiod sensitivity</td>
<td>Increased abiotic stress tolerance</td>
<td></td>
</tr>
<tr>
<td>Thinner seed coat and increased seed</td>
<td>Pigment change</td>
<td>Modified hormone sensitivity</td>
<td>Increased biotic stress tolerance</td>
<td></td>
</tr>
<tr>
<td>softening and ornamentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inflorescence architecture (including shape,</td>
<td>Flavor change</td>
<td>Synchronized flowering time</td>
<td>Improved eating quality</td>
<td></td>
</tr>
<tr>
<td>number, and determinacy)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased yield potential and productivity</td>
<td>Change in starch content</td>
<td>Shortened or extended life cycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss of dormancy</td>
<td>Non-shattering seeds‡</td>
<td>Dwarfism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Determinate growth</td>
<td>Reduced germination inhibition</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Root and tuber</th>
<th>Flavor change</th>
<th>Reduced toxicit</th>
<th>Hybridization using effect of heterosis</th>
<th>Improved nutritional quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource allocation</td>
<td>Vegetative propagation and</td>
<td>Promotion of allogamy</td>
<td>Improve multiplication ability and rate</td>
<td></td>
</tr>
<tr>
<td>Change in starch content</td>
<td>reduced sexual propagation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to thrive in modified landscape</td>
<td>Abiotic stress tolerance</td>
<td>Increased yield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced branching</td>
<td>Biotic stress tolerance</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Flavor change</th>
<th>Increased fruit size variation</th>
<th>Improved pollination success</th>
<th>Delayed ripening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource allocation</td>
<td>Selfing breeding system</td>
<td>Reduced fruit shedding</td>
<td>Increased postharvest quality</td>
<td></td>
</tr>
<tr>
<td>Larger seed size</td>
<td></td>
<td>Continuous fruiting</td>
<td>Increased yield</td>
<td></td>
</tr>
<tr>
<td>Larger fruit size</td>
<td></td>
<td></td>
<td>Increased abiotic stress tolerance</td>
<td></td>
</tr>
<tr>
<td>Shortened life cycle</td>
<td></td>
<td></td>
<td>Increased resistance</td>
<td></td>
</tr>
<tr>
<td>Softer fruit</td>
<td></td>
<td></td>
<td>Attractiveness and even ripening</td>
<td></td>
</tr>
</tbody>
</table>


‡ A stage 1 trait in some crop species
In several wild grasses that were later domesticated like wheat, barley, and rice, it took approximately 2000–4000 years to fix the non-shattering spikelet phenotype that serves as a key indicator of cereal domestication. A number of examples in the modification of inflorescence are available that show how these changes lessen or remove the shattering phenomenon and aid in domestication. One such interesting example is seen in barley. The wild-type progenitor (*H. vulgare* ssp. *spontaneum*) of cultivated barley (*Hordeum vulgare* ssp. *vulgare*) has a two-rowed phenotype, with rudimentary, lateral rows which are a natural adaptation for seed dispersal after shattering. A study of the *vrs1* (*six-rowed spike 1*), the gene responsible for the six-rowed spike, showed that the loss of function of *Vrs1* led to conversion of the rudimentary lateral spikelets in two-rowed phenotype into the fully developed fertile spikelets in the six-rowed ones.

1.8.2 Loss/Reduction in Seed Dispersal Aids

Many plants often have specialized structures aiding in seed dispersal like hooks, barbs, hairs, and awns which facilitate wind and animal dispersive processes. If we look in family Poaceae, the general shape of the spikelet in grasses also has similar function. Wild barley and wheat have fragile spikes, and their ears disarticulate immediately upon maturity which is the main diagnostic trait that serves for
distinction of wild cereals from their cultivated counterparts. The spikelets in
domesticated species are less hairy, have shorter or no awns, and are plump, whereas
in the wild they are heavily haired, barbed, and aerodynamic in shape. Some of the
traits which have been reduced in the domesticated form have considered to have
come about by the removal of natural selection for effective dispersal. Once
removed, the metabolic “expenditure” on these structures is reduced.

**Fig. 1.4** Morphological differences between wild and domesticated einkorn wheat. Examples of
dehiscent wild einkorn wheat ear (**a**), wild einkorn spikelet (**b**), detail of wild einkorn spikelet with
smooth wild abscission scar (**c**), and wild einkorn seeds (**d**). Indehiscent domesticated ear (**e**),
domesticated spikelet (**f**), detail of domesticated spikelet with jagged break (**g**), and domesticated
seeds (**h**). (Reprinted by permission from Springer Nature: Genetic diversity, evolution and
domestication of wheat and barley in the fertile crescent, Martin K, Sauerborn J, In: Glaubrecht M
(ed) Evolution in action, 2010)


1.8.3 Loss of Seed Dormancy

Seed dormancy is defined as a block to the completion of germination of an intact viable seed under favorable conditions. A completely non-dormant seed has the capacity to germinate over the widest range of normal physical environmental factors possible for the genotype. Although seed dormancy has been classified into various types by different researchers, Baskin and Baskin (1998, 2004) proposed a comprehensive classification system which includes five classes of seed dormancy:

(i) Physiological (PD): found in seeds of gymnosperms, all major angiosperm clades and in most seed model species “in the laboratory.”
(ii) Morphological (MD): found in *Apium graveolens* (Apiaceae).
(iii) Morphophysiological (MPD): found in *Trollius* (Ranunculaceae) and *Fraxinus excelsior* (Oleaceae).
(iv) Physical (PY): found in *Melilotus* and *Trigonella* (both members of Fabaceae).
(v) Combinational (PY + PD): found in *Geranium* (Geraniaceae) and *Trifolium* (Fabaceae).
(vi) Physiological dormancy is the most prevalent form of dormancy which involves abscisic acid (ABA) (Fig. 1.5a) and gibberellin (GA) (Fig. 1.5b) metabolism. It is further subdivided into deep, intermediate, and nondeep types.

Apart from this plants also exhibit morphological dormancy, viz., seeds having an underdeveloped embryo and requiring long time to germinate. Dormancy provides a strategy for seeds to spread germination over a period of time to reduce the risk of plant death and possible species extinction in an unfavorable environment. In the wild environment, seeds germinate after certain conditions of day length, temperature, or physical damage to seed coat are met. In contrast the cultivated species tend to germinate as soon as they are planted and watered since they have thinner seed coats as compared to the wild ones. Although this has been less useful for Old World crops, it is a particularly important trait for the study of New World domestications like in members of the genus *Chenopodium*. In grasses

![Fig. 1.5 Structure of (a) abscisic acid and (b) gibberellic acid](image_url)
germination inhibitors are mainly localized in the glumes, lemma, palea, and other appendages. Thus, selection pressure tends to reduce appendages in some grasses, while in others a lower concentration of inhibitors is favored.

### 1.8.4 Synchronous Tillering and Ripening

Planting a crop at one time and harvesting most of it at one time will favor plants that grow in synchronization. Wild germplasm of maize, pearl millet, and sorghum generally have branched stems with several inflorescences that mature at different times over a period of time. Uneven ripening that is more common in wild taxa causes greater losses as compared to shattering. In grasses there has been a trend toward uniform ripening which is based mainly on reduction in the number of inflorescences and a concurrent increase in inflorescence size. Uniform ripening of the produce facilitates easy and cost-efficient harvesting.

### 1.8.5 More Compact Growth Habit

One of the important traits selected during crop domestication is a more compact growth habit that is best exhibited in the legumes. The wild races of legumes are generally herbaceous, viny, highly branched with multiple nodes, long and twining internodes, and diageotropic branch growth. The vininess present in these plants allows them to compete with the surrounding plants for light in the shrubby or arboreal vegetation in which these wild plants grow naturally. During domestication, the plants developed characters like reduced branching, shorter internodes, fewer nodes, reduced twining, and a determinate stem ending. Thus, determinacy is a trait selected during or after domestication. Similarly, in tomatoes compact growth habit (CGH), tomatoes have been developed that are determinate varieties and have low growth and spreading characteristics, forming compact plants that hold fruit above the ground due to its short branches.

### 1.8.6 Size of Usable Part

Domesticated plants generally have larger usable part than their wild counterparts (Fig. 1.6). This is because the early foragers selected for larger seeds, fruits, or tubers, and as a result the domesticated varieties became larger than their wild counterparts over a period of time. For example, cultivated species of potato (*Solanum tuberosum*) are larger in size than their wild relatives. Similarly in papaya (*Carica papaya*), the fruit length of domesticated papaya cultivars has risen up to 30 cm as compared to a few centimeters of the wild ones. Cultivated tomato plants are known to produce fruit several times larger than those of their wild progenitors. This can be attributed to an increase in the number of locules in the cultivated varieties to 8 or more in contrast to 2–4 locules in the wild progenitors which can
**Fig. 1.6** Phenotypes of some crops and their progenitors. (Reprinted from Cell, Vol 127, Doebley JF, Gaut BBS, Smith BD, The molecular genetics of crop domestication, 1309–1321, 2006, with permission from Elsevier)
lead to almost 50% increase in fruit size (Fig. 1.7). It is most likely that mutations associated with larger fruit were selected and accumulated during selection by early humans.

The seeds of domesticated varieties are usually larger than their wild relatives. Studies in wheat have shown that the size and shape of grain are independently inherited traits and domestication resulted in a switch from production of a relatively small grain with a long, thin shape to a more uniform larger grain with a short, wide shape. An increase in seed size is an early adaptive response to cultivation, and greater seed size has been found to be strongly correlated with larger seedlings in many cereal and legume species (Fig. 1.8).
1.8.7 Enhanced Culinary Chemistry

Examples of this feature are the improved bread-making quality of wheat and changes to the sugar-starch balance in maize.

1.9 Molecular Mechanism of Plant Domestication

A general observation in genomics during crop domestication is the genetic bottleneck. Shi and Lai (2015) state that after domestication, only favorable haplotypes are retained around selected genes (Fig. 1.9) leading to the creation of a valley with extremely low genetic diversity.

The reduction in the levels of genetic diversity associated with domestication ranges from less than onefold in cereal like rice and maize to around threefold in cucumber and tomato. Over the past decades, identification of specific genes controlling important morphological changes associated with domestication has gained momentum (Table 1.2).

There are two main approaches for studying the genetic basis of traits associated with domestication (Sang and Li 2013):

(i) Top-down approach – This is a straightforward approach that involves crossing of cultivars with their wild progenitors or relatives and subsequently

Fig. 1.9 Genomic changes associated with crop domestication and breeding. (Reprinted from Curr Opin Plant Biol, Vol 24, Shi J, Lai J, Patterns of genomic changes with crop domestication and breeding, 47–53, 2015, with permission from Elsevier)
Table 1.2  Genes of interest in crop domestication and improvement

<table>
<thead>
<tr>
<th>Gene(s)</th>
<th>Crop</th>
<th>Molecular and phenotypic function</th>
<th>Control phenotype</th>
<th>Selection evidence</th>
<th>Causative change</th>
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<tbody>
<tr>
<td>Genes identified as controlling domestication traits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tb1</td>
<td>Maize</td>
<td>Transcriptional regulator (TCP); plant and inflorescence structure</td>
<td>Yes</td>
<td>Yes</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>tga1</td>
<td>Maize</td>
<td>Transcriptional regulator (SBP); seed casing</td>
<td>Yes</td>
<td>Yes</td>
<td>Amino acid change</td>
</tr>
<tr>
<td>qSH1</td>
<td>Rice</td>
<td>Transcriptional regulator (homeodomain); abscission layer formation, shattering</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>Rc</td>
<td>Rice</td>
<td>Transcriptional regulator (bHLH); seed color</td>
<td>Yes</td>
<td>N.T.</td>
<td>Disrupted coding sequence</td>
</tr>
<tr>
<td>sh4</td>
<td>Rice</td>
<td>Transcriptional regulator (Myb3); abscission layer formation, shattering</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory/amino acid change</td>
</tr>
<tr>
<td>fw2.2</td>
<td>Tomato</td>
<td>Cell signaling; fruit weight</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>Q</td>
<td>Wheat</td>
<td>Transcriptional regulator (AP2); inflorescence structure</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory/amino acid change</td>
</tr>
<tr>
<td>Genes identified as controlling varietal differences</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c1</td>
<td>Maize</td>
<td>Transcriptional regulator (MYB); kernel color</td>
<td>Yes</td>
<td>Yes</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>r1</td>
<td>Maize</td>
<td>Transcriptional regulator (bHLH); kernel color</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>sh2</td>
<td>Maize</td>
<td>Pyrophosphorylase; supersweet sweet corn</td>
<td>Yes</td>
<td>N.T.</td>
<td>Transposon insertion</td>
</tr>
<tr>
<td>su1</td>
<td>Maize</td>
<td>Isoamylase; sweet corn gene</td>
<td>Yes</td>
<td>Yes</td>
<td>Amino acid change</td>
</tr>
<tr>
<td>y1</td>
<td>Maize</td>
<td>Phytoene synthase; carotenoid content</td>
<td>Yes</td>
<td>Yes</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>brix9–2–5</td>
<td>Tomato</td>
<td>Invertase; fruit-soluble solid content</td>
<td>Yes</td>
<td>N.T.</td>
<td>Amino acid change</td>
</tr>
<tr>
<td>Ovate</td>
<td>Tomato</td>
<td>Unknown; fruit shape</td>
<td>Yes</td>
<td>N.T.</td>
<td>Early stop codon</td>
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<tr>
<td>Rin</td>
<td>Tomato</td>
<td>Transcriptional regulator (MADS); fruit ripening</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory change</td>
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<tr>
<td>Sp</td>
<td>Tomato</td>
<td>Cell signaling; determinant plant growth</td>
<td>Yes</td>
<td>N.T.</td>
<td>Amino acid change</td>
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<tr>
<td>R</td>
<td>Pea</td>
<td>Starch branching enzyme; seed sugar content</td>
<td>Yes</td>
<td>N.T.</td>
<td>Transposon insertion</td>
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<tr>
<td>ehd1</td>
<td>Rice</td>
<td>B-type response regulator; flowering time</td>
<td>Yes</td>
<td>N.T.</td>
<td>Amino acid change</td>
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<tr>
<td>gn1</td>
<td>Rice</td>
<td>Cytokinin oxidase/dehydrogenase; grain number</td>
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<td>N.T.</td>
<td>Regulatory/early stop codon</td>
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<tr>
<td>hd1</td>
<td>Rice</td>
<td>Transcriptional regulator (zinc finger); flowering time</td>
<td>Yes</td>
<td>N.T.</td>
<td>Disrupted coding sequence</td>
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(continued)
<table>
<thead>
<tr>
<th>Gene(s)</th>
<th>Crop</th>
<th>Molecular and phenotypic function</th>
<th>Control phenotype</th>
<th>Selection evidence</th>
<th>Causative change</th>
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<tbody>
<tr>
<td>hd6</td>
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<td>Early stop codon</td>
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<tr>
<td>sd1</td>
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<td>Yes</td>
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<tr>
<td>Waxy</td>
<td>Rice</td>
<td>Starch synthase; sticky grains</td>
<td>Yes</td>
<td>Yes</td>
<td>Intron splicing defect</td>
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<tr>
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<td>Wheat</td>
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<td>Yes</td>
<td>N.T.</td>
<td>Early stop codon</td>
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<tr>
<td>vrn1</td>
<td>Wheat</td>
<td>Transcriptional regulator (MADS); vernalization</td>
<td>Yes</td>
<td>N.T.</td>
<td>Regulatory change</td>
</tr>
<tr>
<td>vrn2</td>
<td>Wheat</td>
<td>Transcriptional regulator (ZCCT); vernalization</td>
<td>Yes</td>
<td>N.T.</td>
<td>Amino acid change</td>
</tr>
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</table>

Genes identified by selection screens targeted at individual candidate genes

<table>
<thead>
<tr>
<th>boCal</th>
<th>Cauliflower</th>
<th>Transcriptional regulator (MADS); inflorescence structure</th>
<th>Candidate</th>
<th>Yes</th>
<th>Early stop codon?</th>
</tr>
</thead>
<tbody>
<tr>
<td>bal</td>
<td>Maize</td>
<td>Transcriptional regulator (bHLH); plant and inflorescence structure</td>
<td>Candidate</td>
<td>Yes</td>
<td>–</td>
</tr>
<tr>
<td>ral</td>
<td>Maize</td>
<td>Transcriptional regulator (MYB); inflorescence structure</td>
<td>Candidate</td>
<td>Yes</td>
<td>–</td>
</tr>
<tr>
<td>su1, bt2, ae1</td>
<td>Maize</td>
<td>Starch biosynthetic enzymes</td>
<td>Candidate</td>
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<td>–</td>
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</table>

Genes identified through untargeted selection screens

<table>
<thead>
<tr>
<th>zagl1</th>
<th>Maize</th>
<th>Transcriptional regulator (MADS)</th>
<th>Unknown</th>
<th>Yes</th>
<th>–</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 genes</td>
<td>Maize</td>
<td>Varied functions, including auxin response, growth factor, kinase, methyl-binding protein, transcription factors, amino acid biosynthesis, and a circadian gene</td>
<td>Unknown</td>
<td>Yes</td>
<td>–</td>
</tr>
<tr>
<td>~30 genes</td>
<td>Maize</td>
<td>Varied functions, including auxin response, cell elongation protein, F-box protein, growth factor, heat-shock proteins, hexokinase, kinase, steroid biosynthesis, transcription factors, amino acid biosynthesis, and a circadian rhythm gene</td>
<td>Unknown</td>
<td>Yes</td>
<td>–</td>
</tr>
</tbody>
</table>

quantitative trait locus (QTL) analysis. Due to quantitative nature of the traits, initially mapping of quantitative trait loci (QTL) in progenitor-crop hybrid populations has to be carried out, followed either by positional cloning or cloning using a combination of positional information and candidate gene analysis. This approach has been widely adopted in crop plants due to ease in hybridization. Numerous QTLs have been reported underlying domestication transitions in most of the cereal crops.

(ii) Bottom-down approach – Molecular techniques like large-scale DNA sequencing and expression microarrays have further provided a solid thrust for research on the evolution and diversity of domesticated plants. In the bottom-down approach, genome-wide screening for signatures of artificial selection is carried out. Through a comparison of the distribution of nucleotide polymorphism between cultivars and their wild progenitors, loci/genes that presumably experienced selective sweeps are considered to be candidates involved in domestication.

Recent researches have shown that a number of traits involving domestication have a genetic basis. A number of studies in the last two decades have shown that different genes are involved in seed shattering in plants (Table 1.3).

Lin et al. (2012) raised an F2 population following a cross between a wild sorghum with complete seed shattering, *Sorghum virgatum* (SV), and a non-shattering domesticated sorghum line to ascertain the molecular basis underlying seed shattering in the plant (Fig. 1.10).

The F2 ratio pointed out toward the complete dominance effect of a single gene which was named as *Shattering1 (Sh1)*.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Family</th>
<th>Gene</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Arabidopsis thaliana</em></td>
<td>Brassicaceae</td>
<td>SHP1, SHP2</td>
<td>Liljegren et al. (2000)</td>
</tr>
<tr>
<td><em>Glycine max</em></td>
<td>Fabaceae</td>
<td>PDH1</td>
<td>Funatsuki et al. (2014)</td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td>Poaceae</td>
<td>vrs1</td>
<td>Komatsuda et al. (2007)</td>
</tr>
<tr>
<td><em>Oryza sativa</em></td>
<td>Poaceae</td>
<td>qSH1, Sh4, Sh5</td>
<td>Konishi et al. (2006); Yoon et al. (2014)</td>
</tr>
<tr>
<td><em>Oryza barthii</em></td>
<td>Poaceae</td>
<td>GL4</td>
<td>Wu et al. (2017)</td>
</tr>
<tr>
<td><em>Setaria italica</em></td>
<td>Poaceae</td>
<td>qSH1, Sh1</td>
<td>Odonkor et al. (2018)</td>
</tr>
<tr>
<td><em>Solanum lycopersicum</em></td>
<td>Solanaceae</td>
<td>SLMBP21</td>
<td>Liu et al. (2014)</td>
</tr>
<tr>
<td><em>Sorghum bicolor</em></td>
<td>Poaceae</td>
<td>Sh1</td>
<td>Lin et al. (2012)</td>
</tr>
<tr>
<td><em>Sorghum propinquum</em></td>
<td>Poaceae</td>
<td>SpWRKY</td>
<td>Tang et al. (2013)</td>
</tr>
<tr>
<td><em>Triticum aestivum</em></td>
<td>Poaceae</td>
<td>Q</td>
<td>Zhang et al. (2011)</td>
</tr>
<tr>
<td><em>Triticum turgidum</em></td>
<td>Poaceae</td>
<td>Q</td>
<td>Simons et al. (2006)</td>
</tr>
<tr>
<td><em>Zea mays</em></td>
<td>Poaceae</td>
<td>Sh1</td>
<td>Lin et al. (2012)</td>
</tr>
</tbody>
</table>
Fig. 1.10  Seed shattering phenotype in sorghum (a, b). Seeds were scattered everywhere from the top of the wild sorghum SV plant (a), whereas seeds were firmly retained on the head of the domesticated sorghum Tx430 plant (b, shown only from a panicle branch) at maturity after vigorous shaking. (c, d) Larger views of spikelets in a and b are shown for SV (c) and Tx430 (d) plants after shaking. (e, f) Abscission layers (of curved shape) were present at the junction between the hull and pedicel on SV plants (e), whereas no abscission layer was observed on Tx430 plants (f). AL, abscission layer. (Reprinted by permission from Springer Nature: Parallel domestication of the Shattering1 genes in cereals, Lin Z, Li X, Shannon LM, Yeh CT, Wang ML, Bai G, Peng Z, Li J, Trick HN, Clemente TE, Doebley J, Schnable PS, Tuinstra MR, Tesso TT, White F, Yu J, Nature Genetics 44:720–724, 2012)

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Plant Breeding

Abstract

Plant breeding is the continuous endeavor to develop superior plant phenotypes that are better adapted to human needs by utilizing the available genetic variation. It has been practiced for thousands of years ever since the beginning of human civilization, initially as an art by the farmers and later as a science by breeders. The aim of plant breeding is to improve the quality, diversity, and performance of food, fiber, forage, industrial, and other economically important crops. Crop breeding is a rapidly advancing science and has made use of recent genetic and biotechnological innovations to efficiently develop better crop varieties. After initial genetical work by Mendel on garden pea, the later part of the nineteenth century saw a jump in the interest in plant breeding with the cultivators aiming at producing hardier and higher-yielding crops. Rapid advances using conventional breeding techniques led to Green Revolution during the period between 1960 and 1980 when a remarkable increase in the production of wheat and rice was achieved primarily in wheat and rice by development of high-yielding varieties. Advances in plant biotechnology, molecular markers, and genomics have enabled breeders to formulate new tools for the analysis and manipulation of genetic variability and the development of improved plant types. Molecular tools are being increasingly used in plant breeding to widen its impact for meeting the global needs for sustainable increases in agricultural productivity.

2.1 Introduction

Hunger and malnutrition among the humans have always been a pressing problem and are one of the world’s top health risks. The United Nations have projected that world population will increase by 25% to 7.5 billion by 2020. According to the latest FAO estimates of 2017, the number of undernourished people has increased to...
815 million in 2017, up from 777 million in 2015 (Fig. 2.1) with the food security situation worsening in parts of sub-Saharan Africa and Southeast and Western Asia.

A large number of human populations also suffer from deficiencies of micronutrients such as vitamin A, iron, and zinc. Food insecurity and malnutrition have a deleterious effect on human output resulting in serious public health problems and a lost human potential. The situation is more alarming since the amount of land available for crop production is decreasing rapidly due to urban growth and land use. The answer to all the abovementioned problems lies in integrating the latest innovations in plant biology and genetics to enhance crop improvement, i.e., plant breeding.

Plant breeding is the continuous endeavor to develop superior plant phenotypes that are better adapted to human needs by utilizing the available genetic variation. The constant aim of plant breeding is to improve the quality, diversity, and performance of agricultural and horticultural crops. These changes induced to improve certain aspects of plants to perform new roles or improve the existing ones are permanent and heritable. Gregor Mendel, the father of genetics, was the first to provide scientific explanation of genetic inheritance in the mid-nineteenth century. His monumental paper published in 1866 on the relationship between inherited characteristics in the offspring and the genetic constitution of the parents formed a strong base for conventional plant breeding. Breeding has formed the basis of past and present agriculture by creating multi-generation genetically diverse populations on which selection has been practiced by human beings to raise plants having new combinations of specific desirable traits. Modern selection process is mainly driven by the biological assessment in relevant target environments and thorough insight into genes and genomes. Progress is assessed based on gain under selection, which is a function of genetic variation, selection intensity, and time. Genetic improvement
has been carried out in innumerable crops for diverse traits like increased yield, quality enhancement, elimination of toxic substances, improved agronomic characters, changes in dormancy, and resistance against biotic and abiotic stresses (Fig. 2.2). The strategy followed depends on the specific requirement in each crop.

### 2.2 History of Plant Breeding

Plant breeding has been practiced for thousands of years ever since the beginning of human civilization. It is now practiced worldwide by individuals such as gardeners and farmers or by professional plant breeders employed by organizations such as government institutions, universities, crop-specific industry associations, or research centers. It is difficult to identify the true beginnings of modern plant breeding. Archaeological records indicate that the Babylonians and Assyrians artificially pollinated the date palm as early as 700 BC. During the initial periods, plant breeding was the selection of naturally occurring variants in the wild and thereafter in the cultivator’s fields. The genetic variation available in the populations was continuously subjected to the selection pressure of food gathering or planting-harvesting cycles. This process resulted in deep changes in plant phenotypes in some cases as is evident by the gradual development of maize from teosinte, a group of four annual and perennial species of the genus *Zea* native to Mexico and Central America. Maize and teosinte plants have a similar robust growth form, but their female inflorescences are strikingly different (Fig. 2.3). The teosinte ear possesses about 5–12 kernels, each of which is sealed tightly in a stony casing to form a structure termed as the fruitcase. The teosinte ear disarticulates at maturity with individual fruitcases becoming the dispersal units. The teosinte kernel can survive the digestive tracks of birds and animal due to protection provided by the casing, thus enabling the seed to...
be easily dispersed. However, the maize ear can bear more than 500 kernels, which are naked without adequate protection from predation. The kernels are also firmly attached to the cob, and the ear does not disarticulate due to which the maize ear left on the plant will eventually fall to the ground with its full suite of kernels. When these kernels germinate on approach of favorable conditions in the next season, the plants are unable to obtain adequate light and soil to grow and reproduce due to competition emanating from scarcity of space. Thus, maize is completely dependent on humans for its survival.

R.J. Camerarius (1665–1721), a German botanist and physician, is credited with first reporting sexual reproduction in plants in 1694 in his little known work “De sexu Plantarum epistola.” He chose *Ricinus communis* (castor) and *Zea mays* (maize), both the species bearing sterile and fertile flowers on the same plant. Camerarius cut off the sterile tassel (staminate flowers) in maize and observed that no seeds were formed. Likewise, cutting off the buds of the sterile flowers before the maturity of stamens led to seed abortion. Camerarius got the same results in dioecious plants. In studying mulberry, Camerarius determined that female plants not near to male (staminate) plants produced seedless fruits. Thus by experimentation he came to the conclusion that pollen from male flowers was indispensable to fertilization and seed development on female plants.

Work and scientific identification of hybrids started in earnest in 1716, when Cotton Mather described corn/maize (*Zea mays*) and squash (*Cucurbita* spp.) plants as being of hybrid origin. Mather suggested the occurrence of natural cross-pollination that emanated from the fact that yellow corn grown next to blue or red corn had blue and red kernels in them.

Another contemporary researcher, Thomas Fairchild (1667–1729), produced the first artificial hybrid in the year 1717 by successfully accomplishing an interspecific...
cross by crossing a carnation pink \((Dianthus caryophyllus)\) with a Sweet William \((Dianthus barbatus)\). The resulting plant, described as \(Dianthus caryophyllus\ barbatus\), became known as Fairchild’s Mule. Thus, through hybridization, Fairchild created the first-generation sterile \(Dianthus\) hybrids (which today would be referred to as F1 hybrids).

Joseph Gottlieb Kölreuter (1733–1806), a German botanist, was the pioneer in the study of plant hybrids and was the first researcher to detect self-incompatibility in \(Verbascum phoeniceum\) plants. He was first to develop a scientific application of the discovery of sex in plants carried out by Camerarius in 1694. Kölreuter examined the pollen characteristics of over 1000 plant species and was the first to document male sterility in 1763. He conducted the first known systematic investigations into plant hybridization and conducted nearly 500 different hybridization experiments across 138 species. He made extensive crosses in \(Tobacco\) and \(Solanum\) between 1760 and 1766. Kölreuter produced interspecific hybrids — specifically the tobacco plants \(Nicotiana rustica\) and \(Nicotiana paniculata\) — and was of the view that hybrids surpassed their parents. After his rigorous investigations, Kölreuter concluded that early-generation hybrids tend to be phenotypically intermediate between parents but may be more luxuriant, while later-generation hybrids more closely resemble parental forms.

Thomas Andrew Knight (1759–1838), British horticulturalist and botanist, was the first person to produce several new fruit varieties by using artificial hybridization and published over 100 papers in horticulture. Knight applied scientific principles and techniques to practical horticultural problems and conducted breeding of plants including strawberries, cabbages, and peas.

Le Coutier, a New Jersey farmer, initiated wheat breeding by individual selection of spikes of superior individuals and sowing the seeds from each spike separately. The extensive efforts of Coutier led to the identification of the variety “Talevara.” He published his results on selection in wheat in the year 1843 and concluded that progenies from single plants were more uniform.

Patrick Shirreff a Scotsman of Mungoswells farm practiced individual plant selection in cereals like wheat and oats and developed varieties like Shirreff’s Bearded Red, Shirreff’s Bearded White, Pringle, and Shirreff’s Squarehead. Shirreff began his experiment in 1819, and the results were published in 1873. Shirreff concluded that only the variation of heritable nature responded to selection and that this variation arose through “natural sports” and by natural hybridization.

Vilmorin (1857) formulated “Vilmorin’s principle of progeny testing” wherein he proposed individual plant selection based on progeny testing. He proposed this concept in sugar content in sugar beets \((Beta vulgaris)\), but the method was ineffective in wheat which clearly demonstrated the difference between effect of selection in cross- and self-pollinated crops.

In 1866 Gregor Johann Mendel, “father of modern genetics,” published the scientific foundation for the post-crossing segregation of offspring in garden pea that described how factors for specific traits are transmitted from parents to offspring and through subsequent generations. Mendel conducted experiments between 1856 and 1863 that results in a greater variety enabling breeders to discover new, improved
combinations. Gregor Mendel explained the concepts of heredity by elegantly introducing the concept of dissecting how traits are transferred from one generation to the next. Mendel selected an androgynous plant species, *Pisum sativum* (Fig. 2.4a), for his study which afforded the following advantages with respect to genetical work:

(i) Convenience in handling: Garden pea is a small plant that can be cultivated easily and hybridized.

(ii) Short life cycle: Pea is an annual plant with a short generation time that enables many generations to be raised within a short period.

(iii) Inexpensive and easy to obtain, take up little space, and produce abundant offspring.

(iv) Flowers are bisexual, hermaphrodite, and predominantly self-fertilizing (Fig. 2.4b).

Pea is self-fertilizing since the male and female reproductive organs are enclosed by two petals fused to form a compartment called a keel. However, a breeder can easily achieve cross-pollination and fertilization by performing emasculation wherein the male reproductive part of a flower is removed to make it behave as a female flower. Pollen from the other plant can then be transferred to the receptive stigma of this female flower. Thus, pea plants allowed controlling their fertilization and consequently the possibility to arrange various parental combinations,

(v) Pea plants possess many pairs of contrasting characters which makes distinction quite easy. More importantly these traits were located on separate chromosomes (Fig. 2.5).

![Fig. 2.4](image-url) (a) Pea plant (Wikipedia) and (b) pea flower. (Source: Wikimedia Commons)
Mendel presented his findings to the Brünn Natural History Society in two lectures in the spring of 1865 and then published the lectures in 1866 as a single paper under the title “Versuche über Pflanzen-Hybriden” (Experiments on Plant Hybrids). However, his intention was not to offer any laws of heredity but only a “law of the development of hybrids” in plants. Interpretation of Mendel’s work in the form of laws of inheritance by later researchers provided the foundation for the vast knowledge that has, since then, accumulated in an interesting biological field termed “genetics.” Numerous workers who determined the various modes of inheritance have contributed to the development and understanding of plant breeding.

The later part of the nineteenth century saw a jump in the interest in plant breeding with the cultivators aiming at producing hardier and higher-yielding crops. Walfrid Weibull, a farmer and an entrepreneurial sea captain, realized the potential development of new varieties adapted to the local growing conditions. He started a plant breeding company in the city of Landskrona in the south of Sweden in 1870 that later came to be known as the limited company W. Weibull AB. In 1886, the experimental breeding station at Svalöv was established from resources of the Swedish Seed Association, founded by private entrepreneurs, state officials, and agricultural cooperatives.

The rediscovery of Mendel’s laws of genetics in 1900 independently by three biologists, namely, Hugo de Vries, Carl Correns, and Erich von Tschermak, coupled with the concept of natural selection by Darwin (1859) provided the foundations of modern plant breeding. Bateson stated that the Mendelian laws of hybridization
applied to a huge number of individual hereditary differences among virtually all sexually reproducing organisms and were not limited to the results of crosses between individuals of distinct varieties or species.

In 1903 Wilhelm Johansen (1857–1927) proposed the famous “pure line theory” based on his studies in *Phaseolus vulgaris* which states that a pure line is a progeny of a single self-fertilized homozygous plant. Johansen also coined the terms phenotype, genotype, and gene. Johansen’s work confirmed an earlier observation by other workers that the techniques of selection could be used to produce uniform, true-breeding cultivars by selecting from the progeny of a single self-pollinated crop to obtain highly homozygous lines (true breeding), which he later crossed.

George Harrison Shull (1874–1954), American botanist and geneticist, described heterosis in maize in 1908 and played an important role in the development of hybrid maize which had a tremendous impact upon global agriculture. His breeding work in maize increased the corn yields per acre to the tune of 25–50% and made possible the production of seed capable of thriving under various soil and climatic conditions. In 1909, Nils Heribert-Nilsson, a geneticist and professor of botany at the University of Lund in Southern Sweden, published a paper demonstrating how results between crosses, or hybrids, yielded plants that outperformed either parent. This concept later came to be known as hybrid vigor, which formed the foundation of today’s hybrid crop production programs.

Commercial production of corn hybrids was accomplished by the efforts of Donald Forsha Jones of the Connecticut Agricultural Experiment Station who made the “double cross” in maize involving four inbred lines. The double cross enabled the breeder to balance his inbred lines in such a way that the desirable traits outweighed the undesirable. Foundation inbred lines were developed for greater adaptability. Thus, though Shull developed his first hybrids before 1910, commercial production of them did not begin until 1922 when the corn hybrids were adopted in all the developed countries of the world. In 1925, Charlie Gunn and Tom Roberts established the first hybrid corn-breeding program and within a decade developed hybrids having 35% more yield.

### 2.3 Conventional Breeding

The foundations of conventional breeding depend on the following parameters:

(a) The primary and secondary gene pools available at the disposal of the breeder, i.e., presence of large amount of diversity in the germplasm at hand

(b) Adoption of a suitable breeding methodology using Mendelian and quantitative genetics approaches for an efficient selection

Initially the screening of available diversity was based primarily on phenotypic evaluation and different selection methods suitable for different crops. However, methods of crop improvement have significantly changed since passage of time. Initial breeding methodologies involved selection (mass selection and pure line
selection) and remained popular until the 1930s for most crops. Thereafter, hybridization captured the imagination of the breeders in the 1930s with extensive utilization by maize breeders. The commercial development of double cross hybrids in maize was followed by the extensive utilization of single crop hybrids since the 1960s. Several new selection techniques like pedigree, bulk, and backcross methods were also developed that were specifically tailored for self-pollinating crops. These scientific advances in conventional plant breeding led to “Green Revolution,” which played a major role in feeding the developing world.

2.4 Goals of Plant Breeding

The plant breeder aims for an ideal plant that has maximum number of desirable characteristics. These characteristics may include enhancement in yield, quality enhancement, resistance to biotic and abiotic stresses, modification of specific traits, greater adaptability, and even aesthetic appeal. Thus the breeder rarely focusses his attention on any one trait but must take into account the manifold characters that make the plant more useful in fulfilling the purpose for which it is grown. The main goals of plant breeding are the following:

2.4.1 Higher Yield

The ultimate objective of agronomists and plant breeders is to improve the yield of crop plants. It may be in the form of grain yield, fodder field, fiber yield, tuber yield, cane yield, or oil yield depending upon the plant species (Table 2.1).

It can be achieved by developing more efficient genotypes, e.g., hybrid varieties of maize, sorghum, bajra, etc. For example, hybrid corn has been extremely popular among the US farmers due to immense improvement in grain yield. Corn production showed a sudden increase in yield as well as rates with the introduction of single crosses around the 1930s. The introduction of double-crossed varieties led to an increase of about 1 bushel per acre per year. The annual increase was almost 2 bushels per acre with single crosses. By the year 2000, the yields were about five times higher than what they were in the pre-hybrid days.

2.4.2 Better Quality

Quality parameters differ from crop to crop and determine its price and suitability for diverse uses. Some of the quality parameters in different crops have been provided below:

- Wheat and rice: grain color and size, milling and baking quality
- Barley: malting quality
<table>
<thead>
<tr>
<th>Trait</th>
<th>Plant</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield</td>
<td><em>Hordeum vulgare</em> <em>Oryza sativa</em></td>
<td>Mühleisen et al. (2013)</td>
</tr>
<tr>
<td></td>
<td><em>Triticum sp.</em></td>
<td>Tiwari et al. (2011); Jiang et al. (2016); Hossain et al. (2017)</td>
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<td></td>
<td><em>Zea mays</em></td>
<td>Kant et al. (2001); Whitford et al. (2013)</td>
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<td></td>
<td></td>
<td>Duvick (2001, 2005); Raymond et al. (2009); Torres Flores et al. (2017)</td>
</tr>
<tr>
<td>Foliage/fodder yield</td>
<td><em>Sorghum</em></td>
<td>Naeem et al. (2002); Hassan and Mohammed (2015)</td>
</tr>
<tr>
<td></td>
<td><em>Amaranthus</em></td>
<td>Bhargava et al. (2004); Shukla et al. (2010a, 2010b)</td>
</tr>
<tr>
<td></td>
<td><em>Chenopodium album</em></td>
<td>Bhargava et al. (2006, 2007a, 2008)</td>
</tr>
<tr>
<td></td>
<td><em>Chenopodium quinoa</em></td>
<td>Bhargava et al. (2007b)</td>
</tr>
<tr>
<td>Fiber yield</td>
<td><em>Cannabis sativa</em></td>
<td>Small and Marcus (2002)</td>
</tr>
<tr>
<td></td>
<td><em>Crotalaria juncea</em></td>
<td>Tripathi et al. (2013)</td>
</tr>
<tr>
<td></td>
<td><em>Gossypium hirsutum</em></td>
<td>Zeng et al. (2011)</td>
</tr>
<tr>
<td></td>
<td><em>Hesperaloe</em></td>
<td>McLaughlin (1996)</td>
</tr>
<tr>
<td></td>
<td><em>Hibiscus cannabinus</em></td>
<td>Bahtoee et al. (2012)</td>
</tr>
<tr>
<td></td>
<td><em>Linum usitatissimum</em></td>
<td>Kenaschuk (1975); Sankari (2000), Liu et al. (2013)</td>
</tr>
<tr>
<td>Tuber yield</td>
<td><em>Curcuma longa</em></td>
<td>Anandaraj et al. (2014), Bahadur et al. (2016)</td>
</tr>
<tr>
<td></td>
<td><em>Dioscorea alata</em></td>
<td>Sartie and Asiedu (2014)</td>
</tr>
<tr>
<td></td>
<td><em>Ipomoea batatas</em></td>
<td>Gasura et al. (2008)</td>
</tr>
<tr>
<td></td>
<td><em>Solanum tuberosum</em></td>
<td>Melito et al. (2017)</td>
</tr>
<tr>
<td>Fruit yield</td>
<td><em>Annona squamosa</em></td>
<td>Girwani et al. (2011)</td>
</tr>
<tr>
<td></td>
<td><em>Capsicum annuum</em></td>
<td>Sood and Kumar (2010)</td>
</tr>
<tr>
<td></td>
<td><em>Carica papaya</em></td>
<td>Muthulakshmi et al. (2007)</td>
</tr>
<tr>
<td></td>
<td><em>Cucumis melo</em></td>
<td>Pandey et al. (2010)</td>
</tr>
<tr>
<td></td>
<td><em>Morus alba</em></td>
<td>Vijayan et al. (2012)</td>
</tr>
<tr>
<td></td>
<td><em>Phoenix dactylifera</em></td>
<td>Gros-Balthazard (2013)</td>
</tr>
<tr>
<td></td>
<td><em>Prunus persica</em></td>
<td>Scorza and Pooler (1999)</td>
</tr>
<tr>
<td></td>
<td><em>Psidium guajava</em></td>
<td>Negi and Rajan (2007)</td>
</tr>
<tr>
<td>Oil yield</td>
<td><em>Brassica campestris</em></td>
<td>Jönsson (1977); Kumar et al. (2015)</td>
</tr>
<tr>
<td></td>
<td><em>Brassica juncea</em></td>
<td>Chauhan et al. (2002)</td>
</tr>
<tr>
<td></td>
<td><em>Citrus sp.</em></td>
<td>Nesumi and Matsumoto (2003); Khan et al. (2017)</td>
</tr>
<tr>
<td></td>
<td><em>Helianthus annuus</em></td>
<td>Neanova and Georgiev (2012); Dimitrijevic and Horn (2017)</td>
</tr>
<tr>
<td></td>
<td><em>Linum usitatissimum</em></td>
<td>Grauda et al. (2008); Cullis (2011)</td>
</tr>
<tr>
<td></td>
<td><em>Mentha sp.</em></td>
<td>Patra et al. (2001); Dwivedi et al. (2004)</td>
</tr>
<tr>
<td></td>
<td><em>Ocimum basilicum</em></td>
<td>Lal (2014)</td>
</tr>
<tr>
<td></td>
<td><em>Santalum album</em></td>
<td>Rughkla et al. (2006)</td>
</tr>
</tbody>
</table>
• Cotton: clean, strong, longer, and fine fiber; lower fiber neps, seed coat fragments, organic trash, and microdust
• Cereals: higher lysine content
• Fruits and vegetables: nutritive value and longer shelf life
• Oil seeds: higher oil content, fatty acid composition
• Sugarcane and sugar beets: higher sugar content
• Fruits: appealing flavor

Table 2.2 provides some examples of quality improvement in some crops for different parameters.

2.4.3 Disease and Insect Resistance

Crop plants are attacked by a range of pathogens and pests resulting in considerable yield loss. Resistance has been defined as the “inherent capacity of a plant to prevent or restrict the entry or subsequent activities of a pathogenic agent when the plant is exposed, under suitable environmental conditions, to sufficient inoculum of a pathogen to cause disease.” Flor (1956) was the first to put forward a “gene-for-gene” hypothesis while working on linseed rust caused by *Melampsora lini* which stated that for each resistance gene (R) in the host, there is a specific gene conditioning pathogenicity (Avr) in the pathogen. There are two types of resistances known in plants, viz., horizontal and vertical resistance. Horizontal resistance, first described by J.E. Van der Plank and known by various names as generalized, quantitative, durable, and polygenic resistance, is controlled by polygenes, with a continuous variation in level of resistance (quantitative expression) as a consequence. Horizontal resistance does not protect the plant from infection but slows down the spread of the disease by retarding the development of individual loci of infection on a plant. The

<table>
<thead>
<tr>
<th>Crop</th>
<th>Achievement</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>β-Carotene</td>
<td>Njoku et al. (2011)</td>
</tr>
<tr>
<td>Common bean</td>
<td>Iron</td>
<td>Welch et al. (2000)</td>
</tr>
<tr>
<td>Cotton</td>
<td>Fiber quality</td>
<td>Constable et al. (2014)</td>
</tr>
<tr>
<td>Hot pepper</td>
<td>Color, shape, storage ability</td>
<td>Yoon et al. (1999)</td>
</tr>
<tr>
<td>Maize</td>
<td>Protein quality</td>
<td>Tandzi et al. (2017)</td>
</tr>
<tr>
<td></td>
<td>Oil content</td>
<td>Dudley (1973)</td>
</tr>
<tr>
<td>Rice</td>
<td>Higher protein</td>
<td>Govindaswami and Ghosh (1974)</td>
</tr>
<tr>
<td>Safflower</td>
<td>Oil quality</td>
<td>Hamdan et al. (2008)</td>
</tr>
<tr>
<td>Soybean</td>
<td>Higher protein</td>
<td>Brim and Burton (1979)</td>
</tr>
<tr>
<td></td>
<td>Flavor improvement</td>
<td>Davies et al. (1987)</td>
</tr>
<tr>
<td>Tomato</td>
<td>β-carotene</td>
<td>Kohler et al. (1947)</td>
</tr>
<tr>
<td>Wheat</td>
<td>Protein quality</td>
<td>Johnson and Mattern (1978)</td>
</tr>
</tbody>
</table>
expression of horizontal resistance increases as plant matures, and it is efficient against all races of the pathogen. Contrastingly, vertical resistance is considered to be controlled by one or a few genes and provides a discontinuous variation in the level of resistance. Vertical resistance is also known as race-specific, monogenic, oligogenic, or qualitative resistance. Vertical resistance confers complete but non-permanent protection, whereas horizontal resistance provides incomplete but permanent protection.

Successful breeding programs for disease resistance depend mainly on the two factors, viz., a good source of resistance and an efficient and dependable disease test. Hybridization and selection are the key methods for raising disease-free plants through conventional breeding methods. Apart from this, other modern techniques involve use of mutations, somaclonal variants, and genetic engineering.

Breeding for resistance has the following steps:

- Identification of genotypes that may be inferior in other traits but contains genes for disease resistance
- Crossing this undesirable genotype with a superior but disease-susceptible variety
- Growth of the hybrid so formed in a disease-conducive setting that includes pathogen inoculation
- Selection of disease-resistant genotypes that retain desirable traits such as yield along with disease resistance

### 2.4.4 Abiotic Stress Tolerance

Abiotic stress has been defined as an environmental condition that reduces the growth, survival, and/or fecundity of plants. Crop plants suffer from abiotic factors like cold, frost, hail, drought, salt, UV radiation, and heavy metals that severely influence plant development and crop productivity (Fig. 2.6).

Abiotic stresses adversely affect growth and productivity and induce numerous morphological, physiological, biochemical, and molecular changes in plants. The abovementioned stressful conditions cause yield losses ranging from about 50%, for potato, to about 80%, for sorghum or wheat. Of these, drought and soil salinity are the major causes reducing crop productivity and hence food production worldwide. Since the amelioration of crop environment is an improbable task, breeding of crop varieties resistant to environmental stresses is the most effective method to improve and stabilize yield under stressful conditions. The objective of the plant breeder is to develop resistant varieties for stressful conditions. Crop resistance to various environmental stresses has been improved by conventional breeding methods that involve the stability of yield performance over different environments as a major criterion. In India, varieties of rice such as USAR 1, USAR 2, and CSIR 10 have been developed that can tolerate salt stress. The Central Soil and Salinity Research Institute (CSSRI), Karnal, India, has bred KRL 1–4 of wheat that can be cultivated over saline tracts.
Another major goal of plant breeding is the development of photosensitive and thermosensitive varieties that permits their cultivation in new areas. An example of such a variety is CO 36 in rice that was developed in 1973 at Tamil Nadu Agricultural University, India, by hybridization between IR-8 X CO 32.

**2.4.6 Early Maturity**

Early maturity of crop reduces management period, pesticide spray, duration of stress period, yield losses, and production cost and facilitates double cropping. Development of wheat varieties suitable for late planting has permitted rice-wheat rotation. Wheat cultivation in South Asia provides an excellent example where early maturity is of immense importance in increasing production. Wheat is grown in the Indian subcontinent as a winter crop and is harvested at the onset of summers. The high-temperature stress in South Asia has been categorized into terminal high-temperature stress where the high-temperatures stress occurs during grain filling.

stages, and continual high-temperature stress, where high-temperature stress persists across the wheat growing season. Therefore, the development of high-yielding early maturing lines adapted to high-temperature stress was a priority area for South Asia. The Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) breeding programs developed some high-yielding early maturing lines wherein earliness favored the plants to escape terminal high-temperature stress and also promoted an efficient utilization of available resources under continual high-temperature stress to achieve higher grain yield.

### 2.4.7 Synchronous Maturity

Synchronous maturity refers to maturity of a crop species at a time. Uneven maturity and maturation lead to low-yield potential and low harvest index (HI) especially in crops like *Vigna radiata* (Mung) where several pickings are necessary.

### 2.4.8 Non-shattering Character

Shattering is the dispersal of a crop’s seeds upon their becoming ripe and is essential for the propagation of their offspring in wild plants. However, being a major cause of yield loss, shattering is an undesirable process from the agricultural perspective and has been selected against during the domestication process of distinct crops. From a domestication point of view, retention of mature seeds or fruit on a cultivated plant allows harvesting of the entire yield at the same with minimal loss and spoilage from dropped seed or fruit. Shattering is a serious problem in legumes like *Glycine max* (soybean), *Vigna radiata* (mung), and *Vigna mungo* (urad) and causes severe yield losses. Since reducing shattering is an important objective in classical plant breeding, genes for non-shattering have been introduced in several crops to achieve this goal (Table 2.3).

### 2.4.9 Seed Dormancy

Seed dormancy has been defined as the inability of a viable seed to germinate under favorable conditions. Seed dormancy is desirable in crops such as green gram, black gram, barley, and pea where seeds germinate in the standing crop before harvesting if moisture is available. Pre-harvest sprouting in wheat leads to massive losses in yield as well as downgrading of grain quality resulting in substantial financial losses to farmers and food processors. Therefore, a period of dormancy would check losses due to germination. Similarly in safflower, a short duration of seed dormancy at harvest prevents sprouting of seeds and is a major objective in safflower breeding. In some other cases, however, it may desirable to remove dormancy.
Table 2.3  Breeding for non-shattering trait

<table>
<thead>
<tr>
<th>Crop</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Avena sativa</em></td>
<td>Clarke (1981)</td>
</tr>
<tr>
<td><em>Brassica napus</em></td>
<td>Prakash and Chopra (1988); Morgan et al. (2000)</td>
</tr>
<tr>
<td><em>Brassica juncea</em></td>
<td>Wang et al. (2007)</td>
</tr>
<tr>
<td><em>Carum carvi</em></td>
<td>Van Roon and Bleijenberg (1964)</td>
</tr>
<tr>
<td><em>Fagopyrum esculentum</em></td>
<td>Wang et al. (2005); Suzuki et al. (2012)</td>
</tr>
<tr>
<td><em>Glycine max</em></td>
<td>Tsuchiya (1986)</td>
</tr>
<tr>
<td><em>Hordeum vulgare</em></td>
<td>Clarke (1981)</td>
</tr>
<tr>
<td><em>Lotus corniculatus</em></td>
<td>Peacock and Wilsie (1957); Grant (1996)</td>
</tr>
<tr>
<td><em>Sinapis alba</em></td>
<td>Wang et al. (2007)</td>
</tr>
<tr>
<td><em>Sorghum</em></td>
<td>House (1985)</td>
</tr>
<tr>
<td><em>Vicia sativa</em></td>
<td>Abd El-Moneim (1993)</td>
</tr>
<tr>
<td><em>Vigna unguiculata</em></td>
<td>Mohammed et al. (2009)</td>
</tr>
<tr>
<td><em>Zizania aquatica</em></td>
<td>Elliott and Perliger (1977)</td>
</tr>
<tr>
<td><em>Zizania palustris</em></td>
<td>Everett and Stucker (1983)</td>
</tr>
</tbody>
</table>

2.4.10  Determinate Growth

Genotypes are classified into two categories of stem growth habit viz. indeterminate and determinate types. In indeterminate types, the apical meristems at the stem and branch apices maintain vegetative activity until photosynthate demand by developing seeds causes a cessation in the production of vegetative dry matter. Contrastingly, the apical meristems in determinate types cease vegetative activity at or soon after photoperiod-induced floral induction, after which the meristems become reproductive inflorescences. From a breeding perspective, development of varieties with determinate growth is desirable in crops like cotton, pigeon pea and mung. In cotton, breeding and selection has favored short stature, more determinant cotton varieties leading to higher yields. In grain amaranth, breeding objective has been to develop short stature lines since normally amaranth germplasm lacks uniformity with varied height of individual plants.

2.4.11  Removal of Toxic Compounds

Some crops are reported to have toxic substances that are a threat to humans and limit their uses.

So, it is an important objective of breeders to develop varieties free from toxic substances to make them safe for human consumption. Some of the breeding objective to remove toxic compounds in specific crops is provided below:

(i) Removal of neurotoxin 3-(-N-oxayl)-L-2,3-diaminopropionic acid (ODAP) and β-(N)-oxalyl-amino-L-alanine acid (BOAA), from *Lathyrus sativus* which causes irreversible paralysis of the lower limbs in human and the four limbs in
animals (commonly known as lathyrism). Breeders aim to eliminate the toxic substance by careful selection and through hybridization between low and high toxin varieties.

(ii) Removal or lowering of erucic acid from *Brassica* species for edible consumption. Erucic acid is harmful for human health and is associated with cardiovascular disorders like myocardial lipidosis and heart lesions, respiratory issues, diarrhea, anemia, cancer, and death in severe cases. Low erucic acid plants for edible purpose have been developed from an interspecific hybrid between *B. juncea* and *B. rapa*. The Commonwealth Scientific and Industrial Research Organization (CSIRO) variety Siromo was developed from a cross between Domo and Zem and had low erucic acid content that helped in the establishment of a cold-pressed mustard seed oil industry by the Yandilla Mustard Oil Enterprise at Wallendbeen, New South Wales, in 1989.

(iii) Lowering the terpenoid aldehydes, namely, gossypol, from cotton seed to make them fit for human consumption since gossypol is toxic to nonruminant animals, including humans.

### 2.5 The Green Revolution

One of the major challenges of science has been to feed the ever-increasing human population and rescue humans from famines and food scarcity. The Green Revolution, a term coined by William Gaud of the US Agency for International Development (USAID) in 1968, marks the period between 1960 and 1980 when a remarkable increase in the production of wheat and rice was achieved primarily in wheat and rice by development of high-yielding varieties (HYVs) at the International Corn and Wheat Improvement Center (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines. This was made possible by the efforts of the Rockefeller and Ford foundations along with the diligent leadership of Dr. Norman E. Borlaug (Box 2.1) who is known as the “father of the Green Revolution.”

CIMMYT and IRRI played an important role in the development of semidwarf HYVs of wheat and rice, which were the main reasons behind the success of the Green Revolution. The wheat and rice varieties that were in cultivation prior to the Green Revolution were tall and leafy and had weak stems. On application of high doses of nitrogenous fertilizers, these varieties grew excessively tall, lodge, gave less yield, and had a harvest index of 0.3, which meant that the ratio of grain to straw was 30:70. These varieties produced a biomass of 10–12 t/ha, with maximum yield potential being 4 t/ha. However, the semidwarf varieties of wheat and rice had a harvest index of 0.5 which meant that their total biomass potential was 20 t/ha and hence their maximum yield potential was 10 t/ha.

The most significant impact of the Green Revolution was observed in South Asian countries, namely, India, Pakistan, and the Philippines, during 1960–1970, and in China after 1980. The Green Revolution provided a quantum leap forward in food production by application of fertilizers, pesticides, and irrigation that created
Norman Ernest Borlaug (1914–2009), an American agronomist and “father of the Green Revolution,” was born on a farm near Cresco, Iowa, USA. After completing his primary and secondary education in Cresco, Borlaug, he enrolled in the University of Minnesota where he studied forestry and obtained his Bachelor of Science degree in 1937. Thereafter he worked for the US Forestry Service at stations in Massachusetts and Idaho later returning to the University of Minnesota to study plant pathology. He received the master’s degree in 1939 and the doctoral degree in plant pathology and genetics from University of Minnesota in 1942.

In 1944 he was appointed as a geneticist and plant pathologist and assigned the task of coordinating the Cooperative Wheat Research and Production Program in Mexico which was a joint undertaking by the Mexican government and the Rockefeller Foundation. This program involved coordinated scientific research in genetics, plant breeding, plant pathology, entomology, agronomy, soil science, and cereal technology. For the next 16 years, he worked to solve a series of wheat production problems that were limiting wheat cultivation in Mexico and to help train a whole generation of young Mexican scientists. In 1964, he was made the director of the International Wheat Improvement Program at El Batán, Texcoco, as part of the newly established Consultative Group on International Agricultural Research’s International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maíz y Trigo, or CIMMYT).

His stay in Mexico not only had a profound impact on Dr. Borlaug’s life and philosophy of agriculture research and development but also on agricultural production. Dr. Borlaug developed several wheat varieties with broad and stable disease resistance, broad adaptability across many degrees of latitude, and high yield. The new wheat varieties heralded a pioneer agricultural revolution and transformed agricultural production in Mexico during the (continued)
conditions in which high-yielding varieties could thrive. Green Revolution led to a tremendous increase in food grain production with world cereal yields jumping from 1.4 tonnes per hectare in the early 1960s to 2.7 tonnes per hectare in 1989–1991. There was a 2.53-fold increase in world cereal production during 1961–2006. In India, the production of cereals increased from 70 million tonnes in 1961 to 186 million tonnes during 1961–1999, while in China, an increase from 91 million tonnes to 390 million tonnes during the same period was observed. This enormous increase in yield helped avert a major food crisis in Asia and provided an impetus for rapid economic development in the Indian subcontinent, China, and Southeast Asia.

### 2.6 Modern Plant Breeding

Classical breeding techniques had limitations like sexual incompatibility and the long time to develop a variety using selection and hybridization. The development of a new variety by conventional plant breeding techniques like selection and hybridization took about 5–12 years, starting from inbred production and then hybridization and selection of F₁ hybrids. The issue of pre-fertilization and post-fertilization sexual barrier also limited the benefits that could have accrued from conventional breeding methods. The advent of molecular biology and biotechnology provided an impetus to plant breeding and the genetic improvement of plants. The publication of Mendel’s monumental work in 1866, the elucidation of the DNA structure by James D. Watson and Francis H.C. Crick in 1953, and the cracking of the genetic code illuminated the future breeding path. Breeding showed a transition from an art developed by the cultivators to a discipline driven by scientific methodology. Mendel’s conclusions that the traits of the parents are not transferred randomly to the progenies opened up new avenues in plant breeding and were used by the plant breeders for furthering their goals. Mendel’s laws of inheritance enabled the breeders to combine beneficial traits of different parent plants more rapidly and efficiently than before. The discovery of restriction endonucleases and recombinant DNA technique has enabled the specific identification, isolation, and alteration of
genes and their transfer into other organisms to produce transgenic varieties. There has been a successful transition of conventional plant breeding into molecular breeding that has enhanced the pace of crop improvement. Plant breeders selectively identify phenotypes and genotypes that are associated with traits of interest by utilizing genetic and molecular techniques. Advances in the omics sciences, viz., genomics, proteomics, transcriptomics, and metabolomics, have enabled the plant breeders to efficiently utilize and manipulate the available germplasm.

### 2.7 Molecular Breeding

The era of plant biotechnology began in the early 1980s when transgenic plants were produced using the Gram-negative, non-sporing, motile, rod-shaped bacterium *Agrobacterium tumefaciens* that causes the crown gall disease in a wide range of dicotyledonous plants by transferring part of its DNA to the plant, which integrates into the plant’s genome, causing the production of tumors. *Agrobacterium* has a wide host range with transformation occurring in fungi, yeast, ascomycetes, basidiomycetes, gymnosperms, dicotyledons, and monocots. Most of the genes involved in the crown gall disease are not borne on the chromosome of the bacteria but on extrachromosomal body termed as the Ti (tumor-inducing) or rhizogenic (Ri) plasmid (Fig. 2.7). This Ti or Ri plasmid is 200 to 800 kbp in length and integrates into the plant nuclear genome. The transferred DNA (T-DNA), referred to as the T-region, is about 10–30 kbp in length and usually represents less than 10% of the Ti plasmid. In *Agrobacterium*-mediated transformation, the T-DNA of *Agrobacterium* excises and integrates into the plant genome as part of the natural infection process by this bacterium. So, any desired gene of interest inserted into the T-DNA will also be integrated.

*Agrobacterium* is considered as the “natural genetic engineer,” and its ability to transfer DNA to plant cells has been extensively utilized in plant genetic engineering. In spite of the fact that many economically important plant species or elite varieties remain highly recalcitrant to *Agrobacterium*-mediated transformation, transgenic plants have been produced since the early 1980s using this microbe. Selected genes are engineered into the T-DNA of the bacterial plasmid in laboratory which become integrated into the plant chromosomes when the T-DNA is transferred. With the passage of years, this technique has been improvised resulting in extending the host range of the bacterium to economically important crop species.

### 2.8 Molecular Markers

Molecular marker systems, based on the nucleotide sequences, were developed to create high-resolution genetic maps and exploit genetic linkage between markers and important crop traits. These markers overcome the problems faced in conventional breeding. The first DNA-based genetic markers were restriction fragment length polymorphisms (RFLPs) in 1980 which were utilized for the construction of
first linkage map in tomato in 1986 with only 56 loci. After the introduction of PCR technique, numerous DNA marker systems based on it were developed, like random-amplified polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs), microsatellites or simple sequence repeats (SSRs), and single nucleotide polymorphisms (SNPs) (Fig. 2.8).

DNA markers are more reliable than either morphological or biochemical markers due to their abundance and their origin, i.e., arising from different classes of DNA mutations such as substitution mutations (point mutations), rearrangements (insertions or deletions), or errors in replication of tandemly repeated DNA.
An ideal DNA-based marker should have the following qualities:

(i) High level of polymorphism, i.e., they should show differences between individuals of same or different species (Fig. 2.9)
(ii) Codominant, i.e., marker should differentiate between homozygotes and heterozygotes
(iii) High reproducibility
(iv) Even distribution across the whole genome
(v) Low or null interaction among the markers that enables the simultaneous use of many markers in a segregating population
(vi) Cost-efficient
(vii) Easy detection and automation

There are three categories of molecular markers:

(i) Hybridization-based markers: An example of such a marker is RFLP which is based on the differential hybridization of cloned DNA to DNA fragments in a sample of restriction enzyme-digested DNAs. RFLP was initially used for human genome mapping in 1980 and thereafter for plant genomes.
(ii) Polymerase chain reaction (PCR)-based markers: These make use of the PCR technique developed by Kary Mullis in 1983. Examples of these markers are the RAPD, AFLP, SSR, chloroplast microsatellites (cpSSRs), randomly amplified microsatellite polymorphisms (RAMP), and intersimple sequence repeat (ISSR).
(iii) Sequence-based markers: These comprise the single nucleotide polymorphism (SNP) that were developed by the introduction of the DNA sequencing technologies like next-generation sequencing (NGS) and genotyping by sequencing (GBS) resulting in high polymorphism.
Another grouping of molecular markers is based on their abilities of showing homozygosity (dominant marker) or heterozygosity (codominant marker). Table 2.4 gives a comparative account of the characteristics of the commonly used DNA-based markers.

During the last two decades, the use of DNA markers in plant breeding has resulted in extensive mapping experiments utilized in genetic improvement of plants through marker-assisted breeding.

Fig. 2.9 Monomorphic and polymorphic markers. (Reprinted by permission from Springer Nature: An introduction to markers, quantitative trait loci (QTL) mapping and marker-assisted selection for crop improvement: the basic concepts, Collard BCY, Jahufer MZZ, Brouwer JB, Pang ECK, Euphytica, 142:169–196, 2005)
Table 2.4 A comparative account of the different molecular markers used in crop improvement (Nadeem et al. 2018)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>RFLP</th>
<th>RAPD</th>
<th>AFLP</th>
<th>ISSR</th>
<th>SSR</th>
<th>SNP</th>
<th>DArT</th>
<th>Retrotransposons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Codominant/dominant</td>
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<td>Codominant</td>
<td>Codominant</td>
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<td>Reproducibility</td>
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<td>Medium-High</td>
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<td>Polymorphism level</td>
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<td>Very high</td>
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<td>Required DNA quality</td>
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<td>High</td>
<td>Low</td>
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<td>Low</td>
<td>Low</td>
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</tr>
<tr>
<td>Required DNA quantity</td>
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<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
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</tr>
<tr>
<td>Marker index</td>
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<td>High</td>
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<td>Medium</td>
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<tr>
<td>Genome abundance</td>
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<td>Medium</td>
<td>Very high</td>
<td>Very high</td>
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<tr>
<td>Cost</td>
<td>High</td>
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<td>High</td>
<td>High</td>
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<tr>
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<td>No</td>
<td>No</td>
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<td>No</td>
</tr>
<tr>
<td>Status</td>
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<td>Past</td>
<td>Past</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>PCR requirement</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Visualization</td>
<td>Radioactive</td>
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<td>Agarose gel</td>
<td>Agarose gel</td>
<td>Agarose gel</td>
<td>SNP-VISTA</td>
<td>Microarray</td>
<td>Agarose gel</td>
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<tr>
<td>Required DNA (ng)</td>
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<td>500–1000</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50–100</td>
<td>25–50</td>
</tr>
</tbody>
</table>
2.9 Marker-Assisted Breeding

Plant breeders face the daunting task of continually developing new crop varieties that are superior to the existing ones. Conventional breeding relies on phenotypic selection of superior genotypes within segregating progenies obtained from crosses. However, these and other phenotyping procedures face difficulties like genotype x environment (G X E) interactions, high cost, time constraint, and unreliability for particular traits. In this context, biotechnology has gained rapid strides in the last few decades and has been at the forefront to maximize the probability of success in genetic improvement of plants. The DNA marker technology, derived from research in molecular genetics and the omics technologies, offers immense scope for plant breeding. Foolad and Sharma (2005) defined marker-assisted selection (MAS) as selection for a trait based on genotype using associated markers rather than the phenotype of the trait. MAS, which allows for a breeding approach based on the genotype of plants rather than only phenotype, has turned into an important tool which has increasingly been utilized in varying degrees by plant breeders, breeding companies, and research institutions for the development of improved varieties. MAS avoids the difficulties associated with conventional phenotype-based breeding techniques by changing the selection criteria toward selection of genes. Molecular markers are not affected by the environment and are detectable in all developmental stages of the plant. The successful application of molecular markers to plant breeding programs relies on the following factors:

- A genetic map with molecular markers linked to the major gene(s) of interest or QTLs
- Strong association between the markers and the major gene(s) or QTLs
- Recombination between the markers associated with the trait(s) of interest and the rest of the genome
- Possibility of analyzing a large number of individuals in a time and cost-effective manner

Some of the important schemes used for MAS have been provided below:

(i) Marker-assisted backcrossing (MABC)
(ii) Gene pyramiding
(iii) Marker-assisted recurrent selection (MARS)
(iv) Genomic selection

However, one should not blindly assume that breeding based on molecular markers is always superior to phenotypic selection, which for some characters may be as effective and efficient as MAS. The application of MAS requires careful prioritization of traits or specific genes of economic importance for which DNA markers are to be sought and options for phenotypic selection.
2.10  QTLs and Plant Breeding

The vast majority of the economically important traits are of quantitative nature where the phenotypic expression displays continuous variation attributable to simultaneous segregation of many genes within the genome and this can be measured quantitatively. A quantitative trait locus (QTL), a term coined by Gelderman, is a region of DNA which is associated with a particular phenotypic trait. Also many QTLs are associated with a single phenotypic trait. Thus, QTL may be a single gene or a cluster of linked genes that affect a particular trait. QTLs came to prominence on the realization that if molecular genetics were to contribute to the long-term improvement of crop species, then geneticists needed to focus on the improvement of quantitative traits. QTLs require a suitable mapping population generated from phenotypically contrasting parents, a saturated linkage map based on molecular markers, reliable phenotypic screening of mapping population, and appropriate statistical packages to analyze the genotypic information in combination with phenotypic information for QTL detection. With the advances in molecular genetics, it has now become possible to identify QTL and their relative location in the genome by placing them on genetic maps using statistical methods such as single-marker analysis or interval mapping that shows the association between the quantitative trait phenotype and one or more DNA markers located on a map (Fig. 2.10). This is termed as QTL mapping. QTL mapping is known to be affected by the number of genes controlling the target trait(s) and their genome positions, genetic effects and genetic interactions, heritability of the trait, number of genes segregating in a mapping population, type and size of mapping population, density and coverage of markers in the linkage map, and statistical methodology employed and the significance level used for QTL mapping.

Thus, QTL mapping has become a powerful tool for elucidating the genetic architecture of quantitative traits and provides a strong impetus to marker-assisted selection in breeding programs. QTLs have been used for the mapping of yield, disease resistance, abiotic stresses, and domestication-related traits (Table 2.5).

However QTL mapping is dogged by limitations that include less allelic diversity, lower number of recombination events, being time-consuming in case of mapping population development, and specificity of the detected QTLs to a given population.

2.11  Marker-Assisted Breeding: Success Stories

Marker-assisted selection has been spectacularly utilized in several crop species of diverse utility. During the initial stages of breeding, the DNA-based marker data has been harnessed in ascertaining the identity of cultivars, assessment of genetic diversity, and confirmation of hybrids that was hitherto done on visual selection and morphological analysis. Markers like SSR and STS have been used to confirm the true identity of individual plants which is easier than growing the plant to maturity.
and assessing morphological and floral characteristics. The use of DNA markers has enabled efficient selection of the parental lines for crossing experiments. In hybridization programs, measurement of genetic distance based on DNA markers facilitates the prediction of yields of crosses between germplasm lines from the same group. MAS has also been successfully utilized in the transfer of a single target region in several plant genomes where expression of a trait is regulated by a single gene. Another important area of success has been the incorporation of one or more alleles of interest from a wild relative into an elite cultivar.

Among the major applications, the most spectacular utilization of DNA markers has been carried out in backcrossing which is known by the term “marker-assisted

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**Fig. 2.10** The role of QTLs in marker-assisted selection. (Reprinted with permission from Collard and Mackill 2008)
### Table 2.5  Applications of QTLs in crop improvement

<table>
<thead>
<tr>
<th>Crop</th>
<th>Trait improvement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grain crops</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>Salinity tolerance</td>
<td>Xue et al. (2009)</td>
</tr>
<tr>
<td></td>
<td>Resistance to stripe rust</td>
<td>Visioni et al. (2018)</td>
</tr>
<tr>
<td>Maize</td>
<td>Drought tolerance</td>
<td>Ribaut et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Yield and earliness</td>
<td>Barrière et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Downy mildew resistance</td>
<td>George et al. (2003)</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>Drought tolerance</td>
<td>Sehgal et al. (2015)</td>
</tr>
<tr>
<td></td>
<td>Grain mineral content</td>
<td>Kumar et al. (2018a)</td>
</tr>
<tr>
<td>Rice</td>
<td>Drought stress</td>
<td>Kumar et al. (2018b)</td>
</tr>
<tr>
<td></td>
<td>Mineral biofortification</td>
<td>Zhang et al. (2018)</td>
</tr>
<tr>
<td></td>
<td>Salinity tolerance</td>
<td>Batayeva et al. (2018)</td>
</tr>
<tr>
<td>Wheat</td>
<td><em>Fusarium</em> head blight resistance</td>
<td>Pumphrey et al. (2007)</td>
</tr>
<tr>
<td></td>
<td>Seed size and shape</td>
<td>Williams and Sorrells (2014)</td>
</tr>
<tr>
<td></td>
<td>Water stress</td>
<td>Onyembaobi et al. (2018)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Nitrogen stress</td>
<td>Gelli et al. (2017)</td>
</tr>
<tr>
<td>Zoysia grass</td>
<td>Salt tolerance</td>
<td>Guo et al. (2014)</td>
</tr>
<tr>
<td><strong>Fruits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apple</td>
<td>Fruit firmness and softening</td>
<td>Costa et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Fruit quality</td>
<td>Sun et al. (2015)</td>
</tr>
<tr>
<td></td>
<td>Scab resistance</td>
<td>McClure et al. (2018)</td>
</tr>
<tr>
<td>Grapes</td>
<td>Weight and soluble solid content</td>
<td>Zhao et al. (2015)</td>
</tr>
<tr>
<td></td>
<td>Downy mildew resistance</td>
<td>Divilov et al. (2018)</td>
</tr>
<tr>
<td>Peach</td>
<td>Brown rot resistance</td>
<td>Martínez-García et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>Reproductive phenology</td>
<td>Romeu et al. (2014)</td>
</tr>
<tr>
<td>Pear</td>
<td>Harvest time and fruit skin color</td>
<td>Yamamoto et al. (2014)</td>
</tr>
<tr>
<td></td>
<td>Skin color</td>
<td>Xue et al. (2017)</td>
</tr>
<tr>
<td>Strawberry</td>
<td>Fruit quality</td>
<td>Castro and Lewers (2016)</td>
</tr>
<tr>
<td></td>
<td>Flowering habit and fruit quality</td>
<td>Verma et al. (2017)</td>
</tr>
<tr>
<td><strong>Fiber crops</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>Fiber strength</td>
<td>Yang et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>Salt tolerance</td>
<td>Diouf et al. (2017)</td>
</tr>
<tr>
<td></td>
<td>Verticillium wilt</td>
<td>Yang et al. (2018a)</td>
</tr>
<tr>
<td>Jute</td>
<td>Fiber quality</td>
<td>Topdar et al. (2013)</td>
</tr>
<tr>
<td></td>
<td>Fiber yield traits</td>
<td>Tao et al. (2017)</td>
</tr>
<tr>
<td><strong>Legumes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickpea</td>
<td>Pod number</td>
<td>Das et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>Drought tolerance</td>
<td>Sivasakthi et al. (2018)</td>
</tr>
<tr>
<td>Common bean</td>
<td>White mold resistance</td>
<td>Soule et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>Bacterial blight resistance</td>
<td>Viteri et al. (2014)</td>
</tr>
<tr>
<td></td>
<td>Anthracnose disease</td>
<td>Choudhary et al. (2018)</td>
</tr>
<tr>
<td>Cowpea</td>
<td>Pod shattering, increased organ size</td>
<td>Lo et al. (2018)</td>
</tr>
<tr>
<td></td>
<td>Root-knot nematode resistance</td>
<td>Santos et al. (2018)</td>
</tr>
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</table>

(continued)
backcrossing” wherein three levels have been described by Collard and Mackill (2008) (Fig. 2.11):

Table 2.5 (continued)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Trait improvement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lentil</td>
<td>Earliness and plant height</td>
<td>Tullu et al. (2008)</td>
</tr>
<tr>
<td></td>
<td>Seed weight and seed size</td>
<td>Verma et al. (2015)</td>
</tr>
<tr>
<td>Mung bean</td>
<td>Seed starch</td>
<td>Masari et al. (2017)</td>
</tr>
<tr>
<td>Pea</td>
<td>Nitrogen nutrition</td>
<td>Bourion et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Root rot</td>
<td>Desgroux et al. (2018)</td>
</tr>
<tr>
<td>Pigeon pea</td>
<td>Plant type and earliness</td>
<td>Kumawat et al. (2012)</td>
</tr>
</tbody>
</table>

**Vegetables**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Trait improvement</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell pepper</td>
<td>Fruit size</td>
<td>Chunthawodtiporn et al. (2018)</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Head splitting resistance</td>
<td>Su et al. (2015)</td>
</tr>
<tr>
<td>Chinese cabbage</td>
<td>Leaf morphology and color</td>
<td>Choi et al. (2017)</td>
</tr>
<tr>
<td>Carrot</td>
<td>Root anthocyanin</td>
<td>Cavagnaro et al. (2014)</td>
</tr>
<tr>
<td></td>
<td>Volatile compounds</td>
<td>Keilwagen et al. (2017)</td>
</tr>
<tr>
<td>Cucumber</td>
<td>Aphid resistance</td>
<td>Liang et al. (2016)</td>
</tr>
<tr>
<td>Tomato</td>
<td>Enhanced flavor</td>
<td>Fulton et al. (2002)</td>
</tr>
<tr>
<td></td>
<td>Fruit quality</td>
<td>Lecomte et al. (2004)</td>
</tr>
<tr>
<td></td>
<td>Water and salinity stress</td>
<td>Diouf et al. (2018)</td>
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**Ornamentals**

<table>
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<tr>
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<tbody>
<tr>
<td>Petunia</td>
<td>Scent production</td>
<td>Klahre et al. (2011)</td>
</tr>
<tr>
<td></td>
<td>Flower traits</td>
<td>Cao et al. (2018)</td>
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<tr>
<td>Sunflower</td>
<td><em>Sclerotinia</em> head rot resistance</td>
<td>Zubrzycki et al. (2017)</td>
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<td>Water stress</td>
<td>Kiani et al. (2008)</td>
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**Miscellaneous**

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<tbody>
<tr>
<td>Peanut</td>
<td>Spotted wilt disease</td>
<td>Zhao et al. (2018)</td>
</tr>
<tr>
<td>Radish</td>
<td>Clubroot resistance</td>
<td>Kamei et al. (2010)</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>Pod number</td>
<td>Ye et al. (2017)</td>
</tr>
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<td>Sugarcane</td>
<td>Orange rust resistance</td>
<td>Yang et al. (2018b)</td>
</tr>
<tr>
<td>Walnut</td>
<td>Anthracnose resistance</td>
<td>Zhu et al. (2015)</td>
</tr>
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</table>

**Fig. 2.11** Levels of selection during marker-assisted backcrossing. A hypothetical target locus is indicated on chromosome 4. (a) Foreground selection, (b) recombinant selection, and (c) background selection. (Reprinted with permission from Collard and Mackill 2008)
(i) Foreground selection: markers can be used in combination with or to replace screening for the target gene or QTL.

(ii) Recombinant selection: selection of backcross progeny with the target gene and recombination events between the target locus and linked flanking markers.

(iii) Background selection: selections of backcross progeny with the greatest proportion of recurrent parent (RP) genome, using markers that are unlinked to the target locus.

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Abstract

Green Revolution was a huge success that spearheaded agricultural research for several decades and played an important role in feeding the world by significantly increasing food production mainly in the developing countries. However, in spite of immense turnaround in productivity through Green Revolution, conventional plant breeding has done little to improve the life of subsistence farmers across continents. Formal breeding programs have primarily catered the well-off farmers, and the poor farmers have not reaped the desired benefits. The poor and marginal farmers of the developing countries are faced with problems like inequitable land distribution, insecure ownership, fragmentation of holdings, inadequate irrigation, poor credit facilities, improper marketing, and slow growth of allied sectors remained aloof from this spectacular phenomenon. Participatory plant breeding (PPB) is the development of a plant breeding program in collaboration between breeders and farmers, marketers, processors, consumers, and policymakers. In PPB, farmers and researchers work in tandem with farmers taking a lead role in the design, implementation, and evaluation of the breeding material. The chapter discusses at length the different forms of farmers’ participation in crop improvement.

3.1 Introduction

Initially thought to be a panacea for agricultural ills, the Green Revolution revolutionized plant breeding and crop production and remained in the limelight for many decades. Green Revolution spearheaded the agricultural research for quite some time and played an important role in feeding the world by significantly increasing productivity of food crops notably rice, wheat, corn, and some food legumes. The Green Revolution led to a decrease in food prices for the consumers worldwide and especially for the poor populations since they spend a greater share of their income
on food. If the food supplies post Green Revolution had not increased by 12–13%, then the world food prices would have been 35–65% higher. In spite of this spectacular success, much needs to be done with respect to food security. It is estimated that for stable crops, a minimum target linear yield increase of 1.1% per annum is needed to bring process under control. Table 3.1 shows the population and growth in demand and supply of aggregated crop products across six world typologies, namely, sub-Saharan Africa, West Asia-North Africa, Populous Asia, Green Europe, Russia Plus, and New World. The sub-Saharan Africa and West Asia-North Africa regions have witnessed enormous demand that has been mainly fulfilled by the New World and Russia Plus.

Table 3.1  Population, and growth in demand, and supply of aggregated crop products (expressed as wheat equivalents in mass, based on food energy content) across world typologies ranked by decreasing yield gaps and generally increasing cropping intensification

<table>
<thead>
<tr>
<th>Typology</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>0.89</td>
<td>0.49</td>
<td>3.86</td>
<td>0.67</td>
<td>0.22</td>
<td>1.00</td>
<td>7.13</td>
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<td>West Asia-North Africa</td>
<td>2.75</td>
<td>1.86</td>
<td>1.05</td>
<td>0.10</td>
<td>0.10</td>
<td>1.02</td>
<td>1.20</td>
</tr>
<tr>
<td>Populous Asia</td>
<td>3.57</td>
<td>2.43</td>
<td>1.71</td>
<td>0.18</td>
<td>0.59</td>
<td>1.22</td>
<td>1.58</td>
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<tr>
<td>Green Europe</td>
<td>280</td>
<td>224</td>
<td>1514</td>
<td>455</td>
<td>174</td>
<td>872</td>
<td>3519</td>
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<tr>
<td>Russia Plus</td>
<td>Per cap Consumption 2012, Mt</td>
<td>314</td>
<td>454</td>
<td>392</td>
<td>679</td>
<td>809</td>
<td>872</td>
</tr>
<tr>
<td>New World</td>
<td>Supply factors</td>
<td>Production 2012, Mt</td>
<td>239</td>
<td>115</td>
<td>1414</td>
<td>405</td>
<td>225</td>
</tr>
<tr>
<td>Net imports 2012, Mt</td>
<td>41</td>
<td>109</td>
<td>100</td>
<td>50</td>
<td>−51</td>
<td>−258</td>
<td></td>
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<tr>
<td>Net imports as % consumption 2012</td>
<td>15</td>
<td>49</td>
<td>7</td>
<td>11</td>
<td>Exporters</td>
<td></td>
<td></td>
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<tr>
<td>Crop area change 2001–2014, % p.a.</td>
<td>2.51</td>
<td>−1.86</td>
<td>0.98</td>
<td>−0.37</td>
<td>1.02</td>
<td>1.23</td>
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<tr>
<td>New arable land availability</td>
<td>+++</td>
<td>nil</td>
<td>nil</td>
<td>nil</td>
<td>++</td>
<td>++</td>
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</tr>
<tr>
<td>Crop yield change 2001–2014, % p.a.</td>
<td>0.96</td>
<td>1.57</td>
<td>1.73</td>
<td>1.05</td>
<td>1.80</td>
<td>1.51</td>
<td>1.39</td>
</tr>
<tr>
<td>Crop production change 2001–2014, % p.a.</td>
<td>3.26</td>
<td>−0.01</td>
<td>2.58</td>
<td>0.70</td>
<td>2.73</td>
<td>2.60</td>
<td>2.34</td>
</tr>
<tr>
<td>Current FY 2012, t/ha</td>
<td>1.44</td>
<td>2.01</td>
<td>3.26</td>
<td>5.06</td>
<td>2.34</td>
<td>4.14</td>
<td>3.23</td>
</tr>
<tr>
<td>Yield gap, % FY</td>
<td>200–400</td>
<td>100–300</td>
<td>50–100</td>
<td>20–40</td>
<td>50–75</td>
<td>30–50</td>
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Reprinted from Field Crops Res, Vol 222, Fischer RA, Connor DJ, Issues for cropping and agricultural science in the next 20 years, 121–142, 2018, with permission from Elsevier
The crop area increases are also high globally but cannot sustain without deteriorating the environment. The economically optimal crop varieties developed by a breeder through conventional breeding programs are very effective in homogenous farming systems, but their performance is limited in more complex and risk-prone environments.

### 3.2 Limitations of Conventional Plant Breeding

Conventional plant breeding has been at the core of genetic improvement of plants since centuries and has had tremendous impact on agricultural productivity over the last decades. Breeders play the most important role in the highly centralized classical breeding right from breeding objectives based on a set of priority traits, choice of germplasm, breeding methodologies, and verifying their performances. However, in spite of immense turnaround in productivity conventional plant breeding has several limitations and has done little to improve the life of subsistence farmers across continents. Some of the shortcomings of conventional plant breeding are provided below.

#### 3.2.1 Non-connectivity with Ground Reality

In several developing countries, the environments in experiment station-based national breeding programs that were quite restricted in agroclimatic conditions did not fully represent those areas where many resource-crunched poor cultivators carried out their living. At times the breeders do not have enough resources to carry out extensive multi-locational trail of varieties covering all possible environments. This results in release of varieties that are inadequate to fulfill the varied needs of farmers. It is also true that these varieties show differential performance under farmers’ management practices which is different from the results obtained under researchers’ management practices. Thus, in many instances these formal breeding programs although successful when the crop is grown in ecologically homogenous environments do not fully address the actual needs and preferences of the cultivators.

#### 3.2.2 Limited Beneficiaries

Conventional breeding has generally benefitted the resource-rich farmers who provide inputs in their farms to modify their environment making the land suitable for high-yielding varieties. However, enormous small-scale/subsistence farmers facing financial crunch cannot afford the high-priced inputs like costly seeds, chemical fertilizers, and pesticides to get the desired output. Therefore, in developing countries there are patches of prosperity in the ocean of prosperity.
3.2.3 Limited Role of Actual Stakeholders

Although plant breeders are experts in the theory and practice of crop improvement techniques, they are less frequently in touch with the farmers and do little to elicit structured feedback from them. This may not always be the case, as some breeders constantly visit farms and talk to farmers about the performance of different varieties. However, most of the times, the information about farmers’ varietal preferences is collected in an informal and haphazard manner from a miniscule nonrepresentative sample of respondents. This results in selection for non-optimal combination of traits and defeats the very motive of breeding since the traits considered important by the plant breeders do not correspond with the traits desired by the farmers in a target area.

3.2.4 Persistence of Poverty and Food Insecurity

The relationship between agricultural productivity growth and poverty initially suggested that increase in crop productivity reduced the number of poor people. However, since Green Revolution was primarily based on intensification of agriculture in favorable environments, its contribution to poverty reduction was quite low in the marginal areas, for example, the rainfed regions in South Asia which were the slowest to benefit resulting in widening interregional disparities and high incidence of poverty. The poor and marginal farmers of the developing countries faced problems like inequitable land distribution, insecure ownership, fragmentation of holdings, inadequate irrigation facilities, poor credit facilities, less subsidies, improper marketing, and slow growth of allied sectors. All the abovementioned factors had a bearing on the success of Green Revolution.

3.2.5 Nutrient Availability

Improved availability and decreased staple food prices in the developing countries led to diet diversification and a significant improvement in the calorie uptake by the poor. Nutritional gains from the Green Revolution have been lopsided and have been in favor of the rich. In spite of increase in the overall calorie consumption by the poor people, dietary diversity in this group has decreased leading to prevalence of micronutrient malnutrition. In many countries, the traditional crops that were important sources of micronutrients like vitamins and minerals were replaced by higher-value staple crops. One good example of this is the replacement of conventional leafy vegetables by rice monoculture systems in the Philippines which has resulted in reduced availability of micronutrients to the marginal farmers. Likewise, the spiraling prices of pulses in India has resulted in the decline in pulse consumption among the poor populations.
3.2.6 Environmental Issues

In spite of several benefits, the environmental effects of Green Revolution have been quite alarming. Green Revolution has been associated with burning issues like decline in soil fertility, soil erosion, increased soil toxicity, diminishing water resources, degradation of groundwater, and underground water resources. There have also been reports of the presence of residues of fertilizers and pesticides like nitrates, organochlorines, organophosphates, synthetic pyrethroids, and carbamates at higher level than permissible limit in a range of edible items like vegetables, fruits, milk, dairy products, fodder, and livestock feeds.

3.2.7 Greater Incidence of Diseases

Green Revolution led to development and farming of genetically uniform varieties derived from a limited number of elite lines that tended to be uniform and resulted in a narrow genetic base for the crop. This increased homogeneity offers significant advantages both in terms of the quantity and quality but has also increased susceptibility of the crop to different pathogens. Along with this the large-scale cultivation of these genetically uniform varieties has led to a rapid increase in the genetic vulnerability of many crop species leading to severe consequences. Two factors are critical and interact to enhance the chances for crop failure:

1. The degree of uniformity for the trait controlling susceptibility to the pathogen or environmental stresses
2. Monoculture of the susceptible variety

Greater homogeneity and monoculture of the crop over extensive areas pose a greater threat of disaster since the developed varieties have a narrow genetic base that leads to genetic vulnerability. In a genetically uniform population (varieties developed through plant breeding), no individual has relative reproductive advantage over the others since they are genetically uniform, and no genetic change is expected as far as there is no mutational change in race of the pathogen, the environment, and/or the host itself. The replacement of landraces with improved varieties which reduces the genetic variation is also a major cause of genetic erosion. Farmers using modern varieties specialize in monocultures that facilitate the spread, multiplication, and evolution of pests and diseases throughout the crops. A glaring example of this is the Irish famine caused by the fungus *Phytophthora infestans*, a coenocytic oomycetes and an obligate parasite considered as a near-biotrophic pathogen with a limited host range. The fungus causes irregularly small lesions at the beginning which later turn brown (Fig. 3.1 a, b). The famine occurred between 1845 and 1851 when the potato crop in Ireland was ravaged by *P. infestans* since the potato varieties grown by the farmers had no resistance to the leaf blight disease. The Irish famine led to the death of about a million people and emigration of another million to other areas.
Another example of such an outbreak is the brown leaf spot of rice that led to a serious famine leading to a mortality of about two million people in Bengal in 1943. This disease was caused by Bipolaris oryzae (basionym, Helminthosporium oryzae) (Fig. 3.2), a fungus classified in the subdivision Deuteromycotina (imperfect fungi), class Deuteromycetes, and order Moniliales. The pathogen attacks the coleoptile, leaves, leaf sheath, panicle branches, glumes, and spikelets forming numerous big spots on the leaves which can kill the whole leaf (Fig. 3.3).

Once the pathogen infects the seed, unfilled grains, or spotted or discolored seeds are formed. In 1970, southern corn leaf blight caused by the fungus Bipolaris maydis in the United States resulted in withered plants, broken stalks, and malformed or completely rotten cobs that were covered in a grayish powder. This was due to the plantation of the Texas cytoplasmic male sterile (Tcms) corn which was highly susceptible to a new type (race) of the pathogenic fungus B. maydis race T. Corn production decreased by about 25% in the southern states of the United States with yield losses reaching as high as 50–100% in some areas. Some recent examples include losses of about 95% of the taro crop in Samoa due to taro leaf blight caused by Phytophthora colocasiae, emergence of Ug99 races of the stem rust fungus which is a major threat to wheat production and invasion of the vineyards in California by a new biotype of phylloxera, the pale yellow sap-sucking insects affecting the root system of vines.

Thus, unidirectional and lab-centered conventional plant breeding has not been able to address the complex problems of resource-deficient farmers due to diverse and complex socioeconomic and agroecological conditions.
Fig. 3.2 *Bipolaris oryzae* (MFLUCC 10–0715, MFLUCC 10–0733). (a) Surface view of infected seeds. (b) Conidiophores and conidia. (c–e) Conidiophores. (f–m) Conidia. (n) Bipolar germination of the conidia. Scale bars: A, 500 μm; B, 200 μm; C, 10 μm; D–N, 5 μm. (Reprinted with permission from Manamgoda et al. 2014)
Participation, in simple terms, refers to “an act of taking part in an event or activity.” Sarah White (1996) has described four forms of participation.

(i) Nominal participation: serves as a visible demonstration of the implication of local beneficiaries in a project, which justifies the project to its institutional creators (top-down) and gives a sense of inclusion to the beneficiaries (bottom-up).

(ii) Instrumental participation: incorporation of beneficiary in-kind contributions to a project (work, materials, etc.) to make it more efficient for funders. In this case the beneficiaries have an inherent interest in active involvement in such a project because it helps them to secure the resources offered by the funders.

(iii) Representative participation: allows the beneficiaries to guide a project by expressing their interests and hence ensures project sustainability to funders.

(iv) Transformative participation: empowers beneficiaries through their participation in decisions and actions, which is a goal shared by the top-down originators of such projects, who also undergo a transformation in their perception and relationship of power vis-a-vis the local partner. These abovementioned categories of participation are dynamic with the project’s institutional actors and its local participants changing their attitudes, priorities, and actions with passage of time.

According to Bishnu Raj Upreti of the Nepal Centre for Contemporary Research (NCCR), participation is a “multi-dimensional, dynamic process of contributing, influencing, sharing, or redistributing power and of control, resources, benefits, knowledge, and skills to be gained through beneficiaries’ involvement in decision-making.” Participatory plant breeding (PPB) is the development of a plant breeding program in collaboration between breeders and farmers, marketers, processors, consumers, and policymakers (food security, health and nutrition, employment).
3.4 Terminology

The terminology with respect to participatory plant breeding is intriguing and includes many commonly used interchangeably terms like:

(i) Collaborative plant breeding (CPB)
(ii) Farmer participatory breeding (FPB)
(iii) Participatory crop improvement (PCI)

Participatory crop improvement is sometimes categorized into two areas.

(i) Participatory varietal selection (PVS): where one works on pre-existing varieties or stabilized materials (though at times a suitable pre-existing variety may not exist).
(ii) Participatory plant breeding (PPB): this involves creation of new varieties in breeding programs by collaborative efforts of plant breeders and farmers.

All the abovementioned models described above refer to the multifaceted technical and organizational collaboration in plant breeding by scientists and the end users, i.e., the farmers.

3.5 Brief History of Participatory Plant Breeding

The concept of PPB has its origin since the 1950s when it was observed that several areas of the world did not reap the fruits of modern plant breeding due to lack of resources. In New Mexico, the US Department of Agriculture could not replace the low-yielding traditional corn variety used by the local farmers with a high-yielding hybrid variety due to its peculiar taste, texture, and color. Thereafter several interdisciplinary approaches like farming systems research and the farmer-back-to-farmer model were introduced for incorporating the experience of the cultivator in breeding research including the necessary feedback at every stage. The rationale for this approach is based on the fact that most of the farmers tend to adopt new agricultural technologies when they are a part of the decision-making process. This is more true for resource-deficient farmers who have varied needs that are seldom addressed by plant breeders since the institutional breeding process is more tilted toward development of varieties suited for large commercial farms. However, it was soon realized that such a model considered the farmers as research subjects rather than actual collaborators. The wheat and rice varieties bred at CIMMYT and IRRI prior to the Green Revolution were distributed by agencies to farmers but only some of them benefited from the same, while others were left out because they were unable to adopt the new methods of seeding, fertilizing, and irrigating required to achieve high yields with these varieties. There was a growing realization among the researchers that systematic research was not serving the needs of the marginal farmers and thus evolved the approach of participatory breeding wherein the
anthropologists, cultivators, and the breeders joined hands and reoriented the plant breeding research to cater the needs of the small farmers. In the mid-1970s, the International Potato Center (CIP), a research center of the Consultative Group on International Agricultural Research (CGIAR), based in Lima, Peru, decided to actively incorporate farmer’s knowledge in the breeding of crops to achieve the desired mission. Soon, other CGIAR centers like the International Rice Research Institute (IRRI) in the Philippines, International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria, the International Center for Tropical Agriculture (CIAT) in Colombia, and the International Institute of Tropical Agriculture (IITA) in Nigeria joined in to adopt this new breeding methodology. Besides this, a large group of agricultural laboratories of individual countries, non-governmental organizations, and farmers’ organizations started testing and utilizing participatory models with success. The procedure of testing a range of advanced breeding germplasm lines on cultivator’s fields and incorporating their feedback was quite simple yet effective. The studies included breeding of rice varieties in rainfed areas of India, bush bean and cassava varieties in Columbia, and bean varieties in Rwanda. With respect to the Rwandan trials, it can be safely said that the farmer-selected varieties outperformed local mixtures 64–89% of the time, while the breeder-selected varieties did so only 34–53% of the time. The terms participatory varietal selection (PVS) and participatory plant breeding (PPB) were first used in a 1995 workshop hosted by Canada’s International Development Research Center (IDRC). The concept of the Participatory Research and Gender Analysis (PRGA) was introduced in 1996, and in the year 2000, PPB become an integral part of each CGIAR center’s plant breeding programs.

3.6 Objectives of Participatory Plant Breeding

Participatory plant breeding has the following objectives:

- Increase production and profitability of crop production through the development and enhanced adoption of suitable, usually improved, varieties
- Provide benefits to a specific type of user or to deliberately address the needs of a broader range of users
- Build farmer skills to enhance farmer selection and seed production efforts

A number of accessory objectives of PPB include the following:

- Enhancing biodiversity and germplasm conservation
- Developing adapted germplasm especially for the disadvantaged user groups (e.g., women, poor farmers)
- Make breeding programs more cost efficient that targets more niches especially through decentralization of programs
3.7 Activities Included in PPB

PPB can include a wide array of activities some of which are enumerated below:

(i) Role in the identification of the breeding objectives
(ii) Generating genetic variability (includes the provisioning of genotypes to be included in breeding program)
(iii) Selection within diverse populations to develop experimental varieties
(iv) Evaluation of the experimental varieties
(v) Release of variety
(vi) Popularization of the newly developed variety among the farmers
(vii) Seed production

A critical factor in PPB is the point of control or decision-making, i.e., who decides the objectives, determines the approach, and specifies what results and data are needed? This pivotal role in decision-making differs depending on whether farmers are invited by breeders to join breeding programs, research initiated by formal programs, or whether breeders seek to support farmers’ own systems of breeding, varietal selection, and seed multiplication and dissemination.

Table 3.2 shows the comparison between conventional and participatory plant breeding approaches.

3.8 Types of PPB

Based on the degree of farmer’s participation and according to the stage of involvement, PPB has been variously classified. Morris and Bellon (2004) describe a number of approaches to participatory plant breeding based upon the stages of participation of the farmers in breeding process (Fig. 3.4).

<table>
<thead>
<tr>
<th>Table 3.2 Comparison of conventional and participatory plant breeding</th>
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<tr>
<td>Conventional breeding</td>
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<tr>
<td>Carried out by trained personals termed “breeders”</td>
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<tr>
<td>Centralized operational structure</td>
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<tr>
<td>Takes place under laboratory or controlled environments</td>
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<tr>
<td>Focusses on “broad adaptability” or the capacity of a genotype to produce high yields over a range of environments</td>
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<tr>
<td>Selection and testing is done by breeders; farmers may be incorporated at a later stage</td>
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<tr>
<td>Final output is officially released varieties</td>
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From the perspective of participation, PPB encourages two types of participation:

(A) **Functional Participation**

Plant breeders direct their research as per the needs of the specific groups of farmers since the physical and economic resource bases of different groups necessitate tailored research approaches. Farmers play an important role in the breeding process by assuring the plant breeders that they are assessing tradeoffs among traits correctly. This form of participation facilitates production of varieties under real-life environments and results in greater adoption of innovation by the farmers. On-farm research can be managed by the breeder and/or farmer.

(B) **Empowering Participation**

This entails increasing the skills and knowledge of the farmers to enable their active participation in the collaborative breeding efforts along with their personal efforts.

Another classification is institutional and is based on how the scientists and cultivators will share the responsibility, the work, and the benefits of a joint plant breeding effort. According to this classification, two main institutional approaches have been described:

(A) **Formal-led PPB**

In this the farmers join in breeding experiments which have been initiated by researchers as formal breeding programs. Plant breeders are required to feed...
the information back to the formal research sector with full authenticity in the form of replicability and the validity of the results. Formal-led PPB programs are expected to complement the formal plant breeding research by having strong linkages to formal variety release and seed production systems. The breeders also need to prove the advantages of PPB vis-a-vis conventional breeding approaches.

(B) Farmer-led PPB
This entails support of scientists for farmers’ own systems of breeding, varietal selection, and seed maintenance. Farmers establish breeding objectives and bear the main responsibility for selecting germplasm, conducting experiments, seed multiplication, and its dissemination. Farmer-led PPB provides varieties that suit specific environment and local preferences with less of broader applicability. Farmer-led PPB is more oriented toward a specific group with no obligation either to feedback information for wider geographical extrapolation, nor for formally releasing varieties for other target groups.

PPB can also be categorized into two types, viz., consultative and collaborative approaches (Fig. 3.5).

The approach used in a particular area depends on the type of crop and the availability of resources.

(A) Consultative: farmers select the progenies in breeder’s plots.
In this type the farmers are consulted at virtually every stage like in formulation of the breeding objectives, choosing the suitable parents, and in selection from breeder’s material. Thus, the farmers are consulted after a product is developed for them by the breeders.

(B) Collaborative: farmers grow and select in segregating materials in their fields. Farmers are involved in breeding programs at an early stage, grow the variable PPB material in their fields, and finally select the best performing plants from
the material. Thereafter, the breeders obtain seed from farmers to test their selections in experimental stations and participatory trials.

Thus, the PPB methodologies are known to vary significantly on the basis of project’s resources and goals with the intention of involving the farmers in the breeding process at various points of varietal development (Fig. 3.6).

### 3.9 On-Farm Trials

Participatory on-farm evaluation forms an important component of PPB since farmers take a lead role in the design, implementation, and evaluation on the breeding material. These on-farm trials permit an association of farmers and researchers who work in tandem in technology development. The breeder gets first-hand information about the farmers’ requirement and their innovations which enable the breeder to initiate new research based primarily on the basis of particular biophysical or socio-economic circumstances. On-farm trials are also important in the evaluation of agronomic recommendations under a wide range of environments which are often different from the conditions of the experimental stations. This also provides a realistic assessment of the financial implications at actual field conditions since labor and equipment costs differ from those used at experimental conditions. On-farm trials also provide valuable information to the breeder about the constraints faced by
the farmers and their preferences enabling him to address the specific needs of the farmers through the breeding process. On-farm trials are of the following types (Table 3.3):

(i) Trials designed and managed by researchers
(ii) Trials designed by researchers and managed by the farmers
(iii) Trials designed and managed by farmers

### 3.10 Genotype x Environment Interaction Effects

A major problem that confronts the breeder is the association between selection environment and target environment. In conventional breeding the number of target environments usually outnumbers the number of selection environments since a released variety is cultivated over a wide area. Therefore, it has been observed that direct selection in the target environment (or similar environment) is usually most effective, and the selection efficiency reduces as the selection environment becomes different from the target environment probably due to the presence of genotype × environment interactions (GEI). GEI is defined as the inability of the same genetic material to achieve the same performance in different environments. There are two major approaches for studying GEI and adaptation.

(i) **Parametric or empirical approach**: which involves relating observed genotypic responses to a set of environmental conditions. The parametric measures of stability hold good under certain statistical assumptions and are less likely to perform well if these assumptions are violated.
(ii) **Nonparametric or analytical clustering approach:** which defines environments and phenotypes relative to biotic and abiotic factors. The nonparametric measures cluster genotypes according to their similarity of response to a range of environments. The nonparametric measures have many advantages over the parametric measures that include reduction of bias caused by outliers, easy interpretation, and less variation of estimates on addition/deletion of one or few genotypes.

Formal breeding takes a negative approach toward GEI since the breeder selects only breeding lines with low G × E interaction resulting in high average yield across locations and years. Other lines that show differential performance, i.e., good performance at some sites and poor performance at others are discarded. This is critical for some environments since lines with good performance in unfavorable sites and poor response in favorable conditions lead to low preference and disuse of such lines in breeding programs. However, these breeding lines would certainly be suitable for farmers practicing agriculture in unfavorable locations.

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4.1 Introduction

Participatory plant breeding (PPB) is considered to be highly client oriented since it amalgamates the experiences of farmers and researchers and is suited for breeding new varieties of crops for use by smallholders with low inputs for organic or low-external-input farming systems and is appropriate for selecting cultivars for marginal agroecologies. PPB is considered as a suitable means to overcome the limitations of classical breeding since it treats the farmers as partners and allows them to decide which varieties are more appropriate for them by having a better say during the selection progress. Participatory breeding has given a new hope for the
rural communities by giving the farmers greater control over their livelihoods and provides an opportunity for the people living near subsistence levels to break out of the vicious circle of poverty.

4.2 When Is Participatory Plant Breeding Desirable or Preferred?

A logical question arises as to under which conditions is PPB preferred? Some conditions tend to develop the interest of the cultivators in the breeding process. These play a critical role in his participation along with formal breeders in genetic improvement of crops. Some of such factors have been provided below:

(i) PPB is highly desirable in situations where farmers are generally less served by formal breeding programs. For example, many modern varieties show little potential in unfavorable or heterogeneous regions like cultivation on acidic or saline soils. It is also preferred in cases when poor infrastructure prevents seed or other agricultural inputs from reaching the farmers. PPB is the first choice when the targeted region has specific local requirements or when the priorities of the cropping system differ greatly from that normally targeted by conventional breeding programs.

(ii) PPB is generally resorted to when factors support innovation, e.g., situations where novel combinations of traits are desired or where a certain crop is of immense economic importance or where detailed ethnobotanical knowledge are in existence about a crop.

(iii) The presence of abundant genetic diversity that is perceptible not only to the breeder but also the farmer offers potential that can be manipulated through PPB. PPB also seems to be more successful in case of self-pollinated crops like cereals since maintenance is easier in such crops.

(iv) Finally PPB is most desirable in the case of most minor/underutilized crops which have witnessed very less research activity during the green revolution period.

4.3 Advantages of Participatory Plant Breeding

PPB offers numerous advantages over conventional breeding programs. Some of them have been enumerated below:

4.3.1 Saves Time

Greatly increase the speed of adoption of varieties (saving at least 7 years) and hence increase the benefits from the research. According to the World Development Report, PPB and plant varietal selection accelerates the varietal development and
dissemination to 5–7 years, which is almost half the 10–15 years required in conventional plant breeding programs. Thus, within a short time, appropriate materials are incorporated into farmers’ fields which accelerate adoption and seed dissemination, thus improving research efficiency.

4.3.2 Improving Farmer Seed Systems and Seed Provision to Small-Scale Farmers

Weltzien and Vom Brocke (2001) have defined farmer seed systems as the ways in which farmers produce, select, save, and acquire seeds. A healthy seed system comprises of four essential features:

(a) Maintains a wide germplasm base providing diversity, flexibility, and a strong base for selection
(b) Produces high-quality seeds that are vigorous, are free of diseases, and have high germination rates
(c) Ensures adequate availability of seeds and their efficient distribution through markets, social networks, and other agencies
(d) Efficient availability and sharing of knowledge and information about the seed like their growth requirement, utilization, and knowledge of new materials

During the ancient history of agriculture, seed selection was always a farmer-centric activity that was carried out as an integral part of crop production and without any functional specialization. This slow process carried on over generations and played an important role in the domestication of plants from their wild ancestors. However, the introduction of formal plant breeding programs resulted in a progressive separation between crop improvement and the farming systems, i.e., transition occurred from a traditional “farmer breeder” approach toward research-based breeding in experimental farms. With respect to seed availability to the farmer, seed technologists play a critical role in improving the supply of new varieties and high-quality seed to the cultivators, thereby increasing their food security. Although the formal seed sector has taken rapid strides in providing seed for commercial agriculture, the requirement of the poor farmers in highly heterogeneous environment has not been fulfilled. In formal plant breeding programs, the formal public and/or private sector is required to make available seed of released varieties to the farmers (referred to as the “seed chain”) along with setting of the breeding objectives. In the formal seed sector, there are two distinct delivery channels from which farmers obtain their entire seed requirement (Fig. 4.1).

The first is the more systematic formal sector (often known as the primary or vertical delivery system) comprising public or private seed companies that undertake planned seed production, mechanical processing, and organized marketing and distribution. The second involves various informal mechanisms at the farm or community level. Both the channels supply varying proportions according to the varieties, crops, farming systems, and agroecology. The formal seed chain has been more
successful with big farmers practicing commercial agriculture. However, the small farmers who practice less commercial activity encounter the following difficulties:

(a) Breeding and selection of improved varieties which truly meet farmers’ needs. The products of PPB may include varieties similar to those developed by formal plant breeding programs, improved local varieties, and synthetic landraces.
(b) A low-cost production and marketing system which can provide seed of improved varieties at an affordable price.

Of the abovementioned pressing problems, the first one is automatically addressed by involvement of farmers. For the second aspect, once PPB generates good germplasm, efforts should be made for their widespread usage by systematic intervention through existing formal channels or new initiatives closer to the informal sector. In PPB the responsibility of seed production and distribution is left to the discretion of the cultivators through the informal channels, but often there is no clear obligation and accountability. PPB can be linked to the organized seed supply chain at local and formal levels. The dissemination of seeds through informal systems would also benefit numerous small-scale agricultural activities like input supply, product processing, or output marketing. In this context many researchers have advocated the formation of small seed enterprises (SSEs) wherein business-oriented individuals or farmers with entrepreneurial skills may be considered for seed production and marketing at the local level. These individuals should have access to early-generation seed and can be trained in seed production and marketing and encouraged to evolve into specialized, small- or medium-scale seed companies in the long run. The government intervention can be in the establishment of special systems of variety registration and multiplication to cope with PPB varieties which may not meet the normal registration criteria.
4.3.3 Enhancement of Biodiversity

Biodiversity is very important for survival of mankind. Agriculture can contribute significantly to the conservation and enhancement of biological and habitat diversity within an ecosystem. This is due to the fact that efficient management of vast tracts of land by the cultivators could lead to a significant impact on flora, fauna, and the environment. Negative interactions between farming and biodiversity are often associated with an intensification and local concentration of agricultural production. Intensive agriculture and excessive use of agrochemicals result in a significant decrease in biodiversity in the agricultural land. The loss of biological diversity in terms of cultivation of fewer varieties grown by farmers in farms is expected to have a strong impact on rural livelihoods and food security. The situation is compounded more for poor people who rely on agricultural products for 85–90% of their livelihood needs. An increase in biodiversity occurs if one variety partially replaces another or when several varieties replace a single variety. Biodiversity is also dependent on the extent of the range of cultivation of varieties, i.e., an ecosystem having a large proportion of area under cultivation of a single variety has less diversity and is more vulnerable to stresses than another ecosystem where varieties occupy nearly equal areas. The Food and Agricultural Organization (FAO) estimates that about 7000 species which is less than 3% of the quarter of a million plant species available are used in cultivation today. Thus, modern agriculture is like a huge inverted pyramid that rests on a precariously narrow base by using only a small number of varieties in intensive agriculture. This situation is quite alarming since this genetic erosion could threaten the future food supply if the effectiveness of the high-yielding varieties is reduced that is often the case when the resistance breaks in a host-pathogen relationship. There is mounting evidence to show that several traditional crops and cropping systems are at high risk today. Apart from this, numerous studies have revealed that the maintenance of agrobiodiversity is also integral to people’s cultural identities. An excellent example is the involvement of farmers and the utilization of their vast knowledge in Ethiopia to maintain sorghum landrace diversity, a crop native to this region.

The breeding approach based on PPB leads to the maintenance of more diverse, locally adapted populations which are cultivated by the farmers resulting in in situ conservation of crop genetic resources. Participatory breeding leads to an increase in genetic diversity (biodiversity) within the agricultural system due to the development and adoption of many different genotypes, each having specific adaptations to different regions of the cultivation. Farmers can play an important role in maintaining biodiversity by lending a helping hand in the in situ and ex situ conservation and by strengthening or improving seed production systems through mechanisms such as seed fairs and seed banks. International Development Research Centre (IDRC) started small programs in South Asia to help grassroots organizations and researchers working with cultivators to undertake applied research on the use of agricultural diversity – especially the wild herbs, medicinal plants, food crops, and livestock to meet the needs of rural households and environmental protection. These programs also encourage conservationists, plant breeders, and social scientists for exchange.
of ideas and dissemination of information among the formal and informal sectors for enhancing the sustainable use of agricultural diversity.

Participatory breeding methods are thought to increase the replacement rate of cultivars resulting in reduction of the average age of cultivars that would lead to greater biodiversity over a period of time. PVS reduces biodiversity when a single cultivar is grown over a wide area. However, in the long run when many farmers are exposed to more number of cultivars, the number of cultivars adopted will increase. Contrastingly, PPB leads to increase in varietal biodiversity under most circumstances. Table 4.1 compares the effect of PVS and PPB on biodiversity. PPB focuses on the development of varieties that are suited to extreme agroecological niches and thereby supports the development and maintenance of a more genetically diverse portfolio of varieties. The success of PPB should therefore be gauged by the number of novel varieties produced and used in the stressful environments rather than by the total number of hectares sown globally to a particular variety. Thus, PPB provides a platform for knowledge and skill generation in the conservation genetic resources and empowers the cultivators and rural institutions in biodiversity enhancement.

PPB also plays a pivotal role in maintaining the agrobiodiversity which includes the number of species and the number of varieties (races) cultivated (reared) in a production basin or on a farm and also encompasses all the wild species associated with domesticated ones. PPB appears to be a more sustainable strategy and can play a crucial role in dynamic management (DM) which is one of the strategic options available to manage crop and agrobiodiversity.

Dynamic management aims to conserve a reservoir of genetic variability rather than specific alleles at a locus or some cultivars that are already genetically fixed. It works on the principle of maintaining the context in which evolutionary forces can act on genetically diverse cultivated populations enabling them to adapt to changing climatic conditions, emerging diseases, and agricultural practices. Thus, the efficiency of DM relies on the conservation of a large number of populations, distributed over a large range of contrasting environments, maximizing the diversity in local selective pressures. DM is of the following two types:

- Experimental DM: Institution-led management program
- On-farm DM: Farmer-led management system

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Participatory varietal selection (PVS)</th>
<th>Participatory plant breeding (PPB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-cultivar variability</td>
<td>No effect</td>
<td>Increase</td>
</tr>
<tr>
<td>Number of cultivars in cultivation</td>
<td>Small increase in number of cultivars</td>
<td>Large increase in number of cultivars</td>
</tr>
<tr>
<td>Increase in cultivar number over large areas</td>
<td>Uniform impact</td>
<td>Variable impact</td>
</tr>
<tr>
<td>Breeding strategies</td>
<td>Unchanged: designed to produce finished cultivars</td>
<td>Changed: designed to favor increase in biodiversity</td>
</tr>
</tbody>
</table>

Table 4.1 Comparison of PVS and PPB’s impact on biodiversity
Farmers practicing on-farm DM are involved in a range of activities ranging from the maintenance of local varieties (on-farm conservation) to participatory plant breeding (on-farm PPB). It has been observed that the diversity (both phenotypic and molecular) conserved on farm is not a replica of that what is conserved in the gene banks but is both quantitatively and qualitatively different. The amount of diversity present in most on-farm populations has been found to be greater than that of the gene bank accessions, and the alleles present in the on-farm network are quite different than those present in the gene bank accessions. With reference to genetic variation, exchanges are essential and should exist between different entities for proper management of the germplasm (Fig. 4.2). The presence of diverse structures and organizations minimizes the risk of simultaneous loss of genetic resources in case of any eventuality.

Fig. 4.2 Schematic representation of the links between the three components managing plant genetic resources: gene banks, public and private breeding programs, and dynamic management/participatory breeding initiatives. (Reproduced from Enjalbert J, Dawson JC, Paillard S, Rhoné B, Rousselle Y, Thomas M, Goldringer I. Dynamic management of crop diversity: from an experimental approach to on-farm conservation. Comp Rendes Biologies 2011; 334:458–468. Copyright © 2011 Elsevier Masson SAS. All rights reserved)
4.3.4 Amelioration in Farmer’s Conditions

PPB enhances the farmers’ organizational and social capital, as well as individual farmers’ knowledge and skills and capacity to learn and experiment. It increases access of resource-deficient farmers to improved varieties and has a positive bearing on their productivity, nutrition, marketing, and incomes leading to a more resilient and sustainable farming system. Participatory approach enables rural communities to maintain germplasm as per their requirement and allows them to develop varieties according to their needs. Thus PPB empower groups that were “left out” in the conventional breeding process.

4.3.5 Improves Research Efficiency

PPB significantly enhances the cost-effectiveness of the breeding program and time-saving by simple changes in breeding methods, such as testing for grain quality before yield testing. Since PPB involves the breeding strategy with low cross number and high population size, it increases the cost-effectiveness and is quite attractive as compared to conventional breeding. However, this translation of success using PPB needs some time to percolate and need not necessarily lead to immediate success. This is best exemplified by a case study conducted during the ICARDA Barley Breeding program in Syria. Efficiency was defined as the number of high-yielding varieties identified by diverse approaches. The study showed that the breeder was more efficient than cultivators under high rainfall conditions but that farmers were more efficient under water-deficient regimes. A t-test of significant difference conducted showed that farmers’ selections were as high yielding as those made by the breeder. A comparison of participatory and non-participatory breeding in the same breeding population showed that incorporation of farmer input at the design stage (i.e., third year of the breeding program) resulted in a 3-year reduction in the breeding program. PPB made certified varieties available to the farmer by the sixth year as compared to ninth in the conventional breeding program.

Another case study relates to farmers’ participation in screening the entire pearl millet (*Pennisetum glaucum*) germplasm collection of about 1000 accessions from Namibia. Farmers, on the basis of their experience, recognized three major classes of germplasm with different clusters of desirable traits and assisted breeders to come up with the desired ideotype for the region. Breeders worked on the material in farmers’ fields, and this resulted in an increase in the frequency of the desired traits through introgression due to cross-pollinating nature of the crop. Thereafter, selection was practiced by the cultivators in the outcrosses to provide seed for the next crop cycle, and after about 4 years, breeders selected plants from the farmers’ field. The selected plants were intercrossed with 30 varieties selected by farmers from specially designed, elite, and morphologically diverse nurseries, to create a PPB composite population termed as Maria Kaherero Composite (MKC). MKC was far superior to the local germplasm and to another population Namibia
Composite 90 (NC 90), developed by conventional breeding in 1990 by random-mating eight varieties and two populations selected from the introductory nursery of SADC/ICRISAT SMIP breeding materials, plus a bulk of 14 Namibian germplasm lines. This experiment in Namibia brought out the fact that it was faster, less expensive, and more reliable to involve farmers directly in the development of germplasm for use in the breeding program.

### 4.3.6 PPB Accelerates Adoption

Farmers are quite apprehensive of any new variety, and this often results in low level of acceptability of new varieties by them. It was found that in Ethiopia, only 12 varieties of cereals, legumes, and vegetables were adopted by the farmers till 1997 against a release of 122 varieties. Similarly in Ghana bulk of the modern varieties (MVs) developed by the maize breeders had poor acceptance and were not widely adopted. However, the involvement of the farmers in filed traits and planning strategies resulted in an increase in the adoption of MVs to over two-thirds of Ghana’s maize farmers, and nearly 60% increase in yields. In Syria PPB-derived varieties became popular among the farmers who planted 69% more area to the varieties developed through PPB and obtained a 26% difference in yield between PPB and conventional varieties.

### 4.3.7 Natural Resource Management

Natural resource management refers to the sustainable utilization of natural resources, such as land, water, air, minerals, forests, fisheries, and wild flora and fauna that would lead to upliftment of quality of human life. The basic objective of natural resource management is the utilization of scientific, economic, and social knowledge that would help in the conservation of natural resources in a sustainable manner. A participatory approach to natural resource management can serve as a pivotal role in improvement and swift adoption of technology. Using the participatory approach, researchers try to comprehend how the farmers experiment on their own and enable the scientists to seek partnerships with the cultivators to develop environmentally friendly technologies. The participatory approach has played an important role in the integration of scientific and local knowledge and accelerated capacity building and has facilitated the involvement of local populations, who had hitherto been marginalized, in the decision-making processes for natural resource management. Thus, participatory approaches play a crucial role in natural resource management.

Notable among the above is the CIAT hillside project of Nicaragua that combines participatory research methods at the community, micro-watershed, and watershed levels for the development and management of natural resources through collective action at the landscape level, especially in the fragile hillsides environments. The study area comprised the watershed of the Calico River that covers
about 170 km² and has semiarid climate and having about 15% landless households. Agricultural component comprises of mostly small-scale farmer production systems based on a combination of maize-beans, dual-purpose livestock, and coffee in the higher altitude zones. The area is afflicted by poverty, insufficient health and educational facilities, poor housing conditions, and overdependence on a few crops, along with a number of environmental problems like drought, soil degradation, and deforestation. After organizing participatory workshops for identifying the key problems affecting the watershed landscape and the populations inhabiting the area, Comités de Investigación Agrícola Local (CIALs) or local agricultural research committees were set up as potential building blocks to provide local communities with a methodology to carry out a participatory research process focusing on natural resource management. Eight CIALs had been formed till 1998 all of which organized themselves into a regional association and worked in coordination with other regional entities like Nacional de Tecnología Agropecuaria (INTA). Another development was the formation of multi-stakeholder-based association known as ‘Campos Verdes’ or Green Fields that targets to improve water, soil, and tree management along with technology and managerial development with funding from the Hillsides project. This initiative facilitates the local population to discover linkages and gaps within the working unit by active participation and enables them to look for alternatives at the community and watershed level.

4.4 Disadvantages and/or Limitations of Participatory Plant Breeding

It has often been argued that inclusion of participatory approaches in classical breeding programs would increase complexity and lead to increase in time and cost. Aspects like training of farmers, earlier and more exhaustive testing of varieties, requirement of much larger amount of seeds, conduction of trials outside the experimental fields, and requirement of diverse manpower to effectively communicate with farmers’ lead to inflation of costs. Farmers need to be put at the forefront with lots of inputs from them and more involvement at the design stage. The cost of farmer’s participation may include identification and selection of communities, preparation of training materials, and doing training and capacity building. An overview of breeding of barley using both conventional and participatory approaches brings out the resources involved while involving the farmers directly in a breeding program. In this case, there was an enormous increase in the operational cost due to off station work in Syria and other countries. However, a 3% increase in overall budget should be weighed against the amount of savings generated due to early release of varieties using PPB as compared to conventional breeding methodology. Thus, the argument of cost inflation using PPB does not hold much ground. It is desirable to have a full cost-benefit analysis that should consider adoption of the varieties over time, after the project and not just immediately at the conclusion of the breeding process. The success of PPB is more evident when the benefits accrue
Table 4.2  Total cost of agronomic operations in the centralized-non-participatory program and in the decentralized-participatory program

<table>
<thead>
<tr>
<th>Plot area (m²)</th>
<th>Machine</th>
<th>Input</th>
<th>Labor</th>
<th>Total cost (US$/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US$/ha</td>
<td>%</td>
<td>US$/ha</td>
<td>%</td>
</tr>
<tr>
<td>Research station – short plots – hand planting/hand or machine harvesting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.56</td>
<td>11,101</td>
<td>86.1</td>
<td>755</td>
<td>5.9</td>
</tr>
<tr>
<td>2.03–2.3</td>
<td>6307</td>
<td>87.8</td>
<td>296</td>
<td>4.1</td>
</tr>
<tr>
<td>Research station – medium plots – machine planting and machine harvesting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3600</td>
<td>84.0</td>
<td>531</td>
<td>12.4</td>
</tr>
<tr>
<td>12</td>
<td>2745</td>
<td>86.5</td>
<td>322</td>
<td>10.1</td>
</tr>
<tr>
<td>72</td>
<td>2126</td>
<td>85.9</td>
<td>261</td>
<td>10.5</td>
</tr>
<tr>
<td>96</td>
<td>1919</td>
<td>86.3</td>
<td>224</td>
<td>10.1</td>
</tr>
<tr>
<td>120</td>
<td>1717</td>
<td>86.2</td>
<td>202</td>
<td>10.2</td>
</tr>
<tr>
<td>288</td>
<td>1409</td>
<td>87</td>
<td>151</td>
<td>9.3</td>
</tr>
<tr>
<td>Farmers’ fields – medium plots</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIT-12</td>
<td>1941</td>
<td>68.7</td>
<td>806</td>
<td>28.5</td>
</tr>
<tr>
<td>FAT-24</td>
<td>3226</td>
<td>77.5</td>
<td>806</td>
<td>19.4</td>
</tr>
<tr>
<td>FET-721</td>
<td>2605</td>
<td>79.6</td>
<td>560</td>
<td>17.1</td>
</tr>
</tbody>
</table>

Reprinted by permission from Springer Nature: The cost of participatory barley breeding, Mangione et al. (2006)

aCosts for machine operations include tillage, fertilization, seedbed preparation, plot planting, weeding, mowing of alleys, plot combine harvesting, straw chopping

bInput costs include fertilizers, herbicides, packaging for plot planting, packaging for plot harvesting, seed compensation to farmers (FIT, FAT, and FET)

over time, as more and more farmers adopt the developed varieties and the varieties are cycled back into ongoing on-farm selection and enhancement processes.

Mangione et al. (2006) evaluated the overall costs of centralized-non-participatory and decentralized-participatory plant breeding programs using the data from the barley-breeding program at ICARDA in Syria. The overall costs of the centralized-non-participatory program were comparatively higher than those of the decentralized-participatory program (Table 4.2). In spite of plantations over a wide area, the on-station costs of participatory breeding were 30% lower than those of the centralized trials which was probably due to big size of plots whose operational costs per hectare were lower than those for small plots. In the centralized-non-participatory breeding, bulk of the costs of human resources is involved in on-station activities. However, the participatory breeding programs cause a significant increase in labor costs which is a fallout of the labor-intensive evaluation of the germplasm as well as the use of biological measurements in the field trials. Apart from this, frequent meetings between cultivators and the scientists enhance the total labor costs in the participatory breeding programs. This increased cost is somewhat lowered by reduction in the on-station activities. To conclude, the overall labor costs of the participatory program are equally divided between activities in farmers’ fields and activities on-station.

Table 4.3 shows the comparative analysis of the expenditure involved in participatory and conventional plant breeding programs. The CPB incurred almost double
the expenditure but resulted in ¼ th of the gross economic benefit obtained by the farmers. The benefit-cost ratio for the PPB program was 39 which was much higher than 15 obtained in the conventional programs.

The values for gross economic benefits in Table 4.3 reveals that adopting PPB varieties will lead to generation of more returns (US$33 million more) as compared to CPB in a short span of time.

### 4.5 Participatory Plant Breeding and Women Empowerment

Empowerment is a process by which the capacity of self-determination of a vulnerable group is increased using governance and technology. Empowerment of rural women, the most vulnerable group in rural sector, is of utmost importance since they can influence rural and agricultural development at the grassroots level for gender equity, household security, and poverty eradication. It has been observed that women small-scale farmers, despite their social standing, less expertise, and limited decision-making, can play an important role in enhancing household food security. In Syria, a 6-year study (2006–2011) demonstrated that participatory breeding can play a major role in women empowerment by providing rural women with greater say in agriculture and allied farm activities which might be of interest to them.

From the gender point of view, poor rural women seem to have derived the maximum benefits from the PPB approach. This group forms the bulk of the farm labor, processes and stores the harvest, and prepares the food. It has also been argued that women confidence is enhanced when greater attention is paid towards them in the farm sector by inculcation of new knowledge and skills on crop management which results in an increase in their confidence. The role of women becomes more pronounced in economies that show increasing migration of men to the cities resulting in women becoming “de facto” farm managers. In many economies, women play an important role in preserving the best seed for planting and in the management of plant genetic resources.

<table>
<thead>
<tr>
<th>Table 4.3</th>
<th>Summary of results for participatory plant breeding (PPB) and conventional plant breeding (CPB) programs (Mustafa et al. 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPB program</td>
<td>CPB program</td>
</tr>
<tr>
<td>Research expenditure (million US$)</td>
<td>2.8</td>
</tr>
<tr>
<td>Gross economic benefits (million US$)</td>
<td>110.7</td>
</tr>
<tr>
<td>Annual research expenditure (million US$)</td>
<td>0.122</td>
</tr>
<tr>
<td>Annual economic benefits (million US$)</td>
<td>4.8</td>
</tr>
<tr>
<td>Discount rate (%)</td>
<td>3</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>46</td>
</tr>
<tr>
<td>Benefit-cost ratio</td>
<td>39</td>
</tr>
</tbody>
</table>
However, several factors seem to limit women’s involvement in PPB:

(i) Focus in PPB is primarily on major crops that are within the male sphere of control rather than on many underutilized crops generally controlled by women.
(ii) Although an active member in most farmer-breeding processes, women rarely exercise control over decision-making.
(iii) Many out of farm productive and reproductive responsibilities severely limit women’s time to participate in PPB activities.
(iv) Social constraints in conservative societies may restrict active involvement of women in decision-making.

The most important step in this context is to ensure women’s participation in the breeding process. Different areas have different approaches to fulfill this objective. For example in Rajasthan (India), the staff of an ICRISAT sponsored project was instructed to identify equal number of male and female members of the rural community who might be interested in breeding. Being a conservative area, this was ensured by taking help of a woman investigator to help locate interested women farmers. In another study conducted by the Indian Institute of Management (IIM), the project staff identified few women innovators in PPB programs which led to a reorientation of their strategy. More women students were enrolled who stayed in the villages and helped identify the women innovators ultimately raising the proportion of women to male innovations documented to 20:80.

A case study involving the empowerment of 12 women from three villages of Syria during a PPB program carried out by ICARDA sheds new light on how PPB can actually help women empowerment. A PPB program initiated in 1996 during its tenure showed negligible participation of women. However, the local women were deeply interested in the program, and therefore in 2006, a young female was appointed as a member of the PPB team. She was entrusted with the task to collect interested women farmers and formulate a proactive approach to address the barriers to their involvement. Seven women farmers from Lahetha and Souran actively involved in PPB trials carried out evaluation, selection of varieties, and their nomenclature along with participation in conferences. From 2007 an assessment was undertaken to evaluate the impact of PPB on the empowerment of the newly involved women farmers for a period ranging from 2007 to 2010. The findings indicate that a gender-sensitive evaluation of empowerment can help refine PPB strategies and reduce the risk of negative impacts. The study showed that empowerment of women farmers is extremely important in societies where the feminization of agricultural labor is making women farmer’s key participants in the agricultural development of small-scale farming. The findings suggest that women-driven PPB can provide opportunities and propel the agricultural sector toward women’s individual and group empowerment that can enhance the relevance of PPB and its expected output. PPB has the potential to reach out to more women and to reach to the more marginal
farmers. In Rwanda, women who were brave, reflective, and spoke clearly were preferred as collaborator farmers for bean breeding since male farmer collaborators were not found up to mark. Breeders coordinated with these women and obtained their inputs and experience in field maintenance and innovation.

The maize breeding program in southwest China is a combination of formal-led and farmer-led breeding having its origins in the expertise of women farmers’ in the maize hybridization program. Women are skilled breeders and have been deeply involved in maize improvement through maintenance of landraces, field design, pollination, and in the mass selection procedure. OPV, Tuxpeño 1, was released by the formal system in the region in the early 1980s and went into oblivion on the arrival of new varieties. However, one woman farmer maintained the vigor of OPV, Tuxpeño 1, and made significant improvements in terms of quality and adaptation. By the year 1998, more than 80% of Wenteng’s maize growing area was under cultivation of improved Tuxpeño 1, and this improved variety spread to other neighboring areas through informal seed exchanges.

### 4.6 Participatory Plant Breeding and Farmer’s Rights

Conventional plant breeding focuses on producing high potential varieties that thrive in non-extreme conditions and mainly cater the resource-rich farmers. This is due the fact that the breeder rarely has access to land comparable to that held by the poor farmer and also is less informed about the needs of this section of the farming community. As a result the varieties developed through commercial breeding generally do not perform well in extreme environments, which is often the land held by poor farmers. Participatory plant breeding is advantageous since it increases the possibility that the final products will be well suited to the conditions of the resource-deficient farmers and contribute better to their livelihoods. Several factors in participatory breeding that draw a sense of camaraderie between the breeder and the cultivator have been provided below:

(a) People of diverse background are involved in the selection/breeding process, as well as in field trials.
(b) Experimental field is located within the community which results in greater adaptability of the new varieties.
(c) The experimental material is chosen in consultation with the farmers from the material that is already in cultivation in the area.
(d) Participatory plant breeding provides farmers with access to genetic diversity as a basis for their innovation.

The coordination of the abovementioned factors results in an increasing interest and sense of ownership among the farmers with respect to their involvement in the breeding process. Since the farmers are involved in the decision-making process, they become actively involved in local innovations and become true research partners. Participatory plant breeding also facilitates knowledge and technology transfer
and capacity strengthening, both for the farmers and the formal sector breeders with whom they come into contact.

### 4.7 Participatory Plant Breeding and Organic Agriculture

Several productive agricultural systems have been developed in several parts of the world by intensification of inputs in the form of fertilizers, pesticide, labor, and capital. However, this has led to a decline in the diversity of farmed crops, erosion in the resilience of agroecosystems to anthropogenic disturbances, and an increase in the environmental degradation. One glaring example of this is the wide presence of the herbicide atrazine in streams and groundwater in the United States since more than 90% of the corn farmers rely on herbicides for weed control.

Organic farming is defined as a holistic production management system that promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity. This farming system is promoted by the FAO as an alternative approach to maximize the performance of renewable resources and for optimizing the nutrient and energy flows in agroecosystems. Organic farming combines traditional knowledge with modern technologies in order to exclude chemical inputs such as synthetic pesticides and fertilizers. This farming system augments ecological processes that foster plant nutrition yet conserve soil and water resources, thereby producing many economic, social, and environmental advantages leading to a sustainable agricultural future. Thus, organic farming can be considered as a promising solution for reduction of environmental burdens associated with intensive agricultural management practices and is gaining interest worldwide due to its environmental benefits compared to conventional, intensive agriculture. Although it was initially estimated that organic agriculture led to yield losses of about 30–40% as compared to conventional agricultural practices, recent researches have shown the yield reduction only to about 19%. Organic agriculture has shown remarkable extension with a total of 43.7 million hectares being organically managed by 2.3 million organic producers at the end of 2014 which was about 1% of the worldwide agricultural land. The realm of organic farming is increasing day by day due to the increasing demand, and this form of agriculture is expected to grow up to 20% worldwide of the total agricultural area.

It has recently been suggested that participatory plant breeding should be used for breeding adapted varieties for organic farming systems in developed countries. This realization is based on the fact that organic farmers often encounter the same constraints as faced by participatory breeders, viz., heterogeneous environmental conditions, and lack suitable crop varieties due to minimal market influence. The growing conditions on organic farms are quite different than those found on high-input, conventional breeding centers. Since organic farming does not rely on high and chemical inputs, there is a dearth of reliable varieties better adapted to these low-input environments so that the organic growers have improved yield, stability, and quality. Participatory plant breeding can be effectively utilized for low-input systems in developing countries as well as low-external-input systems such as
organic agriculture in developed countries. Several experiments have demonstrated successful amalgamation of these methodologies. Some of them are discussed below.

In Canada, a pilot project was carried out, and 11 organic farmers were provided with F3 populations of spring wheat (3 populations, 5000 seeds per population). The seeds were planted under normal cultivation conditions, and thereafter selection was carried out by the farmers based on individual priorities for 3 years. A comparison of selection outputs with registered cultivators showed that the farmer-selected populations yielded 107% of conventionally selected cultivars were tall, more vigorous, and reduced weed biomass compared to the conventional cultivars. Thus, the selection of germplasm directly in the target environment yielded improved germplasm wheat that was able to thrive under organic production systems. In France, IBB (Inter Bio Bretagne) a Brittany regional organic umbrella and Institut National de la Recherche Agronomique (INRA) initiated a participatory plant breeding program for organic cabbages and cauliflowers at the PAIS, the agro-biological experimental station of IBB that is dedicated to research in organic crop production. Similar coordination for several crops like durum wheat, bread wheat, sunflower, maize, tomato, radish, broccolis, parsnip, and fennel has been carried out in France. Similarly several vegetable breeding projects in the Northeastern United States and in Oregon show increasing use of participatory plant breeding in organic farming.

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Advantages and Cost of Participatory Plant Breeding


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Abstract

Participatory plant breeding has captured the attention of the policy makers around the world. Since this form of breeding caters more to the needs of the resource-deficient farmers, there is a deep interaction between farmers and breeders for setting objectives, decision-making, sharing responsibility, and generating the desired output. Several governments, private organizations, NGOs, and research labs have given due importance to this form of breeding. Research organizations like ICRISAT, ICARDA, CIMMYT, CIAT, INRA, LI-BIRD, and CENESTA along with several governments are actively involved in PPB activities. This chapter describes the various programs on PPB taking place in different countries spanning across continents.

5.1 Introduction

Participatory plant breeding has captured the attention of the policy makers around the world for bringing about genetic improvement in a crop. Since this form of breeding caters more to the needs of the resource-deficient farmers, there is a deep interaction between farmers and breeders for setting objectives, decision-making, sharing responsibility, and generating the desired output. Different countries have modified the PPB methodology to cater to their local needs, and this alteration has yielded the desired results. The present chapter discusses the role of various organizations in furthering the PPB programs in different countries and the successes obtained therein. Research organizations like ICRISAT, ICARDA, CIMMYT, CIAT, INRA, LI-BIRD, and CENESTA along with several governments are actively involved in PPB activities. Even in developed countries PPB is being explored as an attractive alternative for the organic farmers where the field conditions mimic the environmental conditions encountered by the marginal farmers in their fields.
5.2 Asia

5.2.1 Local Initiative for Biodiversity, Research and Development (LI-BIRD)

LI-BIRD is a nonprofit-making, non-governmental organization (NGO) established in 1995 in Pokhara, Nepal, with the objective of capitalizing on local resources, innovations, and coordination of institutions for sustainable management of natural resources. Nepal is a small, landlocked country with a population of 26.4 million having an agriculture-based economy where bulk of the population is engaged in farming. A number of farmers practice subsistence agriculture while only few have made use of modern technology. LI-BIRD is a pioneer organization in the area that aims at improving the livelihoods of small and marginal farmers who have not reaped the benefits of the Green Revolution. The daunting task of reducing poverty is efficiently carried out through innovative approaches to research and development in agriculture, along with strengthening resilient livelihood systems, improving ecosystem health and services to ensure food, nutrition, and income security of small-scale farmers. LI-BIRD has contributed several innovative methodologies for participatory breeding through partnerships in development-oriented research in agriculture and natural resources management which have led to amelioration in the conditions and the livelihoods of rural poor and marginalized farmers. Dr. Bhuwon Ratna Sthapit, one of the founding members and ex-board chair of LI-BIRD, was a pioneer scientist who worked in developing and strengthening participatory research methodologies in agrobiodiversity and institutionalizing these approaches in the national systems. He extensively worked in agrobiodiversity conservation, research, and development throughout his life. LI-BIRD and Bioversity International have established the “Bhuwon Ratna Sthapit Memorial Fellowship for Agrobiodiversity in Nepal” which is in honor of the late Dr. Sthapit and his life-long commitment to agrobiodiversity conservation, research, and development. The following programs are coordinated by LI-BIRD:

(a) Agricultural Innovations for Food and Nutrition Security
(b) Biodiversity and Ecosystem Services for Sustainable Livelihoods
(c) Community Resilience to Climate Change and Disaster Risks
(d) Inclusive Economic Growth for Income and Employment

5.2.2 Southeast Asia Regional Initiatives for Community Empowerment (SEARICE)

Southeast Asia Regional Initiatives for Community Empowerment (SEARICE), established in 1977, is a regional NGO registered in the Philippines that was formed with the aim of promoting and implementing community-based conservation, development, and sustainable use of plant genetic resources in association with civil society organizations, government agencies, academic institutions, research
laboratories, and local government units in a number of Southeast Asian countries like Lao PDR, the Philippines, Thailand, Vietnam, Cambodia, and Bhutan. Although SEARICE is involved in a variety of tasks, one principle objective is to enable the farmers to manage their genetic resources and secure their local seed systems through means like conservation, plant improvement, and their sustainable utilization. It acknowledges the important role played by the farmer in sustaining a secure food system and envisages linking farmers’ knowledge and innovation systems with formal science and research to build stronger national research systems. SEARICE promotes the development of farmer groups in coordination with research laboratories which has been one of the avowed objectives of PPB. The organization helps formulate programs and policies that lend a helping hand to the farmers and local communities in sustainable use of plant genetic resources and their conservation. Seed sharing is freely carried out through farmer-to-farmer exchange, biodiversity fairs, and farmer field schools.

SEARICE has been involved in a number of initiatives in its area of operation. Community-Based Native Seeds Research Center, Inc. (CONSERVE) was an NGO established in the year 1992 and started as a project of SEARICE to conduct both researcher-managed and on-farm field trials for rice in the Arakan Valley Complex in the Philippines. Initially 299 varieties of rice were collected from Cotabato and Maguindanao provinces in 1992 which were later supplemented with 389 more varieties in 1995. Although started as a program for rice, several varieties of corn, millet, sorghum, and vegetables, along with 59 varieties of unidentified cereal crops, were collected and managed. The researcher-managed or center-based trials were initiated in the experimental farms by breeders and later conducted by the farmers. The farmer-managed or the farmers’ field trials were conducted on farmers’ field where the farmers designed the experiments, made the selection (pedigree or bulk), and executed it fully.

SEARICE also initiated the Community Biodiversity Development and Conservation Program (CBDC) in 1994 that focused on conservation and development of edible crops like rice, corn, cassava (Manihot esculenta), sweet potato (Ipomoea batatas), and yam (Dioscorea alata). The project envisaged participatory on-farm research conducted by the staff, farmers, and farmers’ groups. The germplasm-like conventional varieties, farmers’ selections, and formal release varieties were evaluated by the farmers and subsequently exchanged within the cultivators through the local exchange systems.

5.2.3 Community Biodiversity Development and Conservation Program (CBDC)

CBDC is a global program initiated in 1994 to aid in conservation of farmers’ genetic resources in the context of Green Revolution developments. With the advent of Green Revolution and the development of high-yielding varieties, farmers came to be viewed as mere end user, and the existing farmer seed systems were threatened due to rampant use of technology. Thus, the local agrobiodiversity was at stake
which prompted the civil society groups to work toward strengthening the farmer seed systems and conserve the agrobiodiversity. CBDC has been implemented across the continents in Africa, Latin America, and Southeast Asia. Some countries were specifically chosen due to the following reasons:

Vietnam: due to severe erosion of plant genetic resources in the Mekong Delta
Thailand and the Philippines: due to presence of strong civil society groups

CBDC is based on the premise that the farming communities are better equipped in conservation of biodiversity due to their conventional knowledge of the farming systems.

The Philippines offers an excellent example of farmer participation where in spite of the introduction of the high-yielding varieties (HYVs) in the late 1960s, Boholano farmers continued their tryst with conservation and use of local red rice varieties with assistance from SEARICE. The Boholano farmer-breeders were interested in the creation of varieties according to the following parameters:

- Early maturity
- Long panicle
- Strong culm
- Resistance to biotic stresses
- Aromatic nature
- Good eating quality
- Decent selling price

They acquired the expertise to follow their own breeding objectives from the farmer field schools (FFS) on PGR sponsored by SEARICE. The seed development process led to a significant reduction in the farm expenses since the farmers had no need to buy the germplasm and also was ecologically sound since yield was enhanced with the use of organic fertilizers. These farmer-breeders had a dual benefit, viz., higher yield of developed varieties and monetary gains from the sales of their seeds. The association of the farmers was significant since they played a major role in increasing diversity of red rice which was higher than that prevalent in modern varieties.

### 5.2.4 Biodiversity Use and Conservation in Asia Program (BUCAP)

The Biodiversity Use and Conservation in Asia Program (BUCAP), coordinated by SEARICE with support of Norwegian Development Fund (NDF), was started in 1996 mainly in Bhutan, Lao PDR, and North and Central Vietnam with the
objective of strengthening on-farm management and use of PGR through PPB. The selection of these countries was due to the following reasons:

Bhutan: This tiny country located between China and India is far away from the global market, and most Bhutanese farmers practice subsistence agriculture.
Lao PDR: Here the agriculture is in the transition phase from subsistence to market orientation.
Vietnam: Highly market-oriented country being one of the top rice exporters.

BUCAP was launched in 2001 in Bhutan in collaboration with National Biodiversity Centre (NBC), Renewable Natural Resources Research Centres (RNRRCs), and SEARICE for on-farm conservation of rice germplasm and participatory breeding program with active participation of the local farming communities. Rice is a major crop in Bhutan grown in a range of altitudes from 200 to 2700 masl by socioeconomically poor farmers who practice subsistence agriculture primarily for home consumption. The program was initiated since there was dearth of improved varieties with the farmers who often had unimproved varieties that gave poor yield. Therefore, the program aimed at creation of better varieties (high yielding) for the farmers along with conservation of rice diversity. BUCAP initiated activities like seed purification of conventional varieties using the farmer field school (FFS) approach wherein a number of varieties were purified by the farmers and the seeds exchanged with other members of the farming community. Initially the farmers were reluctant to be part of the program due to the associated risks, but their participation increased with passage of time when they realized that FFS helped in solving the problems faced by them. The breeding lines were planted in a centrally located farmer’s field of one of the participants, and other FFS members actively participated in further evaluation. Farmers set the selection criteria depending upon their requirement that was mainly based on the following parameters:

- Yield
- Kernel color
- Disease resistance
- Maturity period
- Taste
- Plant height
- Easy threshability
- Grain type
- Straw yield
- Marketability
5.2.5  Eastern India Rainfed Farming Project

Eastern India Rainfed Farming Project (1995–2005) was a decent attempt to improve the livelihoods of thousands of resource-deficient farmers of around 19,000 households, who practiced subsistence agriculture in the less fertile areas of the Chota Nagpur Plateau spanning across parts of Jharkhand (erstwhile Bihar), West Bengal, and Orissa. The project was coordinated by the Gramin Vikas Trust (GVT), and the funding came from the Department for International Development (DFID, United Kingdom) and the Government of India. The project started with village surveys which showed that rice was the most important crop for the poor cultivators in these agriculturally poor lands. The farmers here cultivated coarse-grained rice landraces that were poor yielding in the low-input management. This prompted the project coordinators to initiate rice improvement through PVS and PPB. As compared to PVS where the farmers selected germplasm from a range of existing varieties, PPB had a long-term perspective to work upon and improve the varieties identified through PVS.

5.2.6  ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), established in 1972 with a headquarter in Hyderabad, Telangana, India, and offices in several African countries like Mali, Nigeria, Niger, Kenya, Malawi, Ethiopia, Mozambique, and Zimbabwe, is a nonprofit organization with a mission to reduce poverty, hunger, and malnutrition in the dry tropical regions of the world which occupy about 6.5 million square kilometers of land in 55 countries. ICRISAT’s work is mainly centered in sub-Saharan Africa and South Asia on crops that survive in the harsh climates. The organization aims at conserving, analyzing, breeding, understanding on-farm management practices, processing, and agribusiness opportunities using different approaches of which participatory approach forms an important component. The following crops are the main focus of ICRISAT research:

(i) Chickpea
(ii) Pigeon pea
(iii) Groundnut
(iv) Sorghum
(v) Pearl millet
(vi) Finger millet

ICRISAT has a huge germplasm collection of about 122,547 accessions of the six mandate crops collected from about 144 countries.

In West and Central Africa ICRISAT has involved farmers in different regions to evaluate the plant material bred by the breeders and geneticists in the region. For example in Mali, several NGOs and extension services have played an active role with sorghum breeders of ICRISAT and the Malian Agricultural Research Institute
(Institut d’Economie Rurale) to improve the productivity and resilience of small-holder agriculture along the country’s climate-risky Sahelian and Sudanian zones. The story of Mali-ICRISAT partnership began in 1979 with the establishment of the ICRISAT-Mali Bilateral Program for research on sorghum and millet, with support from the US Agency for International Development (USAID). The association emphasized on coming together of all the stakeholders including the farmers to work for a positive transformation of the country’s agriculture sector. The vibrant collaboration between ICRISAT and IER led to the relocation of the ICRISAT West and Central Africa (WCA) regional office to Mali in 2011. A number of projects have been implemented in Mali with the collaboration of ICRISAT some of which are mentioned in Table 5.1. ICRISAT and its collaborators have registered 13

<table>
<thead>
<tr>
<th>Name of project</th>
<th>Year of operation</th>
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<tbody>
<tr>
<td>Increasing groundnut productivity of smallholder farmers</td>
<td>2015–2018</td>
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<tr>
<td>Guinea-race sorghum hybrid development</td>
<td>2000–2008</td>
</tr>
<tr>
<td>ICRISAT-WCA-NARS Project on farmer participatory millet-sorghum production in the Sahel</td>
<td>2001–2003</td>
</tr>
<tr>
<td>Fertilizer microdosing</td>
<td>2002–2004</td>
</tr>
<tr>
<td>West African Groundnut Seed Project</td>
<td>2003–2007</td>
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<tr>
<td>Desert Margins Program</td>
<td>2003–2008</td>
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<tr>
<td>Mobilizing regional diversity for creating new potential for pearl millet and sorghum farmers in West and Central Africa</td>
<td>2006–2009</td>
</tr>
<tr>
<td>Intensification of sorghum and millet systems using local biodiversity and market opportunities in semi-arid West Africa</td>
<td>2006–2010</td>
</tr>
<tr>
<td>An Bè Jigi: Enhancing nutrition in sorghum/pearl millet consuming communities</td>
<td>2006–2010</td>
</tr>
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<td>Farmer-participatory improvement of sorghum and pearl millet genetic resources</td>
<td>2006–2010</td>
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<tr>
<td>Sustainable seed supply: Farmer-managed seed marketing initiatives</td>
<td>2006–2010</td>
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<tr>
<td>ALIVE (A Legume Intensification and Variety Enhancement) and nutritious cropping systems: A legume intensification and variety enhancement participatory approach</td>
<td>2006–2010</td>
</tr>
<tr>
<td>Enhancing Grain Legumes’ Productivity and Production and the Incomes of Poor Farmers in Drought-Prone Areas of Sub-Saharan Africa and South Asia</td>
<td>2007–2011</td>
</tr>
<tr>
<td>Community management of crop diversity to enhance resilience, yield stability and income generation in changing West African climates</td>
<td>2008–2011</td>
</tr>
<tr>
<td>Harnessing Opportunities for Productivity Enhancement (HOPE) of Sorghum and Millets in Sub-Saharan Africa and South Asia</td>
<td>2009–2013</td>
</tr>
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open-pollinated varieties (OPVs) and 7 hybrids in the national/regional catalog in Mali in 2016 under the hybrid sorghum program to boost sorghum yield and productivity.

### 5.2.7 CENESTA

The Centre for Sustainable Development (CENESTA) is a non-governmental, not-for-profit, civil society organization that was set up to promote sustainable growth of the indigenous and local communities not just in Iran (where it has its headquarters) but in other regions like Southwest Asia, Africa, Latin America, and Asia and in the international arena in general. CENESTA is a member of UNINOMAD (Union of Indigenous Nomadic Tribes of Iran), ICCA (International Congress and Convention Association) Consortium, IUCN (International Union for Conservation of Nature), and Global Forest Coalition. Following are the main theme areas which are on the priority list of CENESTA:

- Re-empowering the indigenous and traditional local communities: community empowerment and participatory development planning, Community Investment Funds, facilitation of rural credit, women empowerment, and development initiatives
Community management and co-management of natural resources

Agroecology

Combating desertification through policy and practice on arid lands, nomadic pastoralism, etc.

Conservation of watersheds, fisheries, water resources, and pasturelands

Sustainable development through nonchemical control of pests, regenerative soil management, agroforestry schemes, and farming systems research

CENESTA works in tandem and with active collaboration and/or participation with local communities in Iran, local and national governmental agencies, academic and research institutions, and with non-government organizations (NGOs). A number of international bodies like United Nations Development Programme (UNDP), United Nations Statistical Office (UNSO), United Nations Convention to Combat Desertification (UNCCD), United Nations International Children’s Emergency Fund (UNICEF), Food and Agriculture Organization (FAO), and International Fund for Agricultural Development (IFAD) work in tandem providing support to major activities carried out by CENESTA (Fig. 5.1).
5.3 Africa

Africa occupies a peculiar place in world agriculture since it could not reap the benefits of the Green Revolution during the 1960s. This was primarily due to the fact that several African countries were being born at that time and the human and institutional capacities required for Green Revolution were nonexistent in the region. Secondly, the Green Revolution mainly concentrated on crops like wheat and rice, whereas other crops that were important for Africa like coarse cereals, cassava, and maize took a backseat. In fact it was the only continent where the agricultural sector’s growth has lagged behind national economic growth. Surprisingly the annual rate of agricultural production between 1973 and 1980 in Africa was a mere 0.3% as compared to the population growth rate of 2.8%. One specific example can be given of cocoa whose yields in Africa increased by 10% between 1961/1965 and 1987, while in Latin America and Asia the yields doubled and tripled. The result has been delayed economic turnaround and higher poverty rates in Africa. African agriculture has not performed well in the last century and faces the following constraints:

(i) Rapid urbanization  
(ii) Climate change  
(iii) Integration into local markets  
(iv) Rising food prices  
(v) Burgeoning population  
(vi) Unrest and civil war in many countries  
(vii) Frequent climatic adversities  
(viii) Poor linkage between universities and research institutions  
(ix) Lack of market facilities and poor government regulations

Apart from the abovementioned factors, some specific factors need special mention. It has been observed that even after the Green Revolution in which many developing countries reaped the benefits of modern technology, crop yields in Africa are very low and have lagged behind many regions. An FAO report mentions that Africa has only 7% of its area sown under high-yielding varieties compared to 70% in Asia and 30% in Latin America. This was primarily due to the fact that the chief crops of the Green Revolution, viz., wheat and rice, were not important to Africa. Most of the research on rice focused on *Oryza sativa* and ignored the African rice *O. glaberrima* that was cultivated in Africa. The conventional African crops like millets, sorghum, yam, plantain, and cassava were not accorded due importance, and the words of Warren Baum, former chairman of CGIAR, that the “green revolution bypassed Africa” seemed true. Coupled with this is the problem associated with research systems in Africa where most of the national agricultural systems have serious financial problems. Finally the lack of information is the most pressing problem faced by most of the African farmers who are ignorant about the modern advances in agriculture. All the abovementioned factors have led to a slow pace of agricultural development in Africa.
5.3 Africa

5.3.1 REST: Community Seed Banks and Expert Seed Selection in Tigray, Ethiopia

Ethiopia had been ravaged by a bloody civil war that began in 1974 and lasted until 1991 which left at least 1.4 million people dead. Tigray, the northernmost of the nine regions of Ethiopia, witnessed a drastic fall in general productivity of food and cash crops during the civil war period since the region was disconnected from most sources of support, including foreign aid. The project REST began in 1988, toward the end of the long civil war, as an emergency program for areas (districts or woredas) under Tigrayan rebel control that were hard hit by drought. The project was administered by the Relief Society of Tigray (REST), an NGO based in Tigray that provided relief efforts to the civilians and coordinates development work in this northern Ethiopian region. The project was primarily focused on self-reliance and seed security with evolved links to biodiversity conservation. The initial focus was on crops like sorghum, wheat, barley, and maize, but later grain legumes were brought under its ambit. The project offered good quality seeds at seasonal credit, particularly emphasizing poorer farmers by mobilizing the best traditional seed selectors. This was an important component of this project since it locally linked biodiversity conservation with seed supply and crop improvement. From 1988 to 1993, there were 42 genebanks operating at the woreda level with the number of beneficiaries increasing to 24,959 in 1993.

A seed committee comprising of two elected woreda representatives, a BoA member, and two elected farmers coordinated genebanks at the woreda level including its financial management. Seed purchase and selection was organized by a local committee comprised of two elected officials and 1–2 expert farmers known for selection abilities at the Tabia level. This committee selected and purchased seed before harvest, appointing 2–4 farmer-curators to store the seed on-farm using traditional granaries and practices (drying, with ash and peppers as insect repellent, occasionally supplemented with chemical pesticides). Each curator separately stored 10–20 varieties and experienced low seed losses (1–3%). During plantation time, the poor farmers received seed on credit, which they must repay at season’s end, at the harvest price plus an average interest of 6%.

5.3.2 AfricaRice [Formerly West African Rice Development Association (WARDA)]

AfricaRice is a pan-African, intergovernmental, nonprofit research and training center currently affiliated with CGIAR. The center was initially set up in 1971 as West African Rice Development Association (WARDA) comprising 11 countries. In September 2009 its name was officially changed to “Africa Rice Center” (AfricaRice) which currently has 26 member countries headquartered in Abidjan with research centers in Benin, Liberia, Madagascar, Nigeria, and Senegal. The primary task of AfricaRice is poverty alleviation and food security in Africa through the development and introduction of new rice varieties that are high yielding and
specifically adapted to the African conditions. The AfricaRice genebank alone contains about 22,000 African rice germplasm accessions comprising of five African indigenous wild species (\textit{O. barthii}, \textit{O. longistaminata}, \textit{O. eichingery}, \textit{O. punctata}, and \textit{O. branchyata}), as well as \textit{O. glaberrima} and \textit{O. sativa}. In 1999, NERICA (New Rice for Africa), an interspecific hybrid obtained by successful crossing of African (\textit{Oryza glaberrima}) and Asian (\textit{Oryza sativa}) rice, was developed by AfricaRice to improve the yields of African farmers. NERICAs were unique in the sense that they were high yielding like \textit{O. sativa} but had a shorter growth duration and tolerance to biotic and abiotic stresses. The center was awarded the CGIAR King Baudouin Award in the year 2000 for developing these NERICA varieties. In 2010 AfricaRice established a new, continent-wide Rice Breeding Task Force that accelerated rice varietal development through multi-locational continent-wide trails of elite lines from the center and its partners. The Global Rice Science Partnership (GRiSP) is a CGIAR research program for rice, led at the global level by the International Rice Research Institute (IRRI) and for Africa by AfricaRice. AfricaRice has collaborations with the following organizations/institutions for addressing specific problems:

- Institut de recherche pour le développement (IRD), France: resistance to rice yellow mottle virus (RYMV)
- International Center for Tropical Agriculture (CIAT) and IRD: drought tolerance, panicle architecture, root development, iron-toxicity tolerance, and bacterial leaf blight resistance
- Japan International Research Center for Agricultural Sciences (JIRCAS): Drought research with focus on deep rooting

AfricaRice examined several participatory approaches such as participatory plant breeding and plant technology development and adopted the plant varietal selection (PVS) approach to develop NERICA varieties that were best suited to the farmers. The NERICA farmer participatory program spans across 20 African countries and involves thousands of cultivators across the African continent. During 2000–2006, AfricaRice developed 18 upland NERICA and 60 lowland NERICA-L varieties for use in different agro-climatic regions of Africa and exposed the farmers to these varieties using participatory varietal selection (PVS) and community-based seed systems (CBSS). AfricaRice is also involved in Participatory Adaptive Research and Dissemination of Rice Technologies (PADS) project in several African countries to make rice research and development more client-responsive.

### 5.3.3 Participatory Tree Domestication

Participatory tree domestication, an amalgamation of the scientific principles and traditional knowledge, is a method adopted by the rural communities in Africa whereby they select, propagate, and manage tree species according to their own needs. This is carried out in coordination with the scientific personnel, civic
authorities, and commercial companies. Initially the trees were considered as an impediment in the expansion of agricultural activities in the resource-rich region of West and Central Africa. A statute in 1994 was introduced with the aim to promote the forest resources by community involvement but was perceived by the local farmers as an opportunity to exploit the timber resources. This was when World Agroforestry Centre (ICRAF) stepped in to correct the anomaly and help the farmers to develop a more sustainable approach by promoting domestication of tree species and harmoniously utilizing the forest resources. Under this initiative, domestication activities were carried out in “pilot” villages, each of which maintains its own set of cultivars leading to farmer empowerment and maintenance of genetic diversity. The selected local villagers were assisted in developing local nurseries, taught principles of plant propagation, and made to learn the selection of superior trees for cultivar development that met specific market-oriented “ideotypes.” Initially 20–30 farmers were selected, but this size was reduced to 10–20 in later stages to incorporate only those farmers who were committed to the training program. After the completion of the training, the trained farmers were encouraged to use the techniques on their own trees. Thereafter visits were arranged within and between countries so that the new batches of farmers undergoing training could go and see by themselves what the first batch of the trained farmers had already achieved in their respective areas. Different types of nurseries like dependent, semi-dependent, and semi-autonomous were set up initially in Cameroon and later extended to Southeast Nigeria, Democratic Republic of Congo, Gabon and Equatorial Guinea, Ghana, Liberia, and Sierra Leone. Thus, participatory domestication allowed the outputs and benefits of domestication to remain with the community, as per the mandate of the Convention on Biological Diversity (CBD). Since 1998, the World Agroforestry Centre (formerly known as ICRAF) along with several community-based organizations, non-governmental organizations, and national agricultural research systems has developed a participatory approach to the domestication of high-value indigenous fruit/nut trees, leafy vegetables, medicinal trees, melliferous trees and shrubs in West and Central Africa.

5.3.4 Agricultural Research Council (ARC) Initiative for Breeding of Leafy Vegetables

The Agricultural Research Council (ARC) is a premier science institution based at Pretoria, South Africa, that conducts research with partners, develops human capital, and fosters innovation to support and develop the agricultural sector. The breeding and genetic improvement of indigenous/traditional vegetables have been a priority area for ARC with the organization working on the research and development of these species that were replaced by modern vegetables in the second half of the twentieth century. The initial research projects of ARC initiated in 1994 focused on the production and utilization practices of African vegetables for identifying species that could address community needs regarding improved nutrition and food security. Later projects were spread over several climatic zones and were targeted to
study the cultivation of the leafy vegetables by different ethnic groups for establishing production and utilization patterns. Participatory rural appraisals were the major strategy followed for the leafy vegetable program. Twenty major African vegetables were identified, and the institute embarked on a research program for the development of production practices for five of the indigenous vegetable crops, viz., *Amaranthus* spp., *Cleome gynandra*, *Vigna unguiculata*, *V. subterrannea*, and *Abelmoschus esculentus*.

### 5.4 South America

#### 5.4.1 Centro Internacional de Agricultura Tropical (CIAT)

The International Center for Tropical Agriculture (CIAT), based in Palmira, Colombia, and one of the 15 specialized research centers of CGIAR, is a not-for-profit research and development organization that aims at reduction of hunger and poverty along with conservation of natural resources. The area of operation of CIAT is mainly in the developing countries with the objective of making farming more competitive, profitable, and resilient.

CIAT-IPRA (Participatory Research for Agriculture) took a major initiative in developing a methodology to foster community-based research by forming local agricultural research committees known as CIALs (Comités de Investigación Agrícola Local) in South and Central America which provide a direct link between local farmers and the formal agricultural research systems. In fact this farmer-run initiative was answerable to the local community. This concept was implemented with financial support from the W.K. Kellogg Foundation which was established in 1930 by the cereal pioneer W.K. Kellogg with the objective of upgrading the life of children and youth in all spheres of life. The CIAL concept was first tested in Columbia and then percolated to neighboring countries. Till the year 1999, about 240 CIALs had been formed in eight Latin American countries, namely, Bolivia, Brazil, Colombia, Ecuador, El Salvador, Honduras, Nicaragua, and Venezuela, with Columbia and Honduras leading the group with 89 and 57, respectively. Since their initial formation, numerous CIALs varying in size and characteristics have sprung up in most of the Latin American countries and have been quite successful with excellent results. CIALs work on the evaluation and stabilization of crop varieties in local environments along with management of pests, diseases, soil, water, and nutrients. Vernooy (2003) has provided some key features of the CIALs of Latin America with reference to the research theme, crops researched, and the gender analysis (Table 5.2).
In the European Union, PPB is emerging as a political project for farmers’ unions and associations who question conventional approaches to plant breeding and look toward PPB for agricultural sustainability. In fact PPB appears as a savior for them in the onslaught of genetically modified crops and multinational companies involved in agriculture solely with profit motive. It has been a growing realization that PPB is of prime importance for sustainable organic farming for European growers since the organic farming sector in Europe faces the same constraints faced by the marginal farmers of the developing countries, viz., the prevalence of heterogeneous environment, diverse needs of the farmers, lack of suitable varieties, and disinterest on part of the formal breeders. Therefore, the PPB projects in Europe are mainly concerned with organic farming. A workshop entitled the “Consultative workshop on participatory plant breeding” (Conpab) was aimed to provide a specific support action for developing strategies on PPB programs in areas of low water availability.

### Table 5.2 Some key features of 249 CIALs

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<tbody>
<tr>
<td>Evaluation of crop varieties</td>
<td></td>
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<tr>
<td>Pest and disease management</td>
<td>19%</td>
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<tr>
<td>Soil, water, and nutrient management</td>
<td>12%</td>
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<tr>
<td>Small livestock</td>
<td>5%</td>
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<td>Others</td>
<td>2%</td>
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<table>
<thead>
<tr>
<th>Crops researched</th>
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<tbody>
<tr>
<td>Beans</td>
<td>26%</td>
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<td>Maize</td>
<td>16%</td>
</tr>
<tr>
<td>Potatoes</td>
<td>14%</td>
</tr>
<tr>
<td>Vegetables</td>
<td>13%</td>
</tr>
<tr>
<td>Cassava</td>
<td>12%</td>
</tr>
<tr>
<td>Fruit</td>
<td>9%</td>
</tr>
<tr>
<td>Others</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CIALs by gender</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Men only</td>
<td>56%</td>
</tr>
<tr>
<td>Women only</td>
<td>7%</td>
</tr>
<tr>
<td>Mixed</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table 5.3 Comparison of the productivist and integrant philosophies

<table>
<thead>
<tr>
<th>Trait</th>
<th>Productivist</th>
<th>Integrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection criteria</td>
<td>Yield</td>
<td>Yield not the only criteria</td>
</tr>
<tr>
<td>Decision-maker</td>
<td>Breeder</td>
<td>farmer</td>
</tr>
<tr>
<td>Energy source</td>
<td>Fossil</td>
<td>Renewable sources</td>
</tr>
<tr>
<td>Germplasm</td>
<td>Exotic, inbreds</td>
<td>Local adapted populations</td>
</tr>
<tr>
<td>Gene action</td>
<td>Nonadditive (heterosis)</td>
<td>Mainly additive</td>
</tr>
<tr>
<td>Type of seed used</td>
<td>Hybrid, uniformity</td>
<td>Open-pollinated, diversity</td>
</tr>
<tr>
<td>Output</td>
<td>High yielding, quantity</td>
<td>Moderate yielding, quality</td>
</tr>
<tr>
<td>Genetic resources</td>
<td>Erosion</td>
<td>Conservation</td>
</tr>
<tr>
<td>Environmental effects</td>
<td>Leads to exhaustion</td>
<td>Sustainability</td>
</tr>
</tbody>
</table>

5.5.1 VASO Project

The VASO (Sousa Valley) project in the Northern Sousa Valley region of Portugal, based on the “Integrant Philosophy” and opposed to the “Productivist Philosophy,” is an excellent example of farmers’ successful assimilation in the breeding process. The project was initiated in 1984 by Dr. Silas Pêgo, a scholar of The Rockefeller Foundation who laid the foundations of the future Portuguese plant genebank (BPGV). Silas Pêgo was in charge of the Maize National Programme and, together with Dr. Luís Costa Rodrigues, formulated the National Breeding Programme having two main approaches:

(1) On-station approach: a monoculture system following the “Productivist Philosophy”
(2) On-farm approach: a polycrop system adapted to the “Integrant Philosophy”

Table 5.3 compares the two production strategies. It was observed that the American model of commercial agriculture was not suitable for Portugal where a large proportion of small farmers own small tracts of land. The integrated approach considers agriculture from a holistic point of view where the cultivators, local landraces, and plant breeding are considered together. One of the most fertile regions of northwest Portugal was considered as the starting point for VESO project. Two open-pollinated varieties (OPVs), viz., “Pigarro” and “Amíudó,” along with a synthetic population “Fandango” were selected as the starting populations. After about 20 years of on-farm conservation and improvement, it was observed that mass selection was better than S2 recurrent selection since it was cheap and more accessible to the farmers. The project allowed coordination between the farmer and the breeder along with a comparison of their breeding methodologies. The VASO project was unique since it was one of the longest running projects with respect to participatory breeding. The Portuguese maize participatory breeding program was special since the breeding activities were mainly carried out at the farmer’s field, with proper coordination between the breeder and farmer. The selection methodologies demonstrated by the plant breeder at the farmer’s plots were also followed by the farmer in...
another part of the field which allowed the farmer to effectively implement the breeder’s suggestions while the breeder learned thoroughly about the farmer’s management system.

5.5.2 Apfel:gut

The project Apfel:gut was initiated for participatory and organic fruit breeding work in Germany under the aegis of the Saat:gut, i.e., an association of farmers, seed traders, organic farmers, plant breeders, wholesalers, and retailers having a common view of promoting organic plant breeding in pome fruits. The project aims at limiting the loss to genetic diversity due to modern variety development by making the breeding process transparent, public, and eco-friendly. The project uses participatory approaches for development of novel varieties especially with respect to resistance against scab, canker, and mildew. Farmers are the key players in this system with active participation in the selection of the parental genotypes and the seedlings. It was observed that many old varieties had only one or two undesirable traits that limit their use in modern fruit cultivation. The methodology is simple and carried out in the following steps:

(a) Polygenic, resistant, unimproved varieties that have been used since centuries by conventional farmers are crossed with the susceptible modern varieties.
(b) Seedlings are left to grow on their own roots till they start fruiting on organic farms under field conditions.
(c) These are then planted in rows with a distance of 30 cm.
(d) Disease resistance is evaluated for 3 years and the susceptible seedlings of each progeny are removed.
(e) After 3 years the disease-resistant genotypes are selected and planted.
(f) The last stem involves grafting of seedlings having best quality parameters and their evaluation on all the farms.
(g) During the whole length of the breeding process, no chemical fertilizer/pesticide/weedicide is used, and only compost is used as fertilizer.

5.5.3 Participatory Organic Farming in France

In France, a Brittany regional organic umbrella (IBB, Inter Bio Bretagne) and Institut national de la recherche agronomique (INRA) started a participatory breeding program for facilitating production of organic cabbages and cauliflowers in Brittany, a hilly peninsula situated in France’s northwestern region having an area of 27,208 km². Agriculture accounts for 4.2% of the total employment in Brittany since it is France’s leading vegetable growing region, with artichokes, cauliflowers, carrots, and potatoes among the most important crops. INRA is one of the top agricultural research institutes of the European Union founded in 1946 and comprises of 17 research centers and 250 laboratories. The participatory breeding program
was carried out at the PAIS, the agrobiological experimental station of IBB, and comprised of evaluation of germplasm from several European genebanks (INRA and GEVES in France, HRI in Wellesbourne, CGN in Wageningen, CHERAC in Switzerland). Another organization worth mentioning is “Réseau Semences Paysannes” that was set up after discussions among the pioneer organic farmers. This association joins several local producer networks and is a coordinating link between the farmers and the policy makers for stimulating the government agencies to introduce favorable registration laws.

Presently France boasts of a number of PPB initiatives that work on the following crops:

**Durum wheat**: The area of operation is in the Mediterranean region in the southern part of France. The farmers aim at producing grain with high protein content and ample vitrousness primarily for pasta making.

**Bread wheat**: The objective is to produce healthy bread wheat with less gluten content.

**Maize and sunflower**: This is mainly concentrated in the southwest part and aims at improvement in quality, rusticity, and adaptability to arid conditions.

**Tomato**: The objective is production of organic tomatoes having high gustative quality.

**Radish and summer cauliflower**: The targeted area is Pays de la Loire where the organic producers aim to produce cultivars with better adaptability to local conditions.

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Cereals

Abstract
Cereals are members of the family Poaceae, a ubiquitous family of monocotyledonous plants whose members are primarily cultivated for their fruit typically called “caryopsis.” The grain consists of bran (outer layer), endosperm (main part), and germ (smallest part) that are a storehouse of vital nutrients. Cereals are a rich and inexpensive source of carbohydrates, vitamins, minerals, fats, oils, and to some extent proteins, providing more food energy to humans than any other crop group. Four groups of foods are prepared from cereals, viz., whole grain products, baked products, milled grain products, and beverages. Cereals are also a rich source of bioactive substances that play an important role in promoting human health. The present chapter discusses the utility of participatory plant breeding in cereal production with special reference to wheat, rice, maize, barley, sorghum, finger millet, and pearl millet.

6.1 Introduction
Cereals refer to crops that are harvested for grain only. These are members of the grass family, viz., Poaceae, which have a fruit technically known as caryopsis composed of endosperm, germ or embryo, and bran. Cereals are cultivated on about 73% of the world’s harvested area and contribute over 60% of the world food production of which wheat and rice alone account for over 50% of the world’s cereal production. Cereals are a rich and inexpensive source of starches (65–75% of the total weight), proteins (6–12%), fat (1–5%), and a range of nutrients like dietary fiber, minerals, and vitamins that are required for human health. Cereals are important since they are cheap to produce, are easily stored and transported, and deteriorate very slowly if kept dry. Cereals are also a rich source of bioactive substances that play an important role in promoting human health by reducing the risk of coronary heart disease and tumor incidence, lowering blood pressure,
reducing the rate of cholesterol and fat absorption, and delaying gastrointestinal emptying. Thus, cereals can be termed an emerging nutraceutical which offer opportunities for inclusion as probiotics, prebiotics, and fiber in the human diet.

6.2 Pearl Millet \textit{[Pennisetum glaucum (L.) R. Br.]} 

Common names: Bulrush millet, spiked millet, cattail millet, candle millet, \textit{bajra} 

Pearl millet (family: Poaceae) is an annual, diploid (2n = 2x = 14), C4 crop grown in arid and semiarid tropical regions of sub-Saharan Africa and Asia as an important grain and forage crop (Fig. 6.1). It is grown in about 29 million hectares in more than 30 countries across the globe and accounts for almost half of the total worldwide production of all millets. This climate-resilient crop can be grown in harsh and adverse agroecological environments with meager rainfall and less access to irrigation, high temperature stress, and poor soils. According to FAOSTAT (2014), pearl millet is the sixth most important cereal crop in the world next to rice, wheat, maize, barley, and sorghum. Also the nutritious value of pearl millet is better than some of the commonly used cereals like rice, wheat, maize, and sorghum due to abundant levels of protein, vitamins, essential amino acids, antioxidants, and essential micronutrients. Thus, pearl millet can be considered as an important crop for utilization in the marginal areas and can be used to alleviate hidden hunger prevalent among the poor village communities.

![Fig. 6.1 Pearl millet (Reprinted from Dias-Martins et al. 2018, with permission from Elsevier)](image)
6.2.1 Namibia: Maria Kaherero Composite (MKC)

Maria Kaherero Composite (MKC) is a success story in pearl millet breeding in Nigeria that integrated farmers in the breeding process and led to development of new varieties. The origin of the word MKC comes from a field belonging to a farmer named Maria Kaherero located in the Kunene region of Northern Namibia. The pearl millet breeding program in Namibia can be traced back to 1987 when International Crops Research Institute for Semi-Arid Tropics (ICRISAT) began the genetic improvement program in collaboration with a nongovernmental organization called the Rosing Foundation that was established in 1978. Within 2 years farmers identified an early maturing, large grained variety ICTP 8203 for release under the local name Okashana-1, but it showed susceptibility to storage pests and lodging that limited its use. However, the local farmers grew Okashana-1 alongside local cultivars that led to introgression of grain hardness and sturdy stalk. This methodology was followed for four cropping seasons. The ICRISAT program integrated the farmers in breeding program at all stages of varietal development. The cultivators visited the experimental farms and exercised selection as well as monitored the program along with the breeders. The half-sib progenies from Maria Kaherero’s were selected and randomly mated with 30 farmer selected varieties during the 1992–1993 crop season and thereafter for 3 successive seasons. The result was the Maria Kaherero Composite (MKC). Field trials of accessions from MKC and its comparison with varieties developed through classical plant breeding showed that majority of the genotypes selected by farmers in coordination with the breeders were early maturing, thick stemmed, medium to tall plants having excellent seed set with large bold grains.

6.2.2 India

Rajasthan, the largest state of the Union of India, has a net cropped area of 20 million hectare of which only 20% is irrigated and bulk is rainfed. Pearl millet is an important food and fodder crop in Rajasthan since the weather is arid and hot, and large portion of the state frequently encounters drought. In this arid zone, the farmers normally prefer the cultivation of landraces since the modern varieties show poor yield under drought stress. However, some cultivators prefer modern varieties (MVs) that have been developed without farmer participation, due to their high yield under conducive environments. Another group of farmers mix small amount of MVs with landraces to avoid total yield loss in the event of drought.

Local farmers divide pearl millet into two broad groups primarily on the basis of phenotypic and developmental traits:

(i) Local landraces (“desi”)
(ii) Modern varieties (“sankar”)

---

6.2 Pearl Millet \([\textit{Pennisetum glaucum} (L.) R. Br.]\)
A detailed study was undertaken to quantify the effects of farmers’ seed management practices on the adaptability and performance of important traits under different abiotic stresses with the objective of testing the fruitfulness of the different selection methods followed by the farmers’ and determining the effectiveness of different characters as selection criteria. Table 6.1 denotes three management groups that were set up for the pearl millet farmers in the region:

(i) Farmers who grew and maintained pure landraces only. This group also preferred a winnowing method for separation of the seed and food grain.
(ii) Farmers who occasionally introgressed modern varieties and used the winnowing method.
(iii) Farmers who frequently introgressed MVs into their seed stock and practiced panicle selection for separation of the seed from food grain.

It was observed that the plant morphological and agronomic traits employed by the farmers in describing adaptive value and productivity proved to an effective approach in discriminating the pearl millet genotypes showing adaptation to various types of stresses. The cultivators in the region were of the view that the MVs were less adaptable to stress conditions which was possibly due to their development and testing at experimental farms under favorable conditions. Since drought is a major limiting factor in Rajasthan, the farmers gave high priority to ensuring an adequate food supply during water scarcity. Pure varieties exhibited a trend toward improvement in yield-related characters under water stress, but the condition reversed for populations’ introgressed by MVs. The formal breeding programs in the region had the objective of achieving higher productivity across a wide range of environments, while the farmers gave preference to risk avoidance, followed by nutritional productivity and quality. It was observed that farmers’ seed management could form an important component of participatory programs in Rajasthan where the cultivators would play a pivotal role in local-selection decisions.

### 6.3 Finger Millet (*Eleusine coracana* L.)

Finger millet, commonly referred to as korakan or ragi (in India), dagusa (in Ethiopia), and rapoko (in South Africa), is widely grown as a grain crop for edible use in Eastern and Central Africa, India, and Sri Lanka with the cultivation extending to Southern China, the hills of Southeast Asia into the hills of Taiwan, and parts of Indonesia and Guam. *Eleusine coracana* was first domesticated about 5000 years ago in the highlands of Ethiopia and Uganda, and thereafter spread to the lowlands of Africa. About 3000 years ago, the crop was introduced in India, thus making it a secondary center of diversity. With a production of 4.5 million tons, finger millet is fourth in production among millets next to sorghum, pearl millet, and foxtail millet in that order. It is an allotetraploid, self-pollinated, herbaceous grain crop (family Poaceae) (Fig. 6.2) that forms the main staple food for millions of people living on marginal lands and with limited economic resources especially in Africa and Asia.
Table 6.1 Description of genetic materials examined in this study

<table>
<thead>
<tr>
<th>Categories</th>
<th>Region of origin</th>
<th>Abbreviation</th>
<th>Grain stock characterization</th>
<th>Farmers’ seed management</th>
<th>Number of stocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management group</td>
<td>Western Rajasthan</td>
<td>LR</td>
<td>Pure landraces</td>
<td>Winnowing</td>
<td>3 3 8</td>
</tr>
<tr>
<td>IG1</td>
<td>Landraces with occasional introgression of modern varieties</td>
<td></td>
<td>Winnowing</td>
<td>6 6 7</td>
<td></td>
</tr>
<tr>
<td>IG2</td>
<td>Landraces with frequent introgression of modern varieties</td>
<td></td>
<td>Panicle selection</td>
<td>6 6 3</td>
<td></td>
</tr>
<tr>
<td>Farmer-multiplied modern variety</td>
<td>Central Rajasthan</td>
<td>MVF</td>
<td>Farmer-multiplied RCB-IC 911, farmer-generated modern variety composites</td>
<td>Seed multiplied by farmers</td>
<td>21</td>
</tr>
<tr>
<td>group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modern variety group</td>
<td>ICRISAT genebank</td>
<td>MV(^a)</td>
<td>HHB67 (68), ICMH 356 (69), ICMH 90852 (70), CZ-IC 912 (71), ERajPop C0 (72), RCB-IC 911 (73), IVMV 155 (74), RCB-IC 924 (75), CZ-IC 922 (76), FCB-IC 846 (77), RCB-IC 956 (78), CZ-IC 923 (79)</td>
<td>Released or experimental varieties</td>
<td>12</td>
</tr>
</tbody>
</table>

\(^{a}\)In brackets entry number

Reprinted by permission from Springer Nature (vom Brocke et al. 2003)
A unique feature of the crop is its ability to grow on marginal soils that support little plant growth as well as little requirement of irrigation and other agricultural inputs. The seeds of finger millet are a rich source of protein (5–8%), essential amino acids (leucine, methionine, phenylalanine), dietary fiber (15–20%), and a range of minerals which makes it nutritionally superior to common cereal crops like wheat, rice, and maize. The plant is especially treasured for its exceptionally high calcium content (0.34%) which is quite high as compared to 0.01–0.06% in most other cereals. Besides this, the plant is known to have several health benefits like hypoglycemic, hypocholesterolemic, and anti-ulcerative effects along with providing protection against cardiovascular diseases, type II diabetes, gastrointestinal cancers, and a range of other disorders. Recent studies have demonstrated that the plant exhibits antidiabetic, anti-tumorigenic, atherosclerogenic effects, antioxidant, and antimicrobial properties.

6.3.1 India

In India, Karnataka is the largest finger millet producing state accounting for 56.21 and 59.52% of area and production of the crop. PPB approach was followed in Chitradurga, Holalkere and Hosadurga taluks of Chitradurga district of Karnataka for identification of cultivars suited for harsh environments and acceptable to resource-poor farmers. The study was carried using six finger millet varieties that were evaluated in a farmer managed varietal trial (FAMPAR) involving 150 farmers from 7 villages. It was observed that the participatory approach was highly effective in identifying varieties for cultivation in extreme environments and sporadic/specific niches which are difficult to replicate in the research station. Other benefits of PPB include the high rate of adoption of varieties identified and significant reduction in the number of years required for varietal identification and adoption.
6.3.2 Ethiopia

Finger millet is an important crop in Ethiopia in terms of usage and is cultivated on approximately 5% of the total land devoted to cereal production. In 1993, 57 finger millet lines were introduced from East African Regional Sorghum and Millets Network (EARSAM), and two of the lines were released in 1998 with the names “Tadesse” and “Padet” and another line named “Boneya” in 2002. However, in spite of the release of a number of improved varieties for the farmers, the crop yield is low due to nonparticipation of the farmers in the breeding process and the resulting ignorance about the varieties. In 2010 a breeding program was initiated in the districts of Chilga and Delgi in Northwestern Ethiopia using eight varieties of finger millet for selection of varieties taking maturity period, yield, and disease resistance as the selection criteria. Farmers were involved in the evaluation and selection of improved finger millet varieties through the formation of farmer research extension group (FREG). The selection criteria followed by the farmers were more or less similar in both the districts with the farmer relying on uniformity, maturity period, finger length, number of fingers per ear, tillering capacity, yield, resistance to blast disease, and seed color (Table 6.2). Based on these traits, varieties Tadesse and Wama for Delgi, and Degu and ACC#213572 for Chilga were recommended.

6.3.3 Tanzania

Another study was conducted in Tanzania, which is located in Eastern Africa within the African Great Lakes region and is home to around 55 million people. Agriculture accounted for 24.5% of gross domestic product in 2013 and for half of the employed workforce in this country. Finger millet is used as a minor food crop in subsistence farming systems in Tanzania since it is drought tolerant and nutritious and can be stored for a long time without risks of insect damage. Like in Ethiopia, the improved varieties released by research centers were less popular among the farming communities because the varieties were neither evaluated in the cultivator’s fields nor had any involvement of the farmers. This resulted in less interest among the farmers’ leading to ignorance about the agronomic practices as well as their economic potential. Thus a participatory approach was carried out in Central Tanzania between 2009 and 2015 to identify, evaluate, release, and promote finger millet varieties. Eight genotypes selected from regional Multi Evaluation Trials (MET) for high yield and resistance to blast along with a local variety were evaluated for adaptation in 15 farmer fields each in Singida and Iramba districts of Central Tanzania. After identifying the production and market constraints, farmers were asked to rank the varieties based on their preferred traits during the field trials when the crop was at physiological maturity. The traits were classified into the following three types:

(i) Most important: high yield, large fingers, and marketability
(ii) Important: drought resistance, early maturity, good taste, large grains, and grain color
(iii) Less important: blast resistance
<table>
<thead>
<tr>
<th>Variety</th>
<th>Merits</th>
<th>Drawbacks</th>
<th>Rank</th>
<th>Merits</th>
<th>Drawbacks</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tadesse</td>
<td>Good grain filling and tolerance to blast</td>
<td>Short finger length, low tillering capacity, and low straw biomass</td>
<td>4</td>
<td>Broad fingers, tolerance to water logging, early maturing</td>
<td>Its fingers quite short</td>
<td>1</td>
</tr>
<tr>
<td>Acc#213572</td>
<td>Very good tillering capacity, high effective tiller and biomass, high numbers of fingers, and long fingers</td>
<td>Susceptible to blast</td>
<td>1</td>
<td>Large number of fingers, long fingers, and high straw biomass</td>
<td>Susceptibility to blast and late maturing</td>
<td>2</td>
</tr>
<tr>
<td>Degu</td>
<td>Large number of fingers, effective tiller, and high straw biomass</td>
<td>Weak stalk and susceptible to blast</td>
<td>3</td>
<td>–</td>
<td>Late maturing, short finger length</td>
<td>5</td>
</tr>
<tr>
<td>Boneya</td>
<td>–</td>
<td>Short and low number of fingers, poor tillering capacity</td>
<td>7</td>
<td>Long plant height, early maturing, and water logging tolerance</td>
<td>Poor stand and tillering capacity</td>
<td>4</td>
</tr>
<tr>
<td>Baruda</td>
<td>–</td>
<td>Low number of fingers, short plant height, poor tillering capacity, and late maturing</td>
<td>8</td>
<td>–</td>
<td>–</td>
<td>8</td>
</tr>
<tr>
<td>Wama</td>
<td>–</td>
<td>Short and low number of fingers, poor tillering capacity</td>
<td>6</td>
<td>Good grain filling capacity, long plant height, water logging tolerance, and high biomass</td>
<td>Poor tillering, lack of uniformity at maturity</td>
<td>3</td>
</tr>
<tr>
<td>BRC-029</td>
<td>High straw biomass and good tillering capacity, long fingers</td>
<td>Short and low number of fingers</td>
<td>5</td>
<td>–</td>
<td>Short plant height, low number of fingers, late maturing, and poor tolerance to water logging</td>
<td>7</td>
</tr>
<tr>
<td>Local</td>
<td>Very good tillering capacity, long fingers, high number of fingers, high straw biomass</td>
<td>Susceptible to blast</td>
<td>2</td>
<td>Long plant height, poor tillering</td>
<td>Susceptible to blast, late maturing</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: Fentie (2012)
It was observed that the farmers were interested in selection and maintenance of varieties not just for yield but other traits like better compatibility with local farming systems and socioeconomic structures. This was done by selecting of traits like taste, grain color, grain size, head size, and compact head shape. Significant correlation was observed between the farmers selected varieties and grain yield which highlighted their importance in variety evaluation and selection. Using participatory approach, there was high rate of adoption of the identified varieties and a significant reduction in the number of years that were required in the varietal identification and adoption. Male and female farmers differed in their perception of selection with the males selecting for market-linked characters like yield and grain color while the female farmers giving preferential treatment to risk averting characters like maturity period, drought tolerance, and disease resistance.

6.4 Barley (Hordeum vulgare L.)

Barley (Hordeum vulgare L.) (family: Poaceae) is the fourth most important cereal crop after maize, rice, and wheat and has been in cultivation since the last 10,000 years. Barley is one of the oldest cultivated crops and has originated from its wild ancestor H. spontaneum in the Fertile Crescent where a large number of barley grains have been unearthed at various locations. However, the origin of H. vulgare cannot be commented upon with certainty since H. spontaneum has been discovered in several geographically distinct locations other than the Fertile Crescent in many countries like Morocco, Algeria, Libya, Egypt, Crete, Ethiopia, and even as far as Tibet which possibly point toward the multicentric origin for this crop. Recent molecular studies indicate toward an additional center of domestication in Central Asia at the eastern edge of the Iranian Plateau which is considered to be the center of origin for cultivated barley from South and East Asia.

Barley is a diploid (2n = 2x = 14) plant with a genome size of 5.1 Gb. Barley shows great genetic diversity that is amply manifested in the different morphological forms available in nature. A large amount of diversity is visible in the mature inflorescence of cultivated barley consisting of the floral stem (rachis) and floral units (spikelets) (Fig. 6.3) as well as the grains (Fig. 6.4). The crop is cultivated across a wide range of ecological zones in the world ranging from sea level to high altitudes (up to 4500 masl) and even close to the Arctic Circle. The crop is adapted to stressful environmental conditions and has the ability to thrive on marginal lands. Although barley is mainly used for malt production, the plant finds an important place in the preparation of healthy foods due to various health effects like lowering blood cholesterol, regulating glycemic index, and potent antioxidant activity. The plant finds an important place in stress biology research due to its natural tolerance to drought, salinity, fungal diseases, and a range of abiotic stresses.

There has been significant headway in barley breeding with respect to traits like grain morphology, higher yield, malt quality, and resistance to various biotic and abiotic stresses. In 1991, the International Center for Agricultural Research in the
Dry Areas (ICARDA) took the lead to decentralize barley breeding resulting in a number of participatory barley breeding programs in countries like Syria, Egypt, Jordan, Tunisia, Morocco, Yemen, Algeria, Iran, and Eritrea.

6.4.1 Syria

Ceccarelli et al. (2000) compared farmers’ and breeder’s selections on experimental farms and in cultivators fields in the northern part of the Fertile Crescent in Syria using 208 barley lines and populations within several environments, most of which were harsh and low potential environments that were unfavorable for high yields.

The germplasm were planted in nine farmers’ fields and in two of ICARDA’s research stations, viz., Tel Hadya, a high-input favorable environment, and Breda, a low-input stressful environment and had the following contrasting traits:

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**Fig. 6.3** Variation of lateral spikelet fertility in intermedium-spike barleys. A. Spikes of normal two-rowed barley “Bowman,” normal six-rowed barley “Morex” and three intermedium-spike barleys with awns removed. B. Distribution of lateral spikelet fertility in 298 intermedium-spike accessions. C. Spikelet triplets of seven intermedium-spike barley. (Reprinted by permission from Springer Nature: Youssef et al. 2017)
(i) Modern germplasm vs. landraces
(ii) Fixed lines vs. segregating populations
(iii) Two rowed vs. six rowed
(iv) White seed vs. black seed

A number of selections were performed that have been provided below:

(i) Individual selection by each participating (host) farmer alone on his own field (decentralized, individual farmer selection): each farmer decided which traits to score for, when, and how often. Each farmer did his final selection by visually inspecting the seed of those entries which received the best score during the last selection before harvesting. Farmers based their selection solely on the performance of the lines in their own field and did not use the performance of the lines in Breda and Tel Hadya although this information was available to them.

(ii) Centralized, farmer’s selection: In this the selection was done for quantitative as well as qualitative data for two consecutive days by the farmer with the help of a researcher.

(iii) Centralized, breeder’s selection and decentralized, breeder’s selection: These were carried out by the senior breeder of DASR (Directorate of Agricultural and Scientific Research) in the farmers’ fields as well as in the experimental plots of Breda and Tel Hadya. The task was carried out independent of the...
farmer’s selection when the crop approached maturity by taking the phenotypic characters into account.

(iv) *Decentralized, farmers group selection:* This was a group selection for both qualitative and quantitative traits carried out by a group of farmers at five of the nine farm locations using visual selection.

The similarity/differences in the selection process carried out by the farmer, group of cultivator, and the breeder in diverse environments were compared in the following ways:

(i) Both farmers and breeder in the farmer fields
(ii) Farmers in their fields and the breeder in the research centers
(iii) Breeder in the research centers as well as in the farmers’ fields
(iv) Farmers in the research centers as well as in their fields
(v) Both breeder and the farmers in the research centers
(vi) Breeder in the farmers’ fields and the farmers in the research stations

Table 6.3 provides the breeder’s and farmer’s selections in each of the nine locations. It was observed that the breeder selected more number of lines as compared

<table>
<thead>
<tr>
<th>Location</th>
<th>Selected by</th>
<th>Type of germplasmb</th>
<th>Total</th>
<th>Fix</th>
<th>Seg</th>
<th>Mod</th>
<th>Land</th>
<th>6R</th>
<th>2R</th>
<th>W</th>
<th>M</th>
<th>B</th>
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<tr>
<td>Ibbin</td>
<td>Farmer</td>
<td></td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>11</td>
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<tr>
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<td>32</td>
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<td>20</td>
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<td>48</td>
<td>74</td>
<td>50</td>
</tr>
</tbody>
</table>

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aExcept for the totals, the other data are the percent of the total number of lines of that group in the 208 entries

bFixed (Fix) or segregating (Seg), modern (Mod) or landraces (Land), six- (6R) or two-row (2R), white-seeded (W), black-seeded (B), or mixed for seed color (M)
to the farmers in all the locations which was due to different selection procedure. Likewise the farmers were generally more successful in identifying the highest yielding lines in their fields (Table 6.4). This was due to the fact that the breeder identified more number of high-yielding lines during the selection process and hence had low percentage success.

### 6.4.2 Morocco

Barley is also an important annual rainfed crop in the marginal areas of Morocco, Syria, and Tunisia. ICARDA performed experiments in farmer participation in these countries with the following objectives:

(i) To determine the type and amount of breeding material which farmers’ can utilize effectively
(ii) The suitability of participation by the farmer
(iii) To ascertain the similarities and/or dissimilarities of the selection criteria followed by farmers’ and breeders
(iv) To analyze the effectiveness of farmers’ selection

A variable number of fixed lines and segregating populations of barley were used for plantation in experimental farms representing favorable and unfavorable growing conditions. The same material was tested in farmers’ fields at several locations in the three countries. The experiments at the experimental farms were managed by the breeders, while the trials were looked after by the farmers. Selection was done by both breeders and farmers at their own fields as well as on each other’s fields. A comparison between the outcome of farmers’ and breeder’s selection at two farmers’

---

### Table 6.4

<table>
<thead>
<tr>
<th>Location</th>
<th>Selection done by</th>
<th>Farmer in his field</th>
<th>Breeder in farmer field</th>
<th>Farmer in Tel Hadya</th>
<th>Breeder in farmer field</th>
<th>Farmer in Breda</th>
<th>Breeder in Tel Hadya</th>
<th>Breeder in Breda</th>
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<tr>
<td>1</td>
<td>36</td>
<td>21</td>
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<td>13</td>
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<tr>
<td>Means</td>
<td>33.3 a</td>
<td>17.2 b</td>
<td>9.1 c</td>
<td>15.0 bc</td>
<td>11.3 bc</td>
<td>11.1 bc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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*Calculated on the number of selected entries
*Means followed by the same letter(s) are not significantly ($p < 0.05$) different
fields close to the experimental fields Merchouch and Jemaa Shaim (Table 6.5) showed that individual farmers selected about 28% and 10% of the lines at Merchouch and Jemaa Shaim in comparison of 20% and 24% selected by the breeder. In the case of the yield trials (Table 6.5), the farmers selected 21% and 16% of the lines at the farmer’s fields near Merchouch and Jemaa Shaim, while the corresponding value for the breeder was 32% and 37% at the two sites. It was interesting to note that of the 36 lines selected by the breeder, only 2 were not selected by any of the farmers.

### 6.4.3 Algeria

Barley, an important cereal and feed grain in Algeria, is grown along the coastal plain and mountains, generally on marginal land. Barley production in Algeria in 2018 is estimated to be around 1,950,000 tons. PPB programs were introduced with government support in the year 2005–2006 in Algeria, the largest country of Africa having an area of 2,381,741 km². Work on barley was conducted at two experimental stations and four farmer plot for four crop seasons. The study indicated the presence of large amount of genotype x environment interactions (GEI) of which the genotype x locations and genotype x years within locations formed the major part. It was interesting to note that the farmers’ selected differently at the experimental stations and in their fields. Farmers’ primarily selected on the basis of plant height, earliness, kernel weight, and spike numbers and identified high-yielding lines showing that they were at par with the breeders. Based on the agronomic performance and selection criteria of the farmers, 8 lines were selected from the initial 75 lines. Seed of the selections was distributed to the cultivators and process was initiated for their formal release.
6.4.4 Jordan

The efficiency of farmers’ selection was assessed by comparing to breeders’ selection for quantitative traits measured under different rainfed growing environments of Jordan, a young state of Southwest Asia having an area of 89,342 km² and a population of about ten million. In Jordan, barley breeders are more interested in development of early maturing and tall plant ideotypes. One hundred and eighty one entries from ICARDA were grown in South Jordan at the research stations of Ghweer on-station (GhS), Rabba (Ra), Ghweer on-farm (GhF), and Mohay (Mo) with both farmers and breeders carrying out the selection on each of the entries at each location. It was observed that the frequency of farmers’ selections was more significant than the frequency of breeders’ selections (Table 6.6).

6.5 Maize

Maize (Zea mays L.; family: Poaceae; 2n = 20), known as mother grain of Americans, is the third most important cereal crop of the world after rice and wheat. Maize was one of the first plants cultivated by farmers between 7000 and 10,000 years ago from Zea mays ssp. parviglumis, with presence in the Balsas region valley of Mexico about 9000 years ago (Fig. 6.5).

In some archaeological sites in Mexico, corncobs have been found in caves of more than 5000 years old. The inhabitants of several indigenous tribes in Central America and Mexico brought maize to Latin America, the Caribbean, United States, and Canada. The plant was taken by the Europeans to Europe and thereafter by traders to Asia and Africa. The world production of maize in 2013–2014 was 967 million metric tons (MMT) with the United States contributing about 35% of the total production, followed by China, Brazil, Mexico, Argentina, and India. Maize contains about 72% starch, 10% protein, and 4% fat, along with a number of B vitamins, minerals, and fiber, but is deficient in calcium, iron, vitamin B12, and vitamin C. It has diverse uses as food, feed, fuel, fiber, and also a model plant for genetic studies. Maize is unique in the sense that it is cultivated over a broad agroecological zones ranging from sea level to about 3400 meters and exhibits high level of morphological, nucleotide, and structural diversity (Fig. 6.6).

6.5.1 India

Maize has emerged as an important grain crop in India in recent years with production touching 23.7 million tons in 2014–2015 from a mere 4.1 million tons in 1960–1961. Major production of maize is in the states of Uttar Pradesh, Bihar, Madhya Pradesh, Rajasthan, Gujarat, and Punjab which account for over 75% of the area and yield. In 1992, the Gramin Vikas Trust (GVT) undertook participatory rural appraisals (PRA) in the states of Gujarat, Madhya Pradesh, and Rajasthan that primarily aimed to gain information on the maize varieties that farmers were growing and
Table 6.6  Frequency (%) of farmers’ selections (FS) and breeders’ selections (BS) included among the top yielding 20 entries, the tallest 20 entries, and among 20 entries with the highest thousand kernel weight on-station and in on-farm locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Grain yield</th>
<th>Biomass</th>
<th>Thousand kernel weight</th>
<th>Straw yield</th>
<th>Plant height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FS BS</td>
<td>FS BS</td>
<td>FS BS</td>
<td>FS BS</td>
<td>FS BS</td>
</tr>
<tr>
<td>Ghweer on-station</td>
<td>45 20</td>
<td>55 35</td>
<td>40 40</td>
<td>55 40</td>
<td>80 95</td>
</tr>
<tr>
<td>Rabba</td>
<td>35 15</td>
<td>25 25</td>
<td>75 20</td>
<td>25 25</td>
<td>0 50</td>
</tr>
<tr>
<td>Ghweer on-farm</td>
<td>30 25</td>
<td>30 15</td>
<td>25 10</td>
<td>20 20</td>
<td>40 20</td>
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<tr>
<td>Mohay</td>
<td>55 30</td>
<td>35 20</td>
<td>40 20</td>
<td>30 15</td>
<td>65 85</td>
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<tr>
<td>Mean*</td>
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<td>36a 24a</td>
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<td>46a 63a</td>
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</table>

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*Means followed by the same letter in each trait are not significantly different at the 0.05 level using paired-sample t-test
Fig. 6.5 Domestication center and hypothetical diffusion of maize through the Americas and Europe. Picture on the left represents typical ears and kernels of teosinte, the wild progenitor of maize. (Tenaillon and Charcosset 2011)
their opinion with respect to the desirable traits. From 1992 to 1995, PVS trials were conducted on maize varieties, but it was observed that none of the released varieties were popular among the farmers. Therefore, a participatory plant breeding program was initiated with the objective to generate varieties that were more acceptable to the farmers. Maize varieties with white and yellow endosperm were crossed, and population improvement was done in subsequent generations using mass selection for characters identified by the cultivators. One of the many varieties that performed well in experimental farms and on-farm trials, GDRM-187 was released as GM-6 for cultivation in hill areas of Gujarat. GM-6 was early maturing, had improved grain quality, and gave 18% more yield than the local varieties at experimental research stations which made it the most successful variety. The participatory breeding led to development of varieties that took less years as compared to those developed through conventional breeding making it cheaper and more beneficial to the farmers.

### 6.5.2 Mexico

Maize is cultivated in rainfed, small-scale production systems in Mexico and provides about 35% of the daily dietary calories. However, despite the establishment of International Maize and Wheat Improvement Center (CIMMYT) in Mexico and release of a large number of genetically improved maize varieties by both the public and private sector companies, improved maize hybrids or varieties were cultivated on only 20% of the area till the 1990s. Maize formed an important component of The McKnight-funded project “Conservation of Genetic Diversity and Improvement of Crop Production in Mexico: A Farmer-Based Approach” that was formulated to...
assess methods for genetic improvement of crop production in consonance with the broad objectives of conservation of biological and cultural diversity. Five farmer leaders were selected as collaborators in the Chalco region in Central Mexico, and selection was practiced on three different Chalqueño maize types grown by these farmers for both pre- and postharvest traits at three locations, viz., Tecámac (experimental station), Poxtla (farm), and Tlapala (farm). The results obtained across two locations for the selection cycles of each variety have been presented in Table 6.7. Results from three selection cycles performed points to the fact that stratified mass selection without pollination control, with selections carried out by scientists in cultivators’ fields would be beneficial in improving yield in the local varieties used by farmers.

6.5.3  Honduras

Maize is a primary staple grain in Honduras, a Central American country with an area of 112,492 km² and a population of about nine million. Although the crop was grown on about 400,000 ha primarily grown by the smallholder farmers, only 16% of the maize area was under improved varieties in the 1990s. To ascertain the reasons for non-adoption of improved varieties developed by the breeders and to aid the small farmers, a project entitled “Conservation and Enhancement of Maize with Small Farmers in Honduras” was formulated which was a joint effort between the Escuela Agrícola Panamericana (Zamorano) and Cornell University, Ithaca, NY. The project was funded by the Cornell International Institute for Food, Agriculture and Development, an organization that aims at improved global food security. The objective of the project was to evaluate alternative approaches for improvement in maize varieties for marginal farmers along with an important aspect of conservation of the best of genetic variation existing in the traditional varieties. The work was initiated by a survey of ten male farmers in each of the two communities near Zamorano, viz., Galeras and Morocelí. Table 6.8 showed differences in the crop usage criteria on both the locations. Size of ears, grain shape, grain size, and grain color formed the most important criteria for seed selection as per the surveys conducted on the ten farmers. Of these ten farmers, four were selected as collaborators on the basis of their interest and recommendations of the extension workers and on the length of time they had been selecting and saving seed of their own varieties. Thereafter, mass selection was simultaneously exercised on the experiment station at Zamorano and in the collaborating farmers’ fields. The results demonstrated that mass selection done by collaborating farmers in their own fields on their own varieties showed greater yield improvement. This was better as compared to the selection practiced by the breeders in experiment station and suggested the potential of participatory breeding in marginal environments since the conditions at the experiment farms are markedly different from farmers’ fields.
Table 6.7  Means of grain yield and other traits for each of three cycles of selection in five farmer-collaborators’ varieties averaged across two locations (on-farm at Pozitla and on-station at Tecamach, State of Mexico, Mexico), 1998

<table>
<thead>
<tr>
<th>Selection cycle</th>
<th>Grain yield (kg/ha)</th>
<th>Days to flower</th>
<th>Plant Ht. (cm)</th>
<th>Ear Ht. (cm)</th>
<th>Kernel size: Width (cm)</th>
<th>Length (cm)</th>
<th>Shelling (%)</th>
<th>No. ears/plant</th>
<th>Ear length (cm)</th>
<th>No. of kernel rows</th>
<th>Lodging (1–5 scale, 1 = Best)</th>
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<td>Collaborator: S. Altamirano</td>
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<td>280</td>
<td>172</td>
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<td>1.8</td>
<td>0.91</td>
<td>1.2</td>
<td>17</td>
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<td>1.7</td>
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<td>0.8</td>
<td>1.6</td>
<td>0.91</td>
<td>0.9</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>4116</td>
<td>98</td>
<td>106</td>
<td>282</td>
<td>184</td>
<td>0.8</td>
<td>1.8</td>
<td>0.89</td>
<td>1.1</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Collaborator: F. Gonzalez</td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>1</td>
<td>3263</td>
<td>100</td>
<td>109</td>
<td>275</td>
<td>175</td>
<td>0.9</td>
<td>1.6</td>
<td>0.89</td>
<td>0.9</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>3557</td>
<td>101</td>
<td>108</td>
<td>288</td>
<td>173</td>
<td>0.8</td>
<td>1.5</td>
<td>0.89</td>
<td>0.9</td>
<td>17</td>
<td>17</td>
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<tr>
<td>3</td>
<td>4955</td>
<td>97</td>
<td>104</td>
<td>285</td>
<td>172</td>
<td>0.1</td>
<td>1.7</td>
<td>0.88</td>
<td>1.0</td>
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<tr>
<td>Collaborator: M.M. Oca</td>
<td></td>
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</tr>
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<td>1</td>
<td>3214</td>
<td>95</td>
<td>104</td>
<td>267</td>
<td>173</td>
<td>1.0</td>
<td>1.6</td>
<td>0.89</td>
<td>1.0</td>
<td>17</td>
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<td>103</td>
<td>268</td>
<td>165</td>
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<td>1.6</td>
<td>0.91</td>
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<td>285</td>
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<td>0.9</td>
<td>1.8</td>
<td>0.89</td>
<td>1.0</td>
<td>17</td>
<td>15</td>
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<tr>
<td>Collaborator: I. Rosas</td>
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<td></td>
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<td>1</td>
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<td>273</td>
<td>163</td>
<td>1.0</td>
<td>1.8</td>
<td>0.90</td>
<td>0.9</td>
<td>16</td>
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</tr>
<tr>
<td>2</td>
<td>2877</td>
<td>95</td>
<td>108</td>
<td>270</td>
<td>169</td>
<td>0.9</td>
<td>1.6</td>
<td>0.90</td>
<td>0.9</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>3691</td>
<td>100</td>
<td>109</td>
<td>265</td>
<td>173</td>
<td>0.9</td>
<td>1.8</td>
<td>0.91</td>
<td>1.0</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>MSD\textsuperscript{a}</td>
<td>988</td>
<td>4</td>
<td>4</td>
<td>25</td>
<td>24</td>
<td>–</td>
<td>–</td>
<td>0.03</td>
<td>0.2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>CV (%)</td>
<td>17.3</td>
<td>3.1</td>
<td>2.8</td>
<td>6.5</td>
<td>10.3</td>
<td>–</td>
<td>–</td>
<td>2.3</td>
<td>16.5</td>
<td>10.4</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Reprinted by permission from Springer Nature (Smith et al. 2001)

\textsuperscript{a}Tukey’s MSD ($p \leq 0.05$) for comparisons among selection cycles within farmers’ populations
Maize is also an important crop for Portugal and has transformed the country’s agricultural scene with several locally adapted maize landraces. The importance of the crop in Portuguese agricultural economy can be gauged from the fact that around 3000 corn accessions have been stored in the National Plant Germplasm Bank, BPGV. “Pigarro,” a FAO 300 maturity open-pollinated variety (OPV) with white flint kernels, high levels of root and stalk lodging, and high kernel-row numbers, was one of the landraces improved within this project. The study was conducted to ascertain as to if the “Pigarro” initial population changed at phenotypic and molecular levels starting from 1984 and if the farmer’s (FS) and breeder’s selection (BS) led to similar or different breeding outputs. The study also aimed at assessing which selection method (FS or BS) was the most useful for supporting participatory breeding in sustainable farming systems. The results showed that FS was more effective in increasing fasciation-related traits, cob weight and grain yield, while BS was more effective in achieving crop uniformity, plant and ear height reduction and higher resistance to stalk lodging. Molecular analysis confirmed that both the breeding methodologies achieved phenotypic modifications without significantly reducing genetic diversity. However, the morphological traits evolved differently in both the selection methods. Breeder’s selection led to longer ears, less fasciation and more uniformity while FS led to short and wide ears, small kernel size and more fasciation. Farmer’s selection also had a positive impact on yield as compared to selection made by the breeder.

Alves et al. (2017a) carried out a study in Portugal with reference to the participatory breeding program in maize that had the specific objective of assessing the evolution of the maize populations within the participatory breeding program. The principle objective of this study was to assess the effect of on-farm stratified mass selection on genetic diversity and quality traits of economic importance and on the agronomic performance of two open-pollinated maize populations, viz., “Amiúdo” (a yellow flint early population having short life cycle and broad adaptability) and “Castro Verde” (an orange flint late population having tall plants and big ears). Both these populations had been an integral part of the participatory program and were part of the on-farm stratified mass selection carried out in Portugal. The breeding objectives for both the populations, along with the timeline and experimental sites have been provided in Fig. 6.7. Significant improvement in the agronomic performance of one population was observed during the multilocalational trials which

### Table 6.8 Comparison of crop usage criteria at both locations in Honduras

<table>
<thead>
<tr>
<th>Trait/Location</th>
<th>Galeras</th>
<th>Moroceli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain color</td>
<td>Yellow</td>
<td>White</td>
</tr>
<tr>
<td>Maturity period (days)</td>
<td>90–110</td>
<td>85–105</td>
</tr>
<tr>
<td>Seed saved</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Period of use of saved seed (years)</td>
<td>4–20</td>
<td>2–10</td>
</tr>
</tbody>
</table>

Adapted from Smith et al. (2001)
points toward the effectiveness of the selection methodology. Molecular analysis using simple sequence repeats revealed that genetic diversity was effectively maintained in both Amiúdo and Castro Verde throughout the selection process. It was concluded that the simple and low-cost on-farm stratified mass selection could be an effective alternative for the on-farm conservation of genetic resources.

A more recent study of the maize populations of the Portuguese farmers evaluated the quality and agronomic performance in diverse environments. Sixteen enduring farmers' maize populations were collected from small farms located in the Central Northern regions of the country and labeled as broa-x where x referred to name given to each population. Apart from this, nine open-pollinated populations developed from maize PPB in Portugal were also included along with BS22(R)C6, a US-bred broad-based synthetic open-pollinated population. Apart from grain yield, ear weight, and stability parameters (AMMI model), quality parameters like flour’s pasting behavior, nutritional components, and bioactive compounds were evaluated during 2010 across nine different sites. Most (~70%) of the quality traits did not exhibit significant correlation with each other, while some showed weak correlations. The principal component analysis (PCA) carried out to summarize multivariate similarities among the maize populations showed that farmers’ populations were clustered into the same group that was defined by quality components like protein, fiber, carotenoids, α- and δ-tocopherol, and volatile aldehydes. Two quality groups were defined of which group I had majority of the farmers’ populations that had high protein and fiber and lower values of total carotenoids, breakdown viscosity values, volatile aldehydes, and α-tocopherol and δ-tocopherol concentrations as compared to the average values found in group II (Table 6.9). However, variability for particular quality traits was present in this quality group with the populations being heterogeneous, uniquely distinct, and low yielding. The study gave future directions on the exploring alternate routes and more choices for future breeding programs.
Rice has been in cultivation since 7000 years and sustains more than half of the world’s population since it is the second largest crop in total global production after maize. Rice is also an important source of nutrition and energy for millions of people worldwide (Table 6.10). Rice belongs to the genus *Oryza* (family Poaceae), which consists of several wild and two cultivated species, viz., *O. glaberrima* Steud. (African rice) and *O. sativa* L. (Asian rice). It is generally considered that rice domestication took place independently in China, India, and Indonesia, giving rise to Asia’s three varietal groups, viz., *japonica*, *indica*, and *javanica*. Rice genetic diversity is enormous and is estimated to be around 140,000 different genotypes of which the International Rice Research Institute (IRRI) gene bank preserves nearly 100,000 accessions. IRRI is a nonprofit, research organization formed in Los Baños, Philippines, in the year 1960 with support from the Ford and Rockefeller foundations and the Philippine government. Human intervention and domestication of the cereal in Africa led to the adoption, selection, and maintenance of *O. glaberrima* varieties. However, with the introduction of *O. sativa* in Africa, the popular cultivars of *O. glaberrima* like Badande and Jatau (irrigated/ floating), Dan Zaria, Godongaji, and Katsina Ala Shendam (upland) were gradually replaced by the Asian rice.

### Table 6.9 Analysis of variance and comparison of mean values for the quality traits among quality-group I and quality-group II, as defined by cluster analysis (Alves et al. 2017b)

<table>
<thead>
<tr>
<th>No.</th>
<th>Trait</th>
<th>Mean square</th>
<th>P(F)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Quality-group</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>1</td>
<td>Protein (PR)</td>
<td>31.89</td>
<td>***</td>
<td>12.18</td>
<td>9.83</td>
</tr>
<tr>
<td>2</td>
<td>Fiber (FI)</td>
<td>0.87</td>
<td>***</td>
<td>2.36</td>
<td>1.97</td>
</tr>
<tr>
<td>3</td>
<td>Fat (FT)</td>
<td>1.47 x 10⁻⁵</td>
<td>ns</td>
<td>4.97</td>
<td>4.97</td>
</tr>
<tr>
<td>4</td>
<td>Breakdown (BD)</td>
<td>2,537,542.80</td>
<td>***</td>
<td>82.38</td>
<td>746.11</td>
</tr>
<tr>
<td>5</td>
<td>Setback1 (SB1)</td>
<td>933,091.60</td>
<td>ns</td>
<td>1971.63</td>
<td>2374.11</td>
</tr>
<tr>
<td>6</td>
<td>Yellow/blue index (b*)</td>
<td>211.46</td>
<td>ns</td>
<td>16.72</td>
<td>22.78</td>
</tr>
<tr>
<td>7</td>
<td>Total carotenoids (TCC)</td>
<td>2307.99</td>
<td>*</td>
<td>15.86</td>
<td>35.88</td>
</tr>
<tr>
<td>8</td>
<td>α-Tocopherol (AT)</td>
<td>20068.17</td>
<td>***</td>
<td>39.29</td>
<td>98.32</td>
</tr>
<tr>
<td>9</td>
<td>δ-Tocopherol (DT)</td>
<td>627.43</td>
<td>***</td>
<td>16.21</td>
<td>26.65</td>
</tr>
<tr>
<td>10</td>
<td>γ-Tocopherol (GT)</td>
<td>8490.42</td>
<td>ns</td>
<td>244.26</td>
<td>282.65</td>
</tr>
<tr>
<td>11</td>
<td>Total free phenolic compounds (PH)</td>
<td>1083.35</td>
<td>ns</td>
<td>159.64</td>
<td>145.92</td>
</tr>
<tr>
<td>12</td>
<td>ρ-Coumaric acid (CU)</td>
<td>5.48 x 10⁻³</td>
<td>ns</td>
<td>0.35</td>
<td>0.38</td>
</tr>
<tr>
<td>13</td>
<td>Ferulic acid (FE)</td>
<td>4.48 x 10⁻⁴</td>
<td>ns</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>14</td>
<td>Volatile aldehydes (AL)</td>
<td>6.84 x 10⁻¹⁴</td>
<td>***</td>
<td>2,440,756.40</td>
<td>13,337,032.00</td>
</tr>
</tbody>
</table>

<sup>a</sup>P(F), Significance of the F-test for differences between quality groups; ns, nonsignificant; *Significant at p < 0.05; ***Significant at p < 0.001

## 6.6 Rice
Table 6.10  Nutrient content of cooked rice meals

<table>
<thead>
<tr>
<th>Type of rice meal</th>
<th>Serving size (g)</th>
<th>Energy (kcal)</th>
<th>Total carbohydrate (g)</th>
<th>Total fat (g)</th>
<th>Total protein (g)</th>
<th>Dietary fiber (g)</th>
<th>Water (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% brown rice and 75% white rice</td>
<td>300</td>
<td>387.0</td>
<td>82.1</td>
<td>1.5</td>
<td>8.9</td>
<td>3.3</td>
<td>206.6</td>
</tr>
<tr>
<td>50% brown rice and 50% white rice</td>
<td>300</td>
<td>405.0</td>
<td>86.1</td>
<td>1.8</td>
<td>9.0</td>
<td>3.9</td>
<td>202.1</td>
</tr>
<tr>
<td>75% brown rice and 25% white rice</td>
<td>300</td>
<td>423.0</td>
<td>90</td>
<td>2.2</td>
<td>9.1</td>
<td>4.5</td>
<td>197.6</td>
</tr>
<tr>
<td>100% brown rice</td>
<td>300</td>
<td>441.0</td>
<td>93.9</td>
<td>2.6</td>
<td>9.3</td>
<td>5.1</td>
<td>193.14</td>
</tr>
</tbody>
</table>

Adebamowo et al. (2017)

### 6.6.1 Nepal

Rice is the most important crop in terms of area, production and livelihood in Nepal which is primarily an agrarian economy with agriculture accounting for about 60% of the GDP. Rice production in Nepal for the year 2019–2019 is expected to touch around 5.23 million tons.

Rice is grown here in three agroecological regions that have been provided below:

1. **Terai and Inner Terai**: 67–900 masl
2. **Mid Hills**: 1000–1500 masl
3. **High Hills**: 1500–3050 masl

The country also boasts of three major production environments, viz., irrigated, rainfed lowlands, and rainfed uplands, where rice is grown.

*Jethobudho* is a popular aromatic rice landrace of the Pokhara valley of Nepal which has been cultivated since centuries due to high market demand for its quality traits like softness, taste, aroma, volume expansion ability, and superior milling recovery (Fig. 6.8). However, the cultivation of Jethobudho has been fairly low as it is susceptible to lodging as well as numerous diseases, poor access to quality seed, inadequate policy support, and low yield compared to modern varieties.

A participatory breeding program was initiated in the Pokhara valley, Central Nepal to make improvements in market-oriented traits of *Jethobudho* that culminated
in the release of an enhanced landrace named *Pokhareli Jethobudho* after 8 years of participatory research. This study comprised of the following steps:

(i) Setting of breeding goals: This was jointly out by the farmers, breeders, and millers. Traits like flakiness and aroma were considered as important by the farmers along with disease resistance, longer panicle length, and dense grain setting, while presence of awn was not preferred.

(ii) Assessing populations for selected traits: Characterization of 338 accessions was carried out with the results showing high variability for several traits. Forty-six accessions were selected for germplasm enhancement.

(iii) Enhancement of local populations for selected traits: The selected 46 accessions were evaluated by the farmers and breeders on two sites. Six *Jethobudho* accessions present in the short-listed 46 accessions showing good postharvest quality as well as disease and lodging tolerance were bulked and distributed for participatory varietal selection as an improved variety.

![Fig. 6.8 Typical grain and cooked rice characteristics of Pokhareli Jethobudho. (Reprinted by permission from Springer Nature: Gyawali et al. 2010)](image-url)
(iv) Evaluating improved populations: Enhanced *Jethobudho* had superior milling recovery and volume expansion, good physical appearance, and better organoleptic weightage as compared to farmers’ own source of *Jethobudho*.

(v) Testing improved population against farmers’ checks: 260 *Jethobudho* growing farmers formed a part of the participatory variety evaluation of improved *Jethobudho* against with their own source *Jethobudho* during 2003 and 2005.

(vi) Seed multiplication and enhancing seed dissemination systems: A network of three community-based seed production groups of six village level seed producer groups was set up.

(vii) Variety release: The Variety Approval, Release and Registration Committee (VARRC) of Nepal recommended the release of the enhanced rice variety after formal registration by the name of *Pokhareli Jethobudho* in June 2006.

### 6.6.2 India

Rice is also grown as rainfed rice in eastern part of India where old varieties of the crop are grown by marginal farmers with low-input system. In this region the crop yield is limited due to two natural phenomena, namely, flash flooding and water stagnation. Initially small farmers of the region were a part of the breeding process and selected the germplasm as per their choice. However, the presence of limited germplasm limited the gains of farmers’ selection. Native farmers till some decades back grew 2–3 traditional cultivars of rice in the lowland areas of Eastern India since they gave decent yield in severe stress and catastrophic conditions like flooding or drought. The traditional cultivars show the following types of resistance to abiotic stresses:

(a) Submergence tolerance: Begunia, Sabita  
(b) Drought tolerance: Madhukar, Rajshree  
(c) Lodging resistance: Chakia 59  
(d) Water logging: Amulya

Most of the improved varieties introduced in the region failed to compete with the traditional varieties since they gave extremely poor yield in adverse environmental conditions in sharp contrast to the comparatively good performance of the conventional varieties where the farmer obtained at least something to harvest. The problem warranted a novel participatory breeding approach in which the farmers shared their experiences and worked in tandem with the breeders to work out a decent rice improvement program. Two different approaches were followed to achieve this aim:

(a) Medium-term approach: This involved using the modified bulk and pedigree methods along with another culture technique for mass production of doubled haploid lines. This was more preferable for the farmers since the double haploid
(DH) lines were uniform and offered abundant phenotypic diversity which can be selected by the farmers for their own conditions.

(b) Long-term approach: This entailed using population improvement method where the farmer participation was as per his knowledge and expertise. The participatory approach also enabled the farmer to learn more about the development of cultivars and crop management.

### 6.6.3 Thailand

Rice is an important crop in Thailand where the north and northeast area produce bulk of the produce in rainfed lowland areas that cover about 75% of the total planted area. However, rice yield in these areas is highly variable, since drought is the main limiting factor that reduces yield to the tune of almost 50% in severe cases. The modern high-yielding varieties developed at research station conditions were not suited to rainfed environment, leading to poor adoption by the farmers. The situation is complicated by the presence of diverse rainfed lowland rice ecosystems in the country that have different production potentials. The farmers are left with no choice but to follow different production practices and farming systems which enables them to reduce risks. Since understanding farmers’ management strategies and their response to environmental vagaries within the rainfed lowland context would help the breeders to formulate a rewarding breeding program, there has been increased farmer participation in the formal breeding programs. A project entitled “Integration of Farmer Participatory Plant Breeding for Rainfed Lowland Rice Improvement” involving Department of Agriculture, Khon Kaen University, Chiang Mai University, and the Rockefeller Foundation aimed to improve the rainfed lowland rice production systems of the North and the Northeast of Thailand. The project emphasized on the varietal improvement approach in rice within the existing farming systems.

### 6.6.4 West Africa

In Africa, rice is grown across diverse environments ranging from the salty delta of the Senegal River to the highlands of Madagascar. The demand for rice has been steadily growing due to increase in consumption and rapid population growth, especially in the western and central regions. This led to a concomitant increase in production, but this was primarily due to increase in cultivated area rather than increase in yield. Domestic production increased at an annual rate of 3.2% between 1961 and 2005 in sub-Saharan Africa, but was not enough to keep pace with the demand. By the year 2000, the demand supply gap led to massive increase in rice imports in the continent with Nigeria topping the list, followed by Côte d’Ivoire. In the year 2008, Africa imported about ten million tons (Mt) of milled rice at a cost of US$3.6 billion. Although a number of improved varieties were released in many African countries, many rice farmers had no access to new varieties that were better adapted to their
farming environment and likely to sell well on the market. Also the varieties were quite narrow in adaptation considering the diverse agroclimatic conditions prevalent in rice-growing African countries. In Africa two species of rice are grown:

(i) *O. sativa*: The Asian rice had high yield potential but attacked by pests and diseases prevalent on the African subcontinent.

(ii) *O. glaberrima*: The hardy native African rice having a cultivation history of 3500 years but now restricted to infertile upland soils or flood-prone inland valleys in inhospitable regions. The African rice, *O. glaberrima*, was domesticated from *O. barthii*, with a peak genetic bottleneck about 3000 years ago, and is well adapted for cultivation in the environmentally harsh West Africa conditions due to traits for increased tolerance to biotic and abiotic stresses including high temperature, drought, soil acidity, and weed competitiveness.

As discussed earlier WARDA developed the NERICA varieties using the PVS scheme that was divided into three years:

First year: Fields were identified by breeders near villages, and a rice garden trail was set up where traditional and modern varieties were grown with local checks. Thereafter, men and women farmers evaluated the germplasm, and their response was noted.

Second year: Every farmer was provided with about six varieties which he had found attractive for three key features, viz., maximum tillering, maturity, and postharvest. Observers recorded the performance of these varieties along with farmers evaluating the threshability and palatability of these varieties to have a totalitarian view.

Third year: The PVS culminated in providing seeds to the farmers on payment so that he can have access to the variety he had selected according to his preference.

The PVS cycle was quite attractive since it cut short the conventional development time of a variety from 12 years to a mere 3 years.

**6.6.5 Ghana**

Rice production and consumption are on the rise in Ghana where the crop has joined cassava and yams as one of Ghana’s three most-consumed foods. Rice consumption in Ghana is expected to reach 63 kg/capita in 2018. Such is the huge demand of rice in the country that although the domestic production increased by 12% over the 2010–2015 period, consumption increased by double over the same time frame. The rice production in Ghana in 2016 stood at 687,680 metric tons that was less than 50% of the demand, and therefore rice was imported from the United States, Vietnam, Thailand, and Pakistan to bridge this huge gap. The crop is grown in the northern region under hydromorphic conditions which accounts for 40% of the
production and on the slopes and inland valleys in the southern part of the country. Due to lack of multilocational trials, most of the upland farmers grow *O. glaberrima* and *O. sativa* varieties that have not been tested for stability. A number of constraints have been identified in rice production that are provided below:

(i) Incidence of weeds  
(ii) Damage by birds  
(iii) Seedling damage by rodents  
(iv) Drought  
(v) Low fertility  
(vi) Access to good quality seeds

Participatory varietal selection (PVS) was initiated in 1997 at Hohoe using mother and baby trials and later extended to three more regions of the country in the forest and savanna zones. Male farmers in both zones ranked high yield and competitiveness to weeds. Female farmers regarded yield, drought, and early maturity, along with a number of postharvest traits of high preference. Seeds of the varieties identified through PVS were distributed to farmers through a variety of channels mentioned below:

- Other farmers who participated in the PVS trials  
- Seed producer groups  
- Extension officers  
- Lead farmers  
- Mobilization officers

Of these the most successful dissemination was through the mobilization officers who distributed seeds as per a unique method, i.e., for every 1 kg of borrowed seed, the farmer had to return two kilograms of seeds in the next year. It was recognized that participatory methods are an attractive way to produce and disseminate new varieties that have been tailored as per the specific needs of the farmers.

### 6.7 Sorghum [*Sorghum bicolor* (L.) Moench]

Common names: Guinea corn, jowar (India), kaoliang (China), kafir corn, milo (United States), sorgho, maicillo (Central America)  

Sorghum (*2n = 2x = 20*) is an important grain and fodder crop that is a cheap source of nutrition to millions of poor people in many regions around the world. Besides being an excellent source of roughage due to high dry matter yield in areas with scarce rainfall, the low buffering capacity and high nutritional value also make it an important source for silage production. Besides this, the crop also provides raw material for the production of slow-digesting starch, fiber, biofuels, alcohol, and several such products. Sorghum is also used for making several alcoholic and nonalcoholic beverages like *Obiolor*, *Pito*, “Mahewu,” and “Kunu.” The plant is a
rich source of protein, fat, carbohydrates, fiber, calcium, iron, niacin, and a wide range of phytochemicals like phenolics, thiols, anthocyanins, tannins, 3-deoxyanthocyanidin, flavone, and flavanone. The slow-digesting starch, unique array of polyphenols, and the unique flavonoid profile make it an important crop conferring therapeutic benefits like protection against diseases linked to oxidative stress and inflammation, cancers of the gastrointestinal tract, as well as in attenuation of glycemic response.

Based on the allocation of the photosynthetic products, sorghum is divided into two types:

(i) Grain types: small-sized plants having dense panicles used as a food source
(ii) Biomass type: large plants having high total biomass and used as forage, sugar, or biofuel production

Although evidences of consumption of sorghum by the hunter-gatherers exist from as early as 8000 BC, the process of domestication of the plant started in and around Ethiopia at around 4000–3000 BC. The improved plant types were dispersed via people and trade routes into other parts of Africa, India, Middle East, and the Far East. Sorghum exhibits enormous genetic variation for different morphological traits (Fig. 6.9) as well as for abiotic stress tolerance.

Sorghum is an important dietary staple crop in several regions of semiarid sub-Saharan Africa. Five races of *S. bicolor* subsp. *bicolor* are grown across Africa with overlapping geographical distributions:

(i) Bicolor: throughout Africa
(ii) Durra: East Africa
(iii) Kafir: Southern Africa
(iv) Caudatum: East Africa to Nigeria
(v) Guinea: West and Southern Africa

### 6.7.1 Burkina Faso

*Burkina Faso*, (formerly known as Upper Volta), is a landlocked country in West Africa with an area of 274,222 km² and a population of 19 million. Food insecurity has grown to be a structural problem in Burkina Faso with malnutrition rampant among women and children and a large chunk of population suffering from micronutrient deficiencies. About 1.5 million children are at risk of food insecurity in the country. Agriculture plays a primary role in the country’s economy since it employs over 85% of the active population and contributes about 40% of the GDP. However, farming is challenging for most local farmers, especially in the North and Central regions, where the climate is dry, with a brief spell of rainy season leading to less than 400 mm rainfall. Sorghum and millet are major staple crops in the country with sorghum being cultivated across more than 1.7 million ha in low-input cropping systems. A collaborative breeding program was developed
between ICRISAT, Mali, and Burkina Faso wherein Guinea type sorghum hybrids were developed which were suited to the harsh and unpredictable conditions of the sub-Saharan zone. These Guinea type hybrids had up to 30% outcrossing rates and an average 40% higher on-farm yields as compared to best adapted local varieties. In the year 2000 approximately 1,225,223 hectares of area was under sorghum cultivation in Burkina Faso that led to production of 1016 million tons of grain as compared to a mere 306 million tons in 1960. In the Center-West region of Burkina Faso, farmers grew Guinea-type sorghum hybrids landraces on about 1.3 million
hectares of low-input cropping systems located in diverse agroclimatic conditions with farmers having no exposure or awareness to either formal or participatory research. Introduction of high-yielding varieties did not bring any significant yield improvement in the country since formal breeding programs and their objectives were less dedicated toward the farmers’ needs and preferences and also didn’t take into account the prevailing growing conditions of Burkina Faso. A conjoint pedigree breeding program in *Sorghum* was executed in the Center-West region of Burkina Faso over a period of 3 years (2001–2003) in two villages wherein the prospects of combining the scientific expertise and the experience of farmers’ were examined. The following were the major objectives of the program:

(i) Identification and evaluation of farmers’ selection criteria for *S. bicolor* in the region
(ii) Comparison of these criteria with the breeder’s traits and agronomic recommendations resulting from the formal breeding program
(iii) Facilitating amalgamation of the selection criteria of both cultivators and breeders into the early stages of a pedigree breeding program

This research was a collaborative effort between the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), a public establishment under the joint authority of the Ministry of Higher Education, Research and Innovation and the Ministry for Europe and Foreign Affairs, and the Institut de l’Environnement et de Recherches Agricoles (INERA), a public body officially mandated to ensure the formulation, execution, and coordination of environmental and agricultural research in Burkina Faso, together with a number of farmer organizations.

The methodology followed is depicted in Fig. 6.10. Participatory selection was initiated with 53 F3/F4 progenies in field trials managed by the farmers. The cultivators evaluated numerous progenies using three traits considered by them of prime importance, viz., earliness, superior grain quality, and high yield. The breeders followed the normal procedure of measuring and analyzing the agronomic traits. It was observed that the methods followed by the farmer were more multivariate than the breeders approach and led to a better understanding of the three characters mentioned above. Also the selection criteria varied between men and women that justified the need to consult both the groups in decision-making. It was concluded that the farmers were better placed for selection of traits on the basis of progeny and single plants especially when the objective includes improvement in specific agronomic traits that would lead to efficient improvement in terms of selection intensity. A highlight of the study was adjustment made by the breeders to fulfill the diverse needs of small cultivators in the semiarid regions of sub-Saharan Africa. The participatory approach resulted in the production of F5/F6 lines which had greater adaptability to local conditions and fulfilled the demand of the cultivators with respect to superior grain quality.
Mali, the eighth largest country in Africa, is a landlocked state with an area of 1,240,192 km² and a population of 18 million. Agriculture accounted for about 42% to the country’s gross domestic product (GDP) and employed more than 57% of the total labor force in 2016 with millet, rice, and corn being the important crops. However, about 29% of the population is malnourished, and agricultural production is low due to lack of irrigation, postharvest crop losses, underdeveloped markets, fluctuations in the prices of agricultural inputs, and vulnerability to climate change. Sorghum is cultivated mainly in the areas around Ségou, Bandiagara, and Nioro. In 2008 in Mali, sorghum was planted on 986,367 ha of land and had an average yield
of 943 kg/ha. In southern Mali the small-scale farmers do not produce adequate harvests due to stressful environments and rarely use the modern varieties (MVs) developed by professional plant breeders due to lack of appropriate varieties suited for specific marginal environments. Therefore, the cultivators mostly prefer farmer varieties (FVs) which are varieties traditionally maintained by farmers. The FVs include landraces, traditional varieties selected by farmers, MVs adapted to farmers’ environments by farmer and natural selection, and progeny from crosses between landraces and MVs. In modern farming a risk-neutral farmer grows a single variety that gives the highest profits per unit area. But, risk averting, small-scale farmers in stressful environments tend to grow two or more varieties of many crops to escape the vagaries of the weather, diseases, or pests. The number of varieties may also depend on seed source, quality traits, or social variables.

A 15-month field study was carried out in 2001–2002 in the village of Dissan in southern Mali, located at 11°36′N, 7°31′W at an altitude of 344 meter above sea level (masl), and inhabited by a community of farming households dating back to seventeenth or eighteenth century. The objective of the study was to examine farmers’ choices among the traditional sorghum varieties in terms of one or more than one variety, short-cycle or long-cycle varieties, and the interaction between these two choices. Sorghum was the most widely grown crop during the experimental years followed by maize, cotton, millet, and rice. It was surprising to note that the Dissan farmers had no access to MVs until 2002 and no farmer procured any FVs from either Compagnie Malienne de Développment des Textiles (CMDT) or any other agency. The farmers grew only seven guinea race sorghum FVs in 2001 and 2002 which have been provided below:

(i) Kalo Saba – fastest variety
(ii) Bakari Kuruni – only 4-month variety
(iii) Boboka – highest yields without adequate rain
(iv) Nzara – one of the oldest local varieties
(v) Nzaraba – one of the oldest local varieties
(vi) Sanko – newest local variety
(vii) Segetono – Striga-resistant variety

None of the farmer grew all seven FVs, and each farmer grew only some of them as per the rainfall and the resources available at hand. It was in 2002 that the Dissan farmers were exposed to the MVs when four households participated in testing sorghum varieties obtained from the ICRISAT program in Mali. Farmers planted a combination of long- and short-cycle varieties, and the choices were dynamic as a result of response to changing conditions within and beyond their households. Generally the farmers preferred long-cycle varieties for their superior taste and yield and grew them when rain and resources permitted. For example, good rainfall in 2002 compared with 2001 appeared to be the deciding factor in a shift toward a greater number and longer cycle length of varieties. It was concluded that the breeding program should aim toward significant improvement in both the long- and short-cycle FVs and strive for helping the cultivators in making suitable choices that optimize crop production.
As in other developing countries, the farmers of several African countries face constraints in seed procurement which is a fall out of the complex steps and regulations required for producing and commercializing seeds, lack of credit facilities, less knowledge about modern markets, and sociocultural inhibitions. In Mali, many farmers maintain their varieties by selection of panicles for specific phenotypic traits, while some favor food grain for sowing over the time-consuming panicle selection method. Since informal seed supply forms an important component of accessibility of germplasm, it is imperative to study effects of farmers’ seed recycling practices on the variety’s properties. The evolution of the phenotypic purity and genetic integrity of an improved sorghum variety (inbred line) called “Soumba” was analyzed to ascertain the diffusion of the variety through a family-based agricultural system in the Magnambougou village (Dioïla district in Koulikoro region) of southern Mali. Soumba, an outcome of the CIRAD/ICRISAT breeding program introduced in 2003, is an inbred line derived from a cross between a guinea landrace from Uganda and an improved caudatum line from Senegal and has the following distinguishing traits:

(i) White to yellowish grains  
(ii) Medium height of about 240 cm  
(iii) Growth period of 105–110 days to maturity  
(iv) Open glumes  
(v) Corneous endosperm with high amylose content  
(vi) Photoperiod insensitive

Six seed lots of Soumba, recycled for 2 to 6 years by farmers using different practices, were collected from six farmer households and assessed in on-station trials in order to compare their agronomic performance and phenotypic purity (off-type plant frequencies) with control versions of the variety. Additionally, 30 panicle (20 g seeds/panicle) samples were randomly collected from 5 farmer fields sown with recycled Soumba and assessed for phenotypic purity in a progeny nursery. These along with another 150 panicles collected from non-Soumba varieties were also assessed for molecular diversity using 12 simple sequence repeat (SSR) markers to investigate the gene flow and its consequences for the Soumba variety. In fields sown with recycled Soumba seed, 2% and 14% of plants showed phenotypic deviations from the typical Soumba variety. The SSR marker analysis revealed 65 alleles across the Soumba and non-Soumba samples exhibiting considerable diversity that confirmed the existence of the off-type plants observed in the field at the molecular level. The STRUCTURE program revealed admixtures with other varieties in 23% of Soumba plants, confirming the presence of gene flow. It was observed that introgression through gene flow and field contamination could be efficiently reduced by the following methods:

(1) Training provided to farmers in seed production  
(2) Use of isolated fields by the farmers  
(3) Practice of true-to-type panicle selection by the farmers
Although the recycled seeds produced by the cultivators did not meet the specifications for certified seed production due to the presence of a large number of off-type plants, the farmers created a suitable seed stock that was superior to the commercial seed in terms of yield performance.

6.8 Wheat

Wheat (genus *Triticum*) comprises a series of diploid, tetraploid, and hexaploid types categorized as the universal cereals of Old World agriculture. Wheat is one of the world’s “big three” cereal crops occupying second place in terms of production after maize. Wheat is unique in its diversity, uses, and the extent of cultivation. It is grown in about 40 countries and caters to the food requirements of over 35% of the world population. Modern wheat cultivars usually refer to two species:

(i) *Triticum aestivum* (2n = 6x = 42, A_A_BBD): hexaploid bread wheat
(ii) *T. durum* (2n = 4x = 28, A_A_B): tetraploid, hard, or durum-type wheat

Although currently hexaploid bread wheat (*Triticum aestivum*) accounts for about 95% of the world’s wheat production, several other types like einkorn (*Triticum monococcum*; 2n = 14), emmer (*Triticum turgidum* ssp. *Dicoccum*; 2n = 28), and spelt (*Triticum aestivum* ssp. *Spelta*; 2n = 42) have driven the Neolithic revolution in agriculture and have been utilized for edible purposes by humans for thousands of years. As per FAOSTAT the worldwide production of wheat in 2016 was 749.5 million metric tons (mmt) with European Union alone producing about 142.7 mmt followed closely by China (131.7 mmt) and India (93.5 mmt). Wheat is an important source of carbohydrates and has a decent protein content (13%), which is relatively higher than other cereals but relatively is low in quality for supplying essential amino acids. *T. aestivum* originated about 9000 years ago from a cross between domesticated emmer wheat *T. dicoccum* and the goat grass *Aegilops tauschii*, most probably in the south and west of the Caspian Sea. The process of wheat domestication has been quite slow as compared to other crops spanning over 2000 years in the Fertile Crescent. Wheat has been spectacularly successful in the temperate regions of the world primarily due to its adaptability and high yields. However, one key characteristic that is often overlooked is its ability to form dough from the flour (viscoelastic property) that allows it to be used in a large range of processed items like breads, cakes, biscuits, pasta and noodles, and other processed foods. These properties are mainly dependent on the structure and interactions of the grain storage proteins, which together form the “gluten” protein fraction.
6.8.1 Bangladesh

Wheat occupies an important place in the agriculture of Bangladesh, a densely populated country situated in Southern Asia having an area of 143,998 km$^2$ and home to about 164 billion people. Apart from having a major part of the Ganga-Brahmaputra delta and evergreen hills in some areas (northeast and southeast), Bangladesh is predominantly rich fertile flat land. Wheat is the second most important cereal crop in the country, and the country produced about 13.02 lakh tons of wheat in the crop year 2013–2014. However, the demand is high, and the country imported 3.1 million metric tons of wheat from 2008–2009 to 2010–2011 for fulfillment of domestic demand. Twenty-four wheat varieties released by the Wheat Research Centre (WRC) of Bangladesh’s Agricultural Research Institute (BARI) found less acceptability among the cultivators due to the following reasons:

(a) Conditions at the experimental farms differed significantly from the on-farm conditions leading to difference in performance
(b) Released varieties lacked adaptability and gave different yield under varied conditions
(c) Inadequate knowledge of the farmers about the varieties and the agronomic requirement

This led to the initiation of a participatory variety selection (PVS) program in the year 2002 in greater Dinajpur (main wheat-growing district in Bangladesh) that aimed at involving the farmers in the selection process according to their needs and dissemination of this information to the small farmers so that they may reap the benefits of the farmer-bred varieties. Twenty fine randomly selected farmers were selected to ascertain the constraints faced by the farmers and their requirements using the participatory rural appraisal (PRA) conducted by a 12-member team of breeders, extension workers, NGOs, and an economist. Eight genotypes were selected from WRC stocks according to farmers’ preference and tested in farmers’ fields in 2002–2003.

Field trials were conducted in the following ways using disease-resistant “Kanchan” as a check variety which had been in use in Bangladesh since a long time.

(a) Mother trials (MT) at on-station and farmers’ fields
(b) Baby trials (BT) at three farmers’ fields

MTs were evaluated at maturity and after harvest by a group of 30 farmers in village who were assisted in this task by the breeders, extension, and NGOs. Scoring was done for each trait and for overall preference on a scale 1 to 8, 1 being the worst and
the best score. Baby trials were evaluated by household-level questionnaire (HLQ). After scaling up seed dissemination, the impact of the PVS was measured by a team headed by an economist who was not involved with PVS activity. The data on impact assessment were collected from 30 farmers from each of the three villages by the team using a household-level questionnaire (HLQ). The top six characters (shown below) prioritized according to total scores and ranked through matrix system showed the expectations of the farmers during the PRA. These traits were:

(i) High yield
(ii) Easy threshability
(iii) Input efficiency
(iv) Large spike
(v) Bold grain
(vi) Grain color

High yield was the most sought-after trait, while grain color lagged far behind. Farmers did not give preference to traits like grain size and weight as long as the grain yield was high. BAW 966, BAW 1006, BAW 1008, and Shatabdi came out as one of the best genotypes for “chapati” making. Shatabdi is a semidwarf variety developed by BARI (released in 2000) which is resistant to leaf rust and blight and has a growth period of 105 days. Seed dissemination between farmers was quite remarkable, and seeds of Shatabdi variety were accessible to 47% of the farmers in 2004–2005. Significant increase was observed in the varietal diversity with seven varieties being grown in the target villages. The cultivated area under Kanchan, one of the earliest released varieties, came down from 100% in 2002–2003 to about 24% in the year 2005–2006.

6.8.2 Iran

In Iran PPB began in 2006 with barley in Garmsar (Semnan province), an area with irrigated agriculture, and shortly after in Kermanshah province, under rainfed conditions, with both barley and wheat. The Fars province is an important agricultural region in Iran where wheat is grown on about half a million hectare of land. Three regions in Fars were identified, and the concept took shape with visits to the farmers from CENESTA officials for discussing about their expectations, the participatory approach to be followed, and its possible outcomes. The first cycle of participatory approach started in 2011–2012 at 100 plots with 78 bread wheat breeding lines, 3 released varieties, and 2 landraces (Sardari and Kal Heydari). The trial was set up in the following six villages:

(i) Kodyan: Shiraz region
(ii) Hemat Abad: Shiraz region
(iii) Tolombe Khaneh Hassani: Nour Abad-Doshman Ziari region
(iv) Baba Monier: Nour Abad-Mahour region
Data were collected by the Department of Agriculture and statistically analyzed by CENESTA on the following parameters:

- Plant height
- Frost damage (%)
- Lodging (%)
- Resistance to brown rust
- Resistance to yellow rust
- Number of plants per square meter
- Number of seeds in per spikes
- 1000 kernel weight
- Grain yield.

The lines selected from first year trials were used in the second-stage trials in 2012–2013 in only four villages, viz., Shiraz-Kodyan, Shiraz-Hemat Abad, Nour Abad-Doshman Ziari, and Nour Abad-Mahou. In 2013–2014, trials comprising 63 lines (excluding checks) were evaluated. The 3-year data was then subjected to stability analysis of the germplasm during the experimental years. This detailed study resulted in the identification of a number of lines suited for each location whose seed can be multiplied and distributed to the farmers. Similarly many lines have also been identified for their future utilization in PPB programs by the department of agriculture.

### 6.8.3 Indo-Pakistan

Pakistan is primarily an agrarian economy with agriculture employing about 43% of the labor force and contributing 21% to the GDP. The country ranks eighth worldwide in farm output and is one of the world’s largest producers and suppliers of agricultural produce with wheat, sugarcane, cotton, and rice together accounting for more than 75% of the value of total crop output. Wheat is a major crop in Pakistan, and the 2018–2019 wheat production is estimated to be around 26.3 million metric tons. Gilgit-Baltistan, the northernmost administrative territory in Pakistan [known as Pakistan occupied Kashmir (PoK) in India, and claimed by India as its sovereign territory], covers an area of over 72,971 km² and is highly mountainous having the world’s three highest mountain ranges, viz., Himalayas, Karakoram, and Hindukush. Wheat is grown in the region both for grain and straw with the local farmers ignoring the dwarf and semidwarf varieties and preferring those having desirable grain color, bread-making quality, high grain, and straw yield. Thus, crop yield is significantly lower as compared to other parts of the country. Therefore, a study was conducted to assess the impact of participatory varietal selection during 1998 to 2001 in the resource-deficient Gilgit-Baltistan.
region for helping the poor farmers. The program envisaged evaluation of a number of indigenous NARC (National Agricultural Research Centre) elite wheat lines and exotic material from CIMMYT, ICARDA, and Turkey. Based on the farmers’ preference, workshops of field management units, and the data obtained, three germplasm lines giving 50% more yield and desirable characters were selected. The selected germplasm was provided to the village and women’s groups for seed multiplication. A household-level survey conducted in 2007 to review the dissemination of recommended wheat lines showed that the selected wheat lines showed high adaptation rates among the local farmers and were in cultivation on about 70% of the target area due to popularity of these lines among the local farmers. It was concluded that a decentralized approach using farmers’ participation is a critical component in higher adoption rate of the varieties in marginal areas.

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Vegetables

Abstract

Vegetables have been part of the human diet from time immemorial with their usage starting before the advent of agriculture. They are a rich source of vitamins, minerals, trace elements and dietary fiber, and therefore play an important role in human nutrition. Consumption of vegetables provides taste, palatability, increases appetite, and prevents constipation by providing roughages which help in movement of food in the intestine. It has been observed that vegetable consumption reduces the risk of cancer by 15%, cardiovascular disease by 30%, and mortality by 20% which is attributed to the presence of antioxidants like ascorbic acid, vitamin E, carotenoids, lycopenes, polyphenols, and other phytochemicals. A diet rich of vegetables protects human beings from the risk of most common epithelial cancers, several non-digestive neoplasms, and oral, pharyngeal, colorectal, esophageal, and breast cancers. Participatory plant breeding has been used for a number of vegetables ranging from leafy vegetables like amaranth and broccoli to tuber crops like onion and taro. The chapter discusses the various approaches of PPB followed by vegetable crops in different parts of the world.

7.1 Introduction

Vegetables refer to all edible plant matter, including the flowers, fruits, stems, leaves, roots, and seeds that are consumed by humans as food either raw or cooked. Vegetables are low in carbohydrate and fat but are a rich source of vitamins, minerals, trace elements and dietary fiber and therefore play an important role in human nutrition. Such is their nutritional significance that the US Department of Agriculture (USDA) Dietary Guidelines for Americans recommends consumption of five to nine servings of fruit and vegetables on a daily basis. Based on their nutritional profile, vegetables are organized into the following five subgroups:
1. Starchy vegetables
2. Dark-green vegetables
3. Red and orange vegetables
4. Beans and peas
5. Other vegetables

Vegetables have been part of the human diet from time immemorial with their usage starting before the advent of agriculture. Different vegetables formed the diet of people living in different regions of the world as has been provided below:

Aztecs in Central America: tomatoes, beans, peppers, pumpkins, squashes, and amaranth
Incas in Peru: potatoes, quinoa, peppers, and tomatoes
Ancient China: yams, soybeans, broad beans, turnips, spring onions, and garlic
Ancient Egyptians: broad beans, lentils, onions, leeks, garlic, radishes, and lettuces
Ancient Greeks: onions, garlic, cabbages, melons, and lentils
Ancient Rome: broad beans, peas, onions and turnips, and leaves of beets

From consumption by the hunter-gatherers, vegetables found their place on the culinary table after domestication and start of the formal breeding work.

Vegetables are also of immense medicinal importance. It has been observed that vegetable consumption reduces the risk of cancer by 15%, cardiovascular disease by 30%, and mortality by 20% which is attributable to the presence of antioxidants like ascorbic acid, vitamin E, carotenoids, lycopenes, polyphenols, and other phytochemicals. A diet rich of vegetables protects human beings from the risk of most common epithelial cancers, several non-digestive neoplasms, and oral, pharyngeal, colorectal, esophageal, and breast cancers.

7.2 Onion

Common names: bulb onion, common onion

Onion (Allium cepa L.), an allogamous species, is an important vegetable and condiment crop in most continents of the world and is commercially cultivated as a culinary crop in various countries. Onion is in the Allioideae subfamily within the family Amaryllidaceae, which is part of the Asparagales, an order containing about 29,000 of the approximately 60,000 known monocotyledonous species. Onion ranks next to tomatoes in area under cultivation in about 175 countries around the world with a global production of almost 90 million tons per annum. With 7 million acres under onion cultivation, the global average onion yield in 2004 was estimated at 18 t/ha. Three-fourths of the global onion production is done in countries like China, India, the USA, Russia, Spain, Iran, Turkey, Brazil, and Japan. Although the genus Allium exhibits different ploidy levels, viz., 2x, 3x, 4x, and 5x, Allium cepa is
a diploid species \((2n = 2x = 16)\) having one of the largest genomes among crop plants, with its 17 pico gram (pg) haploid nuclear genome being more than 100-fold larger than that of *Arabidopsis*. Onion is nutritionally rich with about 89% water, 3–5% sugar, 1% protein, 2% fiber, and 0.1% fat. They contain vitamin C, vitamin B6, folic acid, and numerous other compounds like phenols, thiosulfinates, organosulfur derivatives, steroidal, and triterpenoidal saponins (Table 7.1).

The Dutch organic onion growers in 2001 and 2002 developed an ideotype for organic, long storable onion that could be cultivated with no chemical inputs. It was recognized that establishment of base populations of the crop from open pollinating varieties having a broad genetic base was beneficial since it could offer new gene pools for further breeding of onion varieties for low-input organic farming systems. Keeping this objective in mind, the Centre for Genetic Resources, the Netherlands (CGN), Louis Bolk Institute (LBI, based in Bunnik and dedicated to the development of sustainable agriculture, food and health), and three experienced organic farmers having ample experience in onion breeding initiated a participatory breeding project in 2002–2003 to characterize, evaluate, and select promising germplasm for production of a base population. The first year witnessed evaluation of selected accessions under organic farming conditions on criteria important for organic growers, while the second year was dedicated in the establishment of several base populations that could be beneficial in low-input or organic breeding programs. The characterization and evaluation of the same germplasm clearly showed the differences in the evaluation criteria of the farmers and the researchers. CGN characterized the germplasm as per their standard descriptor list taking a number of standard varieties as reference, while the cultivators gave emphasis on usefulness and selected traits (like leaf color, leaf quantity, and leaf waxiness) that could be used for further selection process. The best performing accessions within the five onion groups were selected jointly by the cultivators and breeders to establish the base populations which may be further exploited to develop better-adapted material for organic farming systems in the region.

Onion is one of the important vegetable produced in Tanzania with the country being tenth in onion production in Africa in the year 2000. Onion is produced in Tanzania for local consumption, but recently exports of the commodity have grown at an exponential pace. Inspite of producing abundant onion, yield of this crop was very low in Tanzania with only 11 t/ha reported for the year 2001. One possible reason for this low yield was the susceptibility of the crop to pests which led to crop losses. This led to the initiation of a survey to collect the information available with the farmers in the Kilosa and Kilolo districts, located in Morogoro and Iringa regions, with respect to production of the crop, pests, and the management practices. A structured questionnaire was designed, pre-tested, and provided to 100 onion growing farmers (60 males and 40 females) in each district for information on production, storage, marketing, pests, pest control measures, and difficulties encountered by the farmers in onion cultivation. The study pointed out that onion thrips (*Thrips tabaci* Lindeman) (*Thysanoptera:Thripidae*) was the highest ranking pest followed by purple blotch (*Alternaria porri*), Mexican poppy weeds (*Argemone mexicana* L.), other weeds, grubs, and grasshoppers. It was observed that although three onion varieties,
Table 7.1 Phenols (mg/g dw; mean ± SD), antioxidant activity (EC50 mg extract/mL; mean ± SD), and total phenols (mg GAE/g dw) of some onion landraces (Liguori et al. 2017)

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<td><strong>Phenols (mg/g dw)</strong></td>
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<tr>
<td>Gallic acid</td>
<td>55.66 ± 2.30a</td>
<td>59.56 ± 1.10b</td>
<td>61.23 ± 2.50b</td>
<td>61.94 ± 1.91b</td>
<td>64.90 ± 1.22b</td>
</tr>
<tr>
<td>Ferulic acid</td>
<td>1.52 ± 0.20a</td>
<td>1.62 ± 0.25a</td>
<td>1.67 ± 0.41a</td>
<td>1.69 ± 0.19a</td>
<td>1.77 ± 0.30a</td>
</tr>
<tr>
<td>Quercetin</td>
<td>6.98 ± 0.42a</td>
<td>7.47 ± 0.30b</td>
<td>7.68 ± 0.28b</td>
<td>7.77 ± 0.30b</td>
<td>8.14 ± 0.20b</td>
</tr>
<tr>
<td>Kaempferol</td>
<td>1.62 ± 0.33a</td>
<td>1.73 ± 0.27a</td>
<td>1.78 ± 0.15a</td>
<td>1.80 ± 0.21a</td>
<td>1.89 ± 0.32a</td>
</tr>
<tr>
<td>Chlorogenic acid</td>
<td>0.84 ± 0.06a</td>
<td>0.90 ± 0.02a</td>
<td>0.92 ± 0.08a</td>
<td>0.93 ± 0.04a</td>
<td>0.98 ± 0.07a</td>
</tr>
<tr>
<td><strong>Antioxidant activity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EC50 (mg extract/mL)</td>
<td>18.80 ± 1.0a</td>
<td>18.50 ± 0.50a</td>
<td>20.90 ± 0.60b</td>
<td>20.25 ± 0.40b</td>
<td>21.27 ± 0.8b</td>
</tr>
<tr>
<td>Total phenols (mg GAE/g dw)</td>
<td>4.75 ± 0.24a</td>
<td>4.90 ± 0.10a</td>
<td>5.14 ± 0.35a</td>
<td>5.06 ± 0.28a</td>
<td>5.31 ± 0.30a</td>
</tr>
</tbody>
</table>

Different letters (a, b) correspond to significant differences ($p \leq 0.05$) among onion landraces
viz., Red Bombay, Red Creole, and Khaki having different characteristics, were cultivated by farmers, there was a need for capacity building for community onion seed-based production for increasing yield and reducing poverty.

### 7.3 Amaranthus

The genus *Amaranthus* (Family: Amaranthaceae, order: Caryophyllales) comprises of about 70 species distributed throughout the world in temperate, subtropical, and tropical climate zones which are known for their nutritional superiority and resistance to various abiotic stresses like heat, drought, diseases, and pests. Amaranth serves as an alternative source of nutrition for millions of people especially in the developing countries, since it is a rich and inexpensive source of nutrients like carotenoid, protein, vitamins (A, K, B6, C, riboflavin, and folate), dietary fiber, and a wide range of minerals (calcium, iron, magnesium, phosphorus, potassium, zinc, copper, and manganese). *Amaranthus* extracts have been used in traditional Indian, Chinese, and Thai medicine as a remedy for urinary infections, gynecological disorders, diarrhea, pain, respiratory diseases, and diabetes and as diuretic. Currently the genus is being explored for anticancerous, antiviral, hepatoprotective, neuroprotective, cardioprotective, and antidiabetic properties. Besides its immense nutraceutical importance, several species can also be grown successfully in varied soils and agroclimatic conditions. The species have been classified primarily on the basis of their utilization method, viz., grain, leafy, ornamental, and weedy amaranth. The genus was domesticated around 8000 years ago by the people of Aztec and the Mayan civilization in South and Central America and thereafter spread to Europe by the 1700s. By the twentieth century, it was cultivated in China, India, Africa, and Europe, as well as in North and South America.

Amaranth is an important component of daily diets for bulk of the population in sub-Saharan Africa where the crop makes a significant contribution to the daily intake of iron and vitamin A of people inhabiting the villages and rural areas. Tanzania is an east African country with an area of 947,303 km² and a population of 55.57 million. Many inhabitants are poor farmers, and about 49.1% of Tanzanians lived below $1.90 USD per day in the year 2011. These areas have rampant malnutrition, vitamin deficiency, and food insecurity. As per the recent Demographic and Health Survey (DHS), 34% or 3.3 million children under 5 years suffer from chronic malnutrition (stunting or low height-for-age), and 58% or 5.6 million suffer from anemia. *A. cruentus* is the most commonly cultivated vegetable amaranth in the country, but there is lack of commercial varieties due to inadequate research work leading to inadequate documentation of farmer-preferred market traits. A participatory program was initiated in 2008–2009 at the World Vegetable Center, Regional Center for Africa, Arusha, Tanzania, for identification of farmer-preferred germplasm and its suitability for genetic enhancement and distribution. The study area for purposive sampling comprised farmers from Arusha, Meru, and Moshi regions who evaluated 84 accessions of the vegetable amaranth. Farmers of these areas cultivated amaranth for markets in nearby areas and thus preferred greenness, freshness, leaf
size and number, and a reduced number of deformed and perforated leaves as selection criteria. The participatory program identified seven accessions for delayed flowering, viz., number 1008, 1004, 1001, 1003, 1002, 5, and 1018. Four accessions had high leaf size (45, 25, 32, and 35), while six accessions (1001, 45, 25, 32, 7, and 35) had excellent taste. Potential accessions identified by the farmers were recommended for multi-locational trials and genetic enhancement in the country.

7.4 Taro

Common names: cocoyam, dasheen, elephant ears, macabo, mukhi kochu, inhame, yìtou, wuh tái, Rukau, satoimo, kolokass, colocasia, dalo, kilkass, ala, gabì, toran, aroei, khoai môn

*Colocasia esculenta* (L.) Schott., a member of family Araceae, is an important vegetable of developing countries in Africa, the Pacific, Asia, and the Caribbean. The plant has been used as a food crop for over 9000 years since it is an excellent source of carbohydrates, dietary fiber, vitamins, potassium, iron, copper, phosphorus, and zinc and contains good amounts of vitamin B complex. The leaves and corms of the plant are consumed after boiling, roasting, or boiling. Taro is probably one of the world’s oldest crops with evidences of its use available as early as 28,000 years ago in the Solomon Islands. Issue regarding its origin is unresolved till now with Northeast India and New Guinea being considered some probable areas where the crop originated. The basic chromosome number of taro is 14, and variations in ploidy like diploid \(2n = 2x = 28\) and triploid \(3n = 3x = 42\) types have been reported (Table 7.2). Genetic studies have indicated that the plant was domesticated more than one time in different regions ranging from India to South China, Melanesia, and northern Australia.

Leaf blight of taro is mainly a foliar disease caused by the fungus *Phytophthora colocasiae* Racib resulting in massive yield losses (50–60%) throughout the tropics and especially in the Pacific Islands. Samoa is a tiny country (area, 2842 km\(^2\)) in the central south Pacific Ocean where agriculture contributes around 7% of the GDP. Taro is an important staple in Samoa both for consumption and income generation. Taro is mostly cultivated in the dryland conditions where the farmer depends on adequate rainfall for good productivity. Apart from this the cultivators are also faced with the appearance of pests and pathogens which leads to production losses that are quite frustrating for them. Initially the yields were high in the region, but the appearance of taro leaf blight (TLB) in 1993 seriously affected crop production and led to massive reduction in yield and income. A conventional breeding program initiated in 1995 for addressing this problem failed due to non-connectivity with the farmers and nonfulfillment of their requirements. Therefore, an urgent need was felt for a more cohesive breeding program involving farmers from diverse regions so that selection could be made for different environmental conditions. Taro improvement project (TIP) was initiated at the University of South Pacific (USP) in 1999 with the objective of bringing together the taro farmers for providing them a suitable
Table 7.2  Somatic chromosome number, karyotypic parameters, and 4C DNA content of ten varieties of *C. esculenta* var. *antiquorum* (Das et al. 2015)

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Somatic chromosome No. ((2n = 2x, 3x))</th>
<th>Karyotype formula</th>
<th>Total genomic chromosome length in (\mu)m ± S.D.</th>
<th>Total genomic chromosome volume in (\mu)m³ ± S.D.</th>
<th>F%</th>
<th>4C DNA content ± S.D.</th>
<th>DNA content per chromosome</th>
<th>Genome length Mbp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muktakesi</td>
<td>28</td>
<td>4A + 12B + 12C</td>
<td>71.20 ± 1.26</td>
<td>28.65 ± 0.66</td>
<td>38.47 ± 0.97</td>
<td>09.25 ± 0.06</td>
<td>0.330</td>
<td>9065.0</td>
</tr>
<tr>
<td>Banky</td>
<td>42</td>
<td>4A + 12B + 16C + 10D</td>
<td>77.00 ± 1.23</td>
<td>29.59 ± 0.35</td>
<td>41.02 ± 0.54</td>
<td>15.22 ± 0.08</td>
<td>0.362</td>
<td>14,915.6</td>
</tr>
<tr>
<td>Sree Kiran</td>
<td>28</td>
<td>2A + 12B + 14C</td>
<td>46.96 ± 2.34</td>
<td>22.24 ± 1.22</td>
<td>24.94 ± 0.56</td>
<td>07.24 ± 0.05</td>
<td>0.258</td>
<td>7095.2</td>
</tr>
<tr>
<td>Telia</td>
<td>42</td>
<td>2A + 18B + 22C</td>
<td>95.19 ± 1.55</td>
<td>36.07 ± 1.30</td>
<td>37.94 ± 0.65</td>
<td>16.98 ± 0.09</td>
<td>0.404</td>
<td>16,640.4</td>
</tr>
<tr>
<td>Sree Pallavi</td>
<td>28</td>
<td>2A + 12B + 14C</td>
<td>53.02 ± 1.25</td>
<td>24.56 ± 1.24</td>
<td>33.29 ± 0.82</td>
<td>08.22 ± 0.08</td>
<td>0.293</td>
<td>8055.6</td>
</tr>
<tr>
<td>Mothan</td>
<td>28</td>
<td>2A + 10B + 16C</td>
<td>55.04 ± 0.95</td>
<td>20.24 ± 0.75</td>
<td>38.43 ± 0.39</td>
<td>08.11 ± 0.08</td>
<td>0.289</td>
<td>7947.8</td>
</tr>
<tr>
<td>Sunajhili</td>
<td>28</td>
<td>2A + 10B + 16C</td>
<td>51.50 ± 2.51</td>
<td>18.22 ± 0.67</td>
<td>35.25 ± 0.76</td>
<td>08.55 ± 0.12</td>
<td>0.305</td>
<td>8379.0</td>
</tr>
<tr>
<td>H-3</td>
<td>42</td>
<td>4A + 18B + 20C</td>
<td>90.64 ± 0.98</td>
<td>31.06 ± 0.98</td>
<td>39.04 ± 0.92</td>
<td>16.10 ± 0.06</td>
<td>0.383</td>
<td>15,778.0</td>
</tr>
<tr>
<td>DP-25</td>
<td>42</td>
<td>6A + 10B + 26C</td>
<td>86.35 ± 2.55</td>
<td>29.03 ± 0.96</td>
<td>34.10 ± 0.45</td>
<td>17.64 ± 0.51</td>
<td>0.420</td>
<td>17,287.2</td>
</tr>
<tr>
<td>Duradin</td>
<td>42</td>
<td>4A + 18B + 20C</td>
<td>100.49 ± 3.24</td>
<td>38.22 ± 1.50</td>
<td>34.25 ± 0.55</td>
<td>18.24 ± 0.25</td>
<td>0.434</td>
<td>17,875.2</td>
</tr>
</tbody>
</table>
program for management of TLB. TIP was unique since it brought the formal breed-
ers, Ministry of Agriculture, Forestry and Fisheries (MAFFM) research and exten-
sion staff, and farmers together for a joint effort. The project had the specific
objective of comparing the taro cultivars using PPB approach and active participa-
tion of the farmers in group discussions (FGDs) on their performance. Participatory
rural appraisals were conducted with farmer groups in the form of interviews, visits,
and group discussions to have a first-hand knowledge about taro cultivation, criteria
used by the farmers for cultivar selection, and the problems faced by the producers.
Farmers were provided with diverse taro germplasm having a range of traits includ-
ing blight resistance for evaluation and selection based on their individual environ-
ments. The cultivators could visit an experimental research station to observe the
cultivars close to harvest, and thereafter the results were again discussed with them.
Farmers were entrusted with the responsibility of management of trials which were
established in blight affected areas and also had the option to visit trials of other
farmers. Data sheets were distributed to each farmer to record the agronomic data
except yield which was collected by the breeders. This coordinated approach involv-
ing farmers and breeders enabled the farmers to quickly select the plant material
suited to them from among a range of cultivars and reduced the risk of recurrent
blight outbreaks in the region.

7.5  Eggplant

Eggplant includes the following closely related cultivated species that belong to
subgenus Leptostemonum of genus *Solanum*:

1. Brinjal eggplant or aubergine: *S. melongena* L.
2. Scarlet eggplant: *S. aethiopicum* L.
3. Gboma eggplant: *S. macrocarpon* L.
4. African eggplant: *S. anguivi*

Eggplant occupies a place of prominence in Tanzania as a vegetable crop conferring
numerous medicinal benefits related to cholera, asthma, dysuria, diabetes, and
toothache. The plant is cultivated throughout the year and ensures food security and
nutritional balance in large sections of the population. However, factors like less
availability of improved varieties, soilborne diseases, and mite infestation limit crop
production in the region. A study was conducted using 26 accessions of four
*Solanum* species during 2008 and 2009 utilizing farmers’ knowledge for identifica-
tion of horticultural traits for establishment of firm breeding objectives to identify
promising accessions for genetic enhancement and commercialization. Farmers
selected the accessions on the basis of intuition, experience in cultivation, as well as
marketing. Most of the cultivators selected Scarlet eggplant as the most preferred
variety followed by Brinjal eggplant, African eggplant, and Gboma eggplant. Farmers
gave high preference to *Fusarium* and *Verticillium* wilts as well as insect
pests. Fruit color showed high preference as compared to fruit yield possibly due to
its attractiveness for the consumers. The participatory selection pointed out that cream-colored fruits were the most preferred, followed by green- and purple-colored ones. Other important traits include fruit yield, fruit size, long fruit production period, and marketability. It was observed that intraspecific hybridization within *S. aethiopicum* (DB3 and MM 1619) and interspecific hybridization between accessions of Scarlet and African eggplants could lead to development of new phenotypes having desirable traits like fruit yield, long fruit production period, and taste. The study culminated in the recommendation of best lines identified through the participatory selection process for multilocation trials and subsequent release in Tanzania.

### 7.6 Yam

Yam belongs to the genus *Dioscorea* (family Dioscoreaceae) that represents more than 600 species worldwide and is a clonally propagated crop mainly cultivated for its starchy tubers. Yams are currently cultivated in about 50 countries worldwide with only a few temperate countries growing this starchy vegetable. The West African region from Nigeria to Côte d'Ivoire produces about 90% of world production of yam and is therefore known as the “yam belt.” Yam is the fourth largest cultivated tuber in the world after potato, cassava, and sweet potato. It is rich in carbohydrates, minerals (calcium, copper, potassium, iron, manganese, and phosphorus), and vitamins (A, B, and especially those of the group C) that are important for human and animal health. Yam is also an important ethnobotanical plant with its tubers being used for birth control and skin infections and curing various diseases in different formulations. The tubers also exhibit antioxidative, antifungal, antimutagenic, hypoglycemic, and immunomodulatory effects. Yams exhibit variability in basic chromosome numbers as well as polyploidy. The basic chromosome number of the American yams is reported to be $n = 9$, while those of Asian and African origins are $n = 10$. Yams show high degree of polyploidy with one race of *D. cayenensis* having $2n = 140$. The two main species of yam were domesticated independently, *D. rotundata* in Africa and *D. alata* in Asia.

Yams occupy an important place in Benin’s agriculture having an estimated production of about 2.73 tons in 2012 with *D. cayenensis* and *D. rotundata* complex occupying more than 95% of the sowing area. Apart from its edible use in the country, about 2–18% of the population also uses yams for medicinal purposes. However, the production of the crop is severely limited in the country due to several biotic and abiotic constraints. An interview-based survey was conducted in 70 villages of Benin representing 11 major ethnic groups that had ample experience of yam cultivation. The questions were primarily based on the cultivation techniques and the maturity period of the varieties (early or late maturing). Of the 313 varieties (named landraces) of *D. rotundata* and *D. cayenensis*, undercultivation roughly half fell in each group, viz., 180 early and 186 late varieties. Early maturing varieties were harvested twice yearly and were grown by traditional farmers living as isolated groups in the remote mountainous areas. Participatory assessment of the varieties by the farmers for their preferred criteria for choice showed that organoleptic
quality (ability to yield good quality *futu*) was the most important criterion, followed by yield. Earliness was important for the milked varieties, while quality of dry chips was important for late varieties. The information on their varieties provided by Benin’s farmers helped in the selection of varieties suited to the various cultivation constraints.

Yam is also an important crop in Ghana which is the third largest producer of the crop in Africa after Nigeria and Cote d’Ivoire. A study was conducted in five yam-growing communities in the Forest Transition Agroecological Zone of Ghana to identify the cultivated varieties of yam and their distribution, the extent of landraces loss, causes, and farmers’ variety preference criteria. A participatory rural appraisal approach primarily based on group discussions and interviews was used to assess the diversity of yams and obtain relevant information from the farmers. *D. rotundata* was the most widely cultivated species followed by *D. alata*, *D. cayenensis*, *D. praehensilis*, and *D. bulbifera*. The selection of the variety depended on the following criteria:

- Good culinary characteristics
- High yield
- Seed generation capacity
- Good storage characteristics
- Resistance to biotic and abiotic stresses

It was concluded that market and utilization were the major factors that resulted in the cultivation of a variety or its gradual disuse.

### 7.7 Broccoli

Broccoli (*Brassica oleracea* var. *italica*; Family: Brassicaceae) is a fast-growing annual plant that grows 60–90 cm tall and whose green-colored flowering head is eaten as a vegetable. Both broccoli and cauliflower were known for 1500–2000 years and probably came from the same gene pools. The term “broccoli” was used for a fairly long time and referred to several forms of plant, mainly the flowering stem of many *Brassica* species. The plant is native to the Eastern Mediterranean and Asia Minor from where it was introduced to England and America in the 1700s. China and India are the biggest producers of this vegetable and together account for about 70% of the world’s output.

There are three types of broccoli:

1. Calabrese broccoli: common “broccoli”; temperate crop with large (10–20 cm) green heads and thick stalks
2. Sprouting broccoli: has large number of heads with many thin stalks
3. Purple cauliflower: grown in Europe and North America and selected in South Africa from Italian forms during the nineteenth century; head shaped like cauliflower but consists of tiny flower buds often with a purple cast to the tips
The plant is an excellent source of vitamin C, vitamin K, and flavonoids and has moderate amounts of B vitamins, folic acid, and dietary mineral manganese. Broccoli has numerous health-promoting properties, and its consumption provides antioxidants, regulates enzymes, and controls apoptosis and cell cycle. With the recent emphasis on more use of microgreens, broccoli is only one of many microgreens that can be conveniently produced and consumed by human beings. Broccoli can be termed as a potential nutraceutical crop since it is a rich source of nutrients as well as beneficial in various human disorders like cancer (bladder, prostate, colon), diabetes, neural disorders, and asthma.

The oceanic climate in the north of Brittany in France facilitates the cultivation of several vegetables especially cauliflowers in different seasons, viz., autumn, winter, and spring. The production of cauliflower in the region developed over a period of time and increased steadily along with a gradual transition from conventional to organic agriculture. Brittany produces about 80% of the total broccoli production in France. However, in spite of the development of the first hybrid winter cauliflower in 1983, it was observed that the research institutions and seed companies only considered their preferences to cater to the needs of commercial agriculture. It was more so for organic farming because of the unsuitability of most modern varieties to the principles of organic agriculture. Therefore, Inter Bio Bretagne (IBB), Plateforme Agrobiologique d’IBB à Suscinio (PAIS), and the French National Institute for Agronomic Research (INRA) collectively initiated a strategy for breeding varieties for cauliflower and cabbage for organic farming followed by farmers’ participation. The cultivators took charge of population breeding using mass selection, and PAIS was responsible for variety improvement and innovative selection, completing the farmer initiatives. PAIS was the focal point for discussions on the aims of plant breeding by collecting the known methods of breeding, experimenting with them, and proposing some new ones.

7.8  Cabbage

Cabbage (*Brassica oleracea* var. *capitata*; family: Brassicaceae) (2n = 18) is a herbaceous, biennial, dicotyledonous flowering plant adapted to cool moist conditions and is cultivated in many countries of the north and south temperate climatic zones around the world. The crop has its origin in Northern Europe, the Baltic Sea coast, and the Mediterranean region where it has been cultivated for about 3000 years. The plant is cultivated for its leaves which form a compact head which is a rich source of vitamin C, vitamin K, moderate source of vitamin B6, and folate along with appreciable amounts of protein, calcium, and iron. Cabbage contains abundant amounts of bioactive compounds like glucosinolates, luteolin, myricetin, quercetin, and polyphenols that confer numerous medicinal benefits to the crop. There are several cultivar groups of cabbage, namely, “Savoy,” “Spring Greens,” “Green,” “Red,” and “White.” In 2014, China was the largest cabbage-producing country followed by India and the European Union.
Cabbage is an important leafy vegetable in sub-Saharan Africa with different forms of the vegetable grown in Kenya, Uganda, Tanzania, Malawi, Zambia, Zimbabwe, Ethiopia, and Cameroon. Tanzania is an important cabbage producer where the crop is cultivated since the mid-1970s and is being grown in the cool highland areas of Arusha, Tanga, Iringa, Mbeya, and Morogoro. Most of the improved varieties released in Africa are less adaptable since they are bred in Europe and Asia. To mitigate this problem, participatory evaluation of varieties alongside head yield was carried out to select preferred varieties. Field experiments were conducted during the 2008 and 2009 seasons at the World Vegetable Center, Regional Center for Africa, Arusha, Tanzania, using 32 hybrid and open pollinated cabbage varieties along with a widely cultivated variety Gloria F1 as check. The following traits were preferred by the farmers and formed the selection criteria for the participatory varietal selection:

- Head size
- Shape and firmness
- Resistance to insect pests and diseases
- Resistance to bolting and loose heads
- Medium and late maturity
- Taste

It was observed that farmer assessment had the potential to improve the relevance of on-station researcher-designed trials to evaluate the varieties and identify the preferred traits. Since preference and selection for varieties might differ within and between locations, the need to conduct similar studies at other locations to note farmers’ preferences and selections was observed.

7.9 Tomato

Tomato (*Solanum lycopersicum; Family: Solanaceae*) is one of the world’s leading vegetables which is consumed worldwide and is used in diverse ways in different world cuisines. Although botanically a fruit (berry), tomato is considered a “culinary vegetable” due to much lower sugar content than culinary fruits. Tomatoes are a rich source of lycopene, β-carotene, folate, potassium, vitamin C (ascorbic acid), chlorogenic acid, flavonoids, rutin, plastoquinones, phenolics, tocopherol (vitamin E), and xanthophylls. It has been observed and proved scientifically that regular consumption of tomatoes may lead to a decreased incidence of cardiovascular disease and reduced risk of breast, colon, lung, and prostate cancers. The worldwide production of tomatoes in 2017 was around 170.8 million tons with China being the leading producer followed by India and the United States. The plant originated in the Andean region now encompassed by part of Chile, Bolivia, Ecuador, Colombia, and Peru. The Aztec word “tomatl” means “plump fruit,” and the crop was called as “tomate” by the Spanish invaders. In Mexico, the plant is known as “xitomate” in the Nahuatl language. Mexico is presumed to be the most probable region of
domestication, with Peru as the center of diversity for wild relatives. The plant was probably introduced to Europe by the Spanish conquistador Hernán Cortés, and its cultivation spread across the region within a short duration. The plant was later introduced to other parts of the world by European explorers and colonists.

Tomato is an important horticultural crop in Europe and especially in Italy. The hybrid varieties for the fresh market are cultivated in open field as well as in greenhouses. However, most of the varieties have been developed outside Italy that has resulted in poor adaptability to the local conditions. Moreover, the cost of commercial varieties is pretty high which has resulted in illegal practice of propagating hybrids by cuttings to reduce production costs. Interestingly, Italy has the highest number of traditional varieties of salad tomatoes in European Union which are highly appreciated by consumers but are less profitable to the cultivators due to the following factors:

1. Susceptibility to low temperatures and consequent low fruit set
2. Susceptibility to fruit cracking
3. Tendency to bear boxed fruits
4. Blossom tip rot
5. Abnormal fruit shape at the blossom end
6. Blotchy ripening at high temperatures

The increasing demand for organic tomatoes led to the initiation of a participatory breeding program for rapid development and delivery of diverse germplasm lines for cultivation in each target microclimate under organic conditions. Visual selection was applied by farmers and researchers in four F2 populations developed by Consiglio per la Ricerca e la sperimentazione in Agricoltura-Unita’ di Ricerca per l’Orticoltura (CRA-ORA) by selfing the F hybrids (05-405, 08-520, 09-611, and 09-651) and in the F3 families obtained from selected F2 plants grown across five locations. The performance of the F2-derived F4 families at the end of two cycles of selection was evaluated by comparing the selected germplasm with four commercial hybrids, viz., “Rally,” “Margot,” “Pozzano,” and “Sakura.” The evaluation and selection were done at each farm independently by the farmers and the researchers using the decentralized participatory and non-participatory selection. The breeding process at the research station was carried out only by the researchers. Agronomic performance was evaluated for diverse traits like plant development, health, vigor, fruiting, rot, green shoulder, true-to-type size and shape, resistance to overripe, and earliness. A total of 15 F4 families were identified, of which three out-yielded significantly the respective commercial F1 hybrid. The putative superior varieties developed from the F4 families represented important germplasm for organic farming as they were likely to assure good productive capacity and seed availability at low cost.

Tomatoes are the largest vegetable crop in Tanzania, grown across thousands of hectares in the regions of Morogoro, Iringa, Tanga, and Zanzibar. However, significant production of tomato in Tanzania is mainly carried out by small-scale producers. Tomato yields in Tanzania are constrained by diseases, insect pests, poor soils,
limited inputs, and limited farmer access to improved cultivars. Besides this, the marginal farmers often lack access to improved cultivars, and breeding programs specifically catering to this target group are totally lacking. Keeping this in view, a participatory crop improvement (PCI) approach was initiated to increase farmer access to improved cultivars through the mother baby trials (MBTs) that are described below:

(a) Mother trials: large, replicated and researcher-led
(b) Baby trials: smaller non-replicated and farmer-led

Tomato cultivars were introduced and evaluated in three villages in the Morogoro Region of Tanzania which was renowned for tomato production. More than a hundred respondents of all age groups (young, middle aged, old) and both sexes (72% male, 28% female) having ample experience in tomato production took part in the surveys. According to the MBT participants, the characteristics important in cultivar selection according to their rank were as follows:

1. Yield – 77%
2. Disease resistance – 68%
3. Durability of fruit for storage and transport – 61%
4. Insect resistance – 39%
5. Fruit size – 39%
6. Drought tolerance – 39%
7. Fruit color – 39%
8. Fruit shape – 26%
9. Marketability – 13%
10. Fruit quality – 10%

Results from baby trials indicated that introduced cultivars were locally acceptable to farmers, except for traits related to marketability. The results of “outcome mapping” used to evaluate participation of the different stakeholders, viz., farmers, extension agents, and village leaders in each of the villages, suggested that high stakeholder participation levels could predict future adoption of introduced cultivars. The findings of the study provided a framework for evaluating, selecting, and breeding tomato using the MBT design for participatory crop improvement.

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Abstract
Fruit is the seed-bearing structure in angiosperms formed from the ovary after flowering. However, the term is restricted to the ripened ovaries that are sweet and either succulent or pulpy. Fruits play an important role in the life cycle of the plant in the dispersal of seeds. Fruits are rich sources of vitamins, minerals, fiber, antioxidants, and a range of phytochemicals. Fruits ripen rapidly and are highly perishable due to which they are sometimes difficult to collect and transport. Therefore, apart from consumed as fresh, fruits are also frozen, canned, or dried. The shelf life of fruits can be extended by use of cooling processes like refrigeration or by the removal of oxygen from their storage or packaging containers. Fruits can be eaten raw or processed into different items like juice, jams, and jellies apart from being preserved by dehydration, canning, fermentation, and pickling.

8.1 Introduction
Botanically a fruit is the seed-bearing structure in angiosperms that is formed from the ovary after flowering. Fruits have an excellent combination of sugars, acids, and aromatic compounds and are consumed by human beings due to their taste and flavor which appears as a result of the ripening process. Fruits are a rich source of vitamins, especially A and C; minerals, especially electrolytes; and phytochemicals like antioxidants. Fruits ripen rapidly and are highly perishable due to which they are sometimes difficult to collect and transport. Therefore, apart from consumed as fresh, fruits are also frozen, canned, or dried. Fruits are an important source of nutrients in many parts of the world and offer advantages over dietary supplements because of low cost and wide availability. Fruit juice offers a balanced diet and promotes good health by serving as an alternative medicine for different ailments like chronic inflammation, arthritis, diabetes, high blood pressure, muscle ache and pains, menstrual disorders, cardiovascular diseases, AIDS, cancers, gastric ulcers, mental depression, arteriosclerosis, drug
addiction, and neurodegenerative diseases. Consumption of fresh fruits is on the rise due to a number of factors like rise in income, aging of a population, market promotion, consumer awareness, year-round availability, and change in consumer preferences.

### 8.1.1 Tropical Fruits

Tropical fruits are a botanically diverse group of fruits indigenous to tropical regions. These fruits have originated and developed in high-temperature climatic zones and present a diversity of fruit cultivars varying in structure, characteristics, and physiology. Tropical fruits are sensitive to cold and are often injured by low temperatures. A similar group that is often merged with the tropical fruits is the subtropical fruits that do not specifically require cold but have slight frost tolerance. Traditionally, tropical fruits were consumed locally, either grown in a subsistence-style agricultural structure or gathered from the wild. Tropical fruits are generally a poor source of proteins and fats but have appreciable amounts of amino acids (tryptophan, methionine, lysine), ascorbic acid, malic acid, tartaric acid, carotenes, vitamin E, carbohydrates, and fiber comprising of hemicelluloses, cellulose, and pectic substances, as well as lignins. Avocado and durian are exceptions since they have a high protein and fat content as compared to other tropical fruits. Apart from their edible use, the volatile compounds present in the tropical fruits are in great demand by the food industries to produce new products which are in great demand by the consumers. It is estimated that more than 90% of the tropical fruit production takes place in developing countries. The most common tropical fruits in edible use come from the following three areas:

1. Central and South America: avocado, guava, papaya, and pineapple
2. Asia: most citrus fruits and litchi
3. South and Southeast Asia: banana, mango, and mangosteen

Demand for tropical fruits has increased at a rapid pace with the European Union being the world’s largest import market, followed by the United States.

### 8.1.2 Temperate Fruits

Fruits that are specifically adapted to climates in the middle latitudes are known as temperate fruits. Temperate fruits require cold period to complete their life cycle and have various degrees of winter hardiness, which conditions their adaptability in cold climates. The area under temperate fruit crops showed a sharp increase in the period 1961–2006, with largest increases observed for blueberries (582%) and plums (446%). By the end of 2009, the total cropped area under temperate fruits reached around 23.5 million hectares. Temperate fruits are usually classified by their growth habit into the following types:

1. Tree fruits: these are members of the family Rosaceae and include the pome and stone fruits. Typical examples include apple, pear, peach, quince, and medlar.
2. Vine fruits: these fruits grow on vines. Examples are grape and kiwifruit.

3. Small fruits: refers to the size of the plant and not necessarily the fruit. Strawberry, raspberry, currant, and blueberry are typical small fruits.

Although participatory programs have been in force for cereals and a number of other crops, fruits have recently gained attention in this regard. Some of the success stories in fruit participatory approaches have been discussed below.

8.2 Olive

Olive (Olea europaea) cultivars and their wild relatives represent two botanical varieties, viz., var. europaea and var. sylvestris. O. europaea has a diploid size of 1.32 Gb (2n = 2x = 46) and is divided into six subspecies: europaea, laperrinei, guanchica, maroccana, cerasiformis, and cuspidata. This predominantly allogamous small tree belonging to the family Oleaceae (order Lamiales) is native to tropical and warm temperate regions of the world and is primarily distributed in the coastal areas of the Eastern Mediterranean basin, the contiguous coastal areas of southeastern Europe, northern Iran, western Asia, and northern Africa. Olive originated in Eastern Mediterranean probably in the north of the Dead Sea, and its domestication took place between 5500 and 5700 years ago. Olive is cultivated on about 9.4 million hectares worldwide with Spain leading the production, followed by Italy and Greece, all of which produced 77% of the world’s olive oil in 2001–2002. These three countries accounted for about 97% of European Union olive oil production, with Spain producing approximately 62% of this amount. Presently cultivation of olive is carried out in several regions of the world, but the Mediterranean region still is the major producer accounting for nearly 98% of the world’s olive cultivation. Outside the European Union, the United States and Argentina are the major producers of olive. Olives are valued as sources of food, wood, and cattle fodder and mainly cultivated for oil and canned fruit production. The fruit is treasured for its peculiar nutritional benefits due to a well-balanced oil composition (highly enriched in monounsaturated fatty acid) and being a rich source of polyphenols and phytosterols. Cultivated olive exhibits enormous genetic variability with about 2600 olive cultivars described till date (Fig. 8.1).

Olive is an important fruit crop in Morocco and is cultivated throughout the country except for a narrow strip along the Atlantic coastline. The cultivated area under the fruit soared from 600,000 ha in 2005 to 640,000 ha in the year 2011. Olive oil contributes about 5% of the agricultural GDP and accounts for 15% of the agricultural exports. Morocco has an ambitious plan of increasing the area under olive orchards to 1.3 million hectares and olive oil production to 330,000 tons in 2020. However, research work on olive improvement in the country is far from satisfactory. Molecular markers have been used to study the genetic diversity in a collection of O. purpurea trees from different traditional agroecosystems in Morocco, featuring interesting agronomic traits that had been selected by the local farmers on the basis of their preferred criteria. The aim of the study was to test
whether the *O. purpurea* tree samples, selected on the basis of local farmers’ knowledge, represented the overall genetic diversity in Morocco and estimate the extent of genetic diversity within the selected *O. purpurea* trees. Eighty-eight olive trees were chosen for their agronomic traits like fruit yield, oil yield, fruit size, low

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**Fig. 8.1** Extent of genetic diversity in olives (Al-Ruqaie et al. 2016)
alternate bearing, usage for oil or fresh consumption, and pulp-to-pit ratio that were based on local farmers’ knowledge. Another set of 57 genotypes (including 8 traditional varieties) that represented the overall olive genetic diversity was analyzed using the same set of SSR loci. Two groups of genotypes were observed:

(a) Genotypes closely resembling the “Picholine Marocaine” variety which resulted from intensive vegetative propagation from a limited number of clones
(b) Genotypes displaying a high number of dissimilar alleles which may have originated from selected spontaneous seedlings

The results exhibited significant difference in allelic richness between the 28 on-farm selected genotypes and the overall olive diversity which indicated that the on-farm selected trees represented a subsample of Moroccan genetic diversity.

8.3 Camu Camu

Camu camu [Myrciaria dubia (Kunth) McVaugh; family: Myrtaceae], a low-growing shrub inhabiting swampy or flooded areas in the Amazonian basin, has gained prominence as an economically important fruit species in recent times. *M. dubia* is diploid (2n = 22) and has a genome size of ~230 Mb. The plant attains a height of 4–8 m, and the dark red to black purple globular fruits contain 5.2% pulp, 19.5% seeds, and 15.3% peel. Prior to the discovery of high ascorbic acid content, the species was seldom used as human food. The species gained prominence on confirmation of high amount of ascorbic acid (vitamin C) in its berries (9–50 g/kg) due to which the fruit is considered to have high nutritional and medicinal value. After reports of high ascorbic acid content, a genetic improvement program was initiated in Peru to cultivate it on the “restinga,” viz., high beaches formed by deposition of the river sediments during flooding. The National Institute of Agricultural Innovation (INIA) and Tropical and Mountain Veterinary Research Institute (IVITA) collaborated to set up the cultivation of *M. dubia* in the first “restinga” trials near Iquitos, Peru, in 1980. In 1991, farmers were invited to participate in the agronomic trials that emphasized on ascorbic acid, yield, precocity, and fruit size which would transform the unimproved species into a lucrative market for the producers. The participation of the farmers increased dramatically from 28 producers in 1994 to about 4000 producers in 1997. After initial reluctance to include farmers in the trials, a planned participatory improvement plan formulated by IIAP and INIA was initiated in the year 2000 to carry on the previous participatory work that included the following aspects:

1. Identification of elite plants by the cultivators and sample collection by the researchers.
2. Incorporation of some plants in on-farm trials and return of the remainder to the farmers.
3. Propagation of best plants obtained from the same seed by the cultivator and exchange of germplasm with other cultivators.
4. Distribution of seeds raised from F2 INIA selections to the cultivators for further evaluation of the germplasm along with their material in the field that facilitated ample cross-pollination.
5. Cultivators play the major role in selection from INIA’s as well as their own germplasm.

The participatory approach resulted in a number of technology transfers in the form of improved seeds and cuttings.

8.4 Feijoa

*Acca sellowiana* (syn. *Feijoa sellowiana*), commonly known as pineapple guava, is an evergreen perennial shrub or small tree of the family Myrtaceae that is grown as an ornamental and for its ellipsoid fruits (Fig. 8.2) which are a rich source of vitamin C. The species is native to southern Brazil, northern Uruguay, northern Argentina, and Columbia. Since the 1950s, there has been growing interest in pineapple guava in several countries for its nutritious fruits having high medicinal value. In Brazil, feijoa is cultivated on a small scale at local level since the fruits are in demand for their unique flavor and aroma and are also attributed to having a number of medicinal properties like antimicrobial, antifungal, anticancerous, anti-depressant, anti-inflammatory, and antioxidant activities. Although feijoa has immense nutritional and medicinal importance, its use remains limited. A participatory approach for the domestication of *A. sellowiana* was carried out in the states of Santa Catarina and Rio Grande do Sul, in southern Brazil wherein the plants possessing desirable traits were selected to achieve commercial cultivation. The process began with the identification and mobilization of farmers that were ready to be a part of the participatory breeding program. Thereafter, an inventory of traditional knowledge was prepared by using ethnobotanical methods where data was collected from four categories, viz., cultivators, users, custodians, and managers.

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**Fig. 8.2** Fruits of pineapple guava. (Source: Didier Descouens- Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=29529627)
The selection criteria followed by the farmers resulted in the selection of 10 promising genotypes out of 300 that were to be utilized in crosses. The next step which is underway involves the mass selection cycles that involves genetic studies on population structures and testing progenies for future evaluation (some already identified in Santa Catarina). Identification of promising genotypes from selected parental material is being carried out by the farmer groups in field studies under diverse environments which would facilitate estimation of production costs and establish ideal agronomic practice for the crop.

8.5  Sweet Cherry/Wild Cherry/Gean

Cherry is the stone fruit (fleshy drupe) of many plants of the genus Prunus. There are about 30 species of cherries most of which are indigenous to Europe and Asia. Two types of cherries are in common use for edible purposes:

(a) Sweet cherry: Prunus avium L.
(b) Sour cherry: Prunus cerasus L.

Sweet cherry (Prunus avium L.) \((2n = 2x = 16)\) is a fast-growing tree of family Rosaceae having a genome size of \(\sim 380\ \text{Mb}\). Occasionally triploid and tetraploid forms are also found. The plant is unique in the sense that except the fruits which are edible, all plant parts exhibit toxicity due to the presence of cyanogenic glycosides. Sweet cherry is a highly perishable fruit which is treasured due to its physical characteristics like sweet-sour taste, color, and flavor along with being a rich source of potassium, dietary fiber, ascorbic acid, carotenoids, and phenolics. Apart from this, the fruits of sweet cherry are a good source of tryptophan, serotonin, and melatonin but have relatively low caloric content. Turkey, the United States, and Iran are the top producers of sweet cherry in the world and together account for about 43% of the world production.

Sweet cherry is an important fruit crop in Patagonia, a distinct geographical region at the base of South America spanning the lower sections of Argentina (70%) and Chile (10%) bounded in the west by the Pacific Ocean and the east by Atlantic Ocean. South Patagonia is a region characterized by soil heterogeneity, mean annual temperature of 8.2–13.5 °C, and an annual rainfall in the range of 200–500 mm. Most of these conditions favor the cultivation of sweet cherry in the Patagonian region of southern Argentina. As a result, the total sweet cherry production area increased from 176 ha in 1997 to 635 ha in 2009, the cultivation area primarily being in Los Antiguos, Lower Valley of Chubut River, Sarmiento, Esquel, and Comodoro Rivadavia in that order. However, in spite of being a profitable and emerging fruit crop, problems related to productivity and commercialization have threatened its sustainability. Therefore, a participatory approach termed as “Participatory Impact Pathways Analysis” (PIPA) was initiated to have a better understanding of the complexity of the cherry sector in the region. The
first step involved identification of the problems faced by the farmers and other stakeholders in cherry cultivation. The following stakeholders were identified:

1. Packers and members of growers organizations
2. Researchers
3. Extension agents and growers
4. Politically important actors

Thereafter, views were taken for how to change the scenario and possible outcome after these changes. The stakeholders described the following constraints to cherry production in the region:

1. Yield losses due to use of obsolete technology at packinghouses and at farm level.
2. Low profitability in the sector since less than 50% of the fruit is exportable and labor efficiency is low.
3. Low commercialization due to low prices, exchange rate, absence of contracts, and unreliable brokers. Thereafter, an outcome logic model was prepared that showed how the project activity will lead to improvement in these aspects resulting in advancement in knowledge and skills. The project performance was monitored and evaluated at regular intervals to ascertain the progress and outcome.

8.6 Banana

Banana is cultivated throughout the tropical areas of the world and is an important food source and a means of livelihood for scores of farmers. The fruit is the fourth most important food crop in developing countries after rice, wheat, and maize and has played a major role in the social life of populations in the several parts of the world. Bananas are a cheap and easily produced source of energy along with being rich sources of vitamins A, C, and B6. *Musa* and *Ensete* are the only two genus in family Musaceae. Almost all the banana cultivars arose from the *Eumusa* group which is the largest and the most geographically widespread, with species being found throughout Southeast Asia from India to the Pacific Islands. Most cultivars are derived from two species:

1. *Musa acuminata* (A genome): most widespread of the *Eumusa* species
2. *Musa balbisiana* (B genome): distributed through the seasonally dry, northern and eastern fringes of the *Eumusa* area

When it comes to bananas the high-yielding and disease-resistant, secondary triploid (3x) NARITA hybrids developed after 20 years of intense breeding by the National Agricultural Research Laboratories Kawanda and the IITA Sendusu research station in Uganda need special mention. These hybrids were developed by a cross between a female fertile EAHB cultivar (3x) and Calcutta 4, a diploid (2x)
black leaf streak resistant accession of the wild species *Musa acuminata* ssp. *burmannica*. Thereafter, crossing of the resulting tetraploid (4x) hybrids was carried out with improved diploids (2x) to produce secondary triploids from which the NARITA hybrids were selected. Some of these promising hybrids have been evaluated in diverse environments in Tanzania and Uganda using the following two participatory varietal selection approaches to promote adoption beyond the populations participating in the mother-baby trials:

(a) Mother-baby evaluation trials: hybrids were evaluated in researcher-managed trials (mother trials) where the farmers made regular visits to the fields during the crop season and after harvest. Promising hybrids are selected by the farmers, and their further testing was carried out in the fields (baby trials) to ascertain their performance against the local cultivars.

(b) “Standalone” baby trials: each farmer received a randomly assigned combination of three hybrids to rank. The objective of this approach was to involve more villages in the program by disseminating information on the hybrid performance using social networks of the farmers.

Banana is affected by wilt disease caused by *Xanthomonas campestris* pv. *musacearum*, in commercial and small-scale farms in East and Central Africa. For raising disease-free plants, it is important that *Xanthomonas* wilt-free germplasm is provided to the farmers after the farm is eradicated from previously infected farms. From a long-term perspective, integrated pest and disease management practices along with competencies of the farmers need to be taken into account. Since there are a number of participating countries, four farms at two *Xanthomonas* wilt-affected locations in each country were selected to have firsthand knowledge of the control measures adopted by the cultivators and the disease incidence. It was observed that the regional strategy of pest management was variably implemented, with varied success across the region.

### 8.7 Passion Fruit

Passion fruit (*Passiflora edulis*; 2n = 18) is a member of family Passifloraceae, which consists of 12 genera and about 500 species that are distributed in tropical America, Asia, and Africa. Passion fruit is widely grown in several countries of South America, Central America, the Caribbean, Africa, southern Asia, Israel, Australia, Hawaii, and other United States. The fruit is known by different names in different countries/regions like *granadilla*, *parcha*, *parchita*, and *parchita maracuyá* in Spanish, *maracuja peroba* in Portuguese, *grenadille* in French, *lilikoi* in Hawaii, *linmangkon* in Thailand, and *parcha amarilla* in Venezuela. The plant is a shallow-rooted, woody, perennial, climbing vine by means of tendrils. The name passion flower is derived from the cross-like structure of the stigmas emerging from the center of the flowers and the ring of appendages of the corona that have been likened
to the crown of thorns of Christ. The round to ovoid fruit contains many seeds surrounded by a gelatinous and tasty pulp. The two main commercial varieties are:

1. *Passiflora edulis f. edulis*: deep purple fruits 4–5 cm in diameter, green tendrils and leaves, more resistant to cold injury, is less acid, and is considered superior in aroma and flavor.

2. *P. edulis f. flavicarpa*: yellow fruit variety, more vigorous vines, showy flowers, reddish-purple tinged tendrils and leaves, bears crops over longer periods, has a greater yield of fruit and pulp, larger fruits, and more acid juice.

The purple passion fruit is native from southern Brazil through Paraguay to northern Argentina, while the yellow form is of unknown origin, or is a hybrid between *P. edulis* and *P. ligularis* (q.v.). The aromatic pulp present around the seed is extremely popular for making juices, ice cream, desserts, sauce, candy, cake icing, cake filling, meringue or chiffon pie, cold fruit soup, and cocktails. Passion fruits are a good source of provitamin A but have a high acid content with pH as low as 3. They are often used medicinally as a sedative or tranquilizer, nervine, antispasmodic, and pain reliever. Recently the peel extract of passion fruit has shown potent antioxidant and anti-inflammatory activity in patients afflicted with osteoarthritis, asthma, and hypertension.

Passion fruit, known as “gulupa” in Colombia, is grown over a large area (1250 ha in 2016) and has a decent production most of which is exported. The export of passion fruit has risen by 150% from 2010 to 2016 placing Columbia as the largest exporter of this fruit to the European markets. However, the crops are affected by serious phytosanitary problems, genetic degeneration, and lack of breeding leading to a reduction of the crop cycle. A participatory mass selection program was initiated to determine the genetic variability available in yellow passion fruit cultivated in the country. Ten fruits per crop were randomly selected and evaluated for quality, yield, and the incidence of insect pests and diseases. It was observed that trips (*Neohydatothrips* spp.) and virosis (SMV) affect the crops to a great extent. High coefficient of variation (CV) was observed for weight of the fruit peel (20.53%) and average seed weight (20.47%). Eight elite accessions from Caldas, Valle de Cauca, and Antioquia having good quality parameters were identified which were incorporated in breeding programs to breed superior plant types for local conditions.

### 8.8 Andean Blackberry

**Common Names:** Mora de Castilla and Andean raspberry

The genus *Rubus* is one of the most diverse taxa and presents wide range of wild and cultivated species that are appreciated for the edible fruits. The Andean blackberry is a perennial semierect climbing shrub of family Rosaceae found in Latin America from Oaxaca to Bolivia, including the northern and central Andes. The plant is grown for its ellipsoid compound drupes which are green when formed, becoming
red when ripe, and then turn dark and bright purple. The plant is native to tropical highlands of northwestern South America and Central America and is found on elevations between 1500 and 3100 m. The consumption of blackberries in the world has recently increased in fresh and processed fruit markets due to high content of ascorbic acid, anthocyanins, phenolic acids, and carotenoids, which provide health benefits against a wide range of diseases including certain degenerative diseases. The presence of natural pigments like anthocyanins provides attractive colors, and so the fruit is also used in the food manufacturing industry in jellies and syrups.

Blackberry holds an important place among the fruit crops of the Colombian Andes with its cultivation taking place on about 12,000 ha and the total production being 105,218 tons/year. The plant is cultivated in Cundinamarca, Santander, Antioquia, Risaralda, and Santander provinces. A participatory plant selection of *R. glaucus* was carried out in the northeastern region of Colombia that brought together the skills and knowledge of the cultivators and breeders to address the loss of crop diversity. Fifty-nine accessions and 9 variables like yield, acid content, fruit length, fruit diameter, fruit weight, maturity period, and farmer ratings were considered. Principal component analysis, contingency matrix, and Ward’s conglomerate analysis method were applied to the variables. The results showed the accessions segregated in three groups that accounted for 71.7% of total variability.

First group: fruit diameter, maturity, yield, and Brix degree
Second group: fruit length and fruit weight
Third group: farmers rating

The participatory diagnostic assessment resulted in identification of 15 promising accessions of the four blackberry growers association that should be selected for micropropagation. In addition, on-farm breeding and conservation helps in maintenance of diversity within and among populations.

## 8.9 Participatory Domestication of Fruit Trees

Many wild fruit trees are excellent sources of nutrition, timber, and other products and have the potential to be domesticated and cultivated for providing economic benefits and livelihood enhancement to the subsistence farmers. Conventional tree improvement programs have been carried out by large research institutes with great emphasis on timber production. However, with the introduction of agroforestry programs in many parts of the world that concentrated on improving the economic conditions of the resource-poor subsistence farmers, a new approach gained ground that was based more on horticultural than forestry products. The World Agroforestry Centre (*ICRAF*) located at Nairobi developed a model that involved the farmers at all stages of decision-making. The process involved taking the opinion of the farmers with respect to the selection of forest trees and development of low-cost technology for their effective propagation. Thus, the time-consuming, elaborate, and expensive micropropagation was replaced by vegetative propagation done by
farmers where they produce and bulk up “cultivars” from the trees that they know and like best in their area. Thus, participatory domestication conforms to the Convention on Biological Diversity (CBD) that aims to protect the rights of local people to their indigenous knowledge and germplasm by empowering and enlightening the farmers who are the main beneficiaries and guardians of indigenous knowledge about inter- and intraspecific variation in the wild population. A study involving subsistence farmers of Cameroon and Nigeria brought out the fact that farmers were very interested in the cultivation of indigenous fruits.

Safou or African plum (*Dacryodes edulis*; family: Burseraceae) is treasured for its boiled or roasted fruits and an important income source in southern Cameroon. Likewise, bush mango or dika nut (* Irvingia gabonensis*; family: Irvingiaceae) is an important indigenous tree in southern Nigeria whose fresh fruits are eaten as a snack while the dried kernel is ground and added to sauces to make them viscous. A participatory tree domestication study was conducted in six villages (four in Cameroon and two in Nigeria) of the region to quantify the tree-to-tree variation in fruit characteristics in *D. edulis* and *I. gabonensis* with the following objectives:

- Identifying combinations of traits that could be brought together and then captured as a “cultivar” by vegetative propagation
- Determination of the levels of diversity available to farmers within the area of their communal ownership
- Ascertaining the levels of selection intensity being applied by the cultivators
- Assessment of variability in fruit or kernel traits that made the fruits more marketable

The results suggested that ideotype selection provided ample opportunities for the development of cultivars suited for fresh fruit trade by combining large fruit size with good quality traits.

Incorporating the information about the traits that are important for selection into the community domestication programs can lead to increased genetic gain achievable by the cultivators in the coming years. In addition to this, since diverse sets of cultivars will be created by different villages, both inter- and intraspecific diversities will be maintained at the farm level, at least in the short-to-medium term. An interesting observation pertained to the unintentional selection practiced by farmers of both Cameroon and Nigeria for desirable traits. The domestication of indigenous fruit trees by the local cultivators and furthering this process can provide market-friendly non-timber forest products that can help the local farmers by providing food security and income generation. Thus, it is possible to develop land use systems to enhance the livelihoods of subsistence farmers and create export commodities to supplement farmers’ income.
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Abstract

PPB has effectively targeted a number of cereals but has been of limited success in only some vegetables and fruits. However, the technique has also found resonance among a number of crops which have been categorized in this book as miscellaneous crops. These include mainly the underutilized crops like amaranth and chenopods which are members of family Amaranthaceae. These plants once enjoyed prominence but were relegated to the background on introduction of new crops in their area of cultivation. Some legumes like common bean, mung bean, and faba bean have also been discussed at length with reference to studies in participatory breeding. A number of such studies are also available in potato, sweet potato, cotton, coffee, cassava, and a number of trees of agroforestry importance.

9.1 Introduction

The term “miscellaneous crops” in this book refer to all crops other than cereals, fruits, and vegetables that are used by human beings in some way or the other. These include legumes, plantation crops like coffee and cotton, underutilized species like quinoa and amaranth, and trees important in agroforestry. Legumes are plants of family Fabaceae (Leguminosae) that are grown on some 180 million Ha or 12–15% of the Earth’s arable surface and are second only to the members of family Poaceae in their importance to humans. Legumes are also ecologically important due to their unique ability of nitrogen fixation to which they play an important role in crop rotation. Potatoes (Solanum tuberosum L.; family: Solanaceae), the fourth most important food crop in the world, and sweet potato (Ipomoea batatas (L.) Lam.) which is seventh among food crops in the world and fifth for its caloric contribution in developing countries form a part of the discussion. Besides legumes a number of underutilized crops like quinoa and amaranth have also been incorporated in participatory
programs, and successful results have been obtained. Participatory methods also have immense potential for the involvement of farmers in the designing of the agro-forestry systems.

9.2 Common Bean

Common bean (*Phaseolus vulgaris* L.; $2n = 2x = 22$) is one of the most important grain legume for human consumption and is a rich and cheap source of protein, vitamins, minerals, and fiber, especially for the poorer populations around the world. The origin of *P. vulgaris* can be traced to two centers of origin, one in Mexico and the other in the Andes. The crop was cultivated as early as 6000 BC in Peru and 5000 BC in Mexico and thereafter introduced to the Old World by the Spaniards and the Portuguese. It is now widespread and cultivated as a major legume and foliage crop in tropical, subtropical, and temperate areas of the Americas, Europe, Africa, and Asia. Common bean is characterized by a number of locally adapted landraces and exhibits ample diversity in morphological characteristics such as growth habit, seed size, and seed color (Fig. 9.1).

![Diversity in seed color in common bean](image)

**Fig. 9.1** Diversity is seed color in common bean. (Reprinted from Scientia Horticulturae, Vol 180, Scarano D, Rubio F, Ruiz JJ, Rao R, Corrado G, Morphological and genetic diversity among and within common bean (*Phaseolus vulgaris* L.) landraces from the Campania region (Southern Italy), 72–78, 2014, with permission from Elsevier)
A participatory research program was initiated by CIAT in the Valle del Cauca, Colombia, to assess the following:

1. Agronomic traits of farmer- and breeder-selected germplasm across a wide range of environments
2. Farmer perceptions of useful genetic variation

Eighteen F2 populations were grown in five environments at the following sites:

1. CIAT-Palmira: Main research station with fertile soils and irrigation facilities; 1000 masl
2. CIAT-Darien: Researcher-managed field station with phosphorus-deficient soil and no irrigation; 1450 masl
3. Farm-Darien region: Farmer-managed station with phosphorus-deficient soil and no irrigation; 1400–1500 masl

Three farmers in the Darien municipality, who produced the crop, had interest in experimentation, and good communication skills were selected as collaborators in the breeding program, along with selection of ten bean lines (including one check) showing variation in growth habit, seed type, and disease resistance. After selection of 18 F2 populations for further study, a simple breeding methodology was followed for advancement of populations till F6 with the farmers being advised to use their own criteria for selection. There were perceptible differences in the selection criteria followed by the farmers and breeders with breeders giving more preference to yield and stress resistance. With respect to yield, it was observed that the selections made by the breeders had more yield potential as compared to the lines selected by the farmers. Farmers used the following traits in their selection criteria:

- Seed color at harvest: 98%
- Seed size: 96%
- Number of pods: 95%
- Foliar diseases: 94%
- Plant growth habit: 83%

One line developed by the farmers, viz., TM 27 G1 having large-sized round seeds and attractive seed color, was the most preferred among all advanced lines tested. The farmers were quite efficient in selecting lines having good commercial qualities; however, these lines did not have the highest yields or good disease resistance. The results were significant since they showed successful coordination between the farmers and breeders right from the start of the breeding program to every stage of the breeding process and finally culminating in the development of mutually acceptable materials.

Common bean is one of the most important legume crops in Ethiopia where it is used as a cheap source of protein, an emergency crop for adverse environmental conditions, supplementary feed for animals, and for increasing farmer’s income.
Vareitual evaluation and selection of common bean varieties performed by formal breeders resulted in varieties having about one third yield as compared to test conditions and a low adoption rate of only 10% by the farmers. The farmers, traders, and the consumers played no role in bean breeding process. This led to a rethinking, and an attempt was made to integrate both farmers’ and traders’ technical insights and preferences into the bean varietal development in the drought-prone areas of the Central Rift Valley (CRV) of Ethiopia. The objective was to identify germplasm that would tolerate drought stress and be more marketable vis-à-vis for domestic consumption as well as for the pressing demand of the canning industry. The participating farmers were small-scale cultivators, both men and women, derived from nine villages within two districts. The participating traders were chosen on the basis of their dominant roles in the CRV in the processing and marketing of beans. The local farmers selected several criteria like seed size and color, drought and disease resistance, adaptability, and growth habit for evaluating the 65 common bean germplasm lines (Table 9.1). The stakeholders evaluated the varieties for yield, culinary characteristics, market value, and canning acceptability at the research station site at the Melkassa Agricultural Research Center (MARC) and on two on-farm sites, viz., Boffa (Boset district) and Siredodota (Sire district). Of the 65 lines, 7 were finally selected on the basis of their performance during 2009 and 2010 trials and evaluated

<table>
<thead>
<tr>
<th>Positive criteria</th>
<th>Negative criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomic criteria</td>
<td>Agronomic criteria</td>
</tr>
<tr>
<td>Good pod load</td>
<td>Low pod load</td>
</tr>
<tr>
<td>High grain yield</td>
<td>Low grain yield</td>
</tr>
<tr>
<td>Good plant stands</td>
<td>Poor plant stands</td>
</tr>
<tr>
<td>Early maturity</td>
<td>Late maturity</td>
</tr>
<tr>
<td>Good stalk strength</td>
<td>Weak stem</td>
</tr>
<tr>
<td>Environmental criteria</td>
<td>Environmental criteria</td>
</tr>
<tr>
<td>Insect resistance</td>
<td></td>
</tr>
<tr>
<td>Disease resistance</td>
<td></td>
</tr>
<tr>
<td>Processing and home use traits</td>
<td>Processing and home use traits</td>
</tr>
<tr>
<td>Not shattering in the field</td>
<td>Shattering in the field</td>
</tr>
<tr>
<td>Suitability for boiled grain (nifro)</td>
<td>Poor taste</td>
</tr>
<tr>
<td>Suitability for wot (stew)</td>
<td></td>
</tr>
<tr>
<td>Good taste</td>
<td></td>
</tr>
<tr>
<td>Fast cooking</td>
<td></td>
</tr>
<tr>
<td>Seed traits (linked to market value)</td>
<td>Seed traits (linked to market value)</td>
</tr>
<tr>
<td>Good seed color</td>
<td>Dull-colored seeds</td>
</tr>
<tr>
<td>Good seed size</td>
<td>Very small seed size</td>
</tr>
<tr>
<td>High market value</td>
<td>Low market value</td>
</tr>
<tr>
<td>Ancillary use features</td>
<td>Ancillary use features</td>
</tr>
<tr>
<td>High forage yield</td>
<td></td>
</tr>
</tbody>
</table>

for seed quality at each site. The seven lines selected by farmers were then evaluated by two companies, viz., ACOS and Umar Baobed involved in bean trading. Three varieties, viz., G80, G87, and G6, were selected on the basis of superior quality. A follow-up was done after 3 years of releasing the PPB-bred varieties to ascertain the adaptability of the lines and the farmer’s interest in them. It was observed that the market prices for G87 ranged between 40 and 70% above the two local varieties (Table 9.2) that amply demonstrated real payoffs and the success of PPB in breeding common bean lines in the region.

Since seed color and size are important characteristics in the context of consumers’ preference in common bean, an experiment was conducted in 2010 under rainfed condition in Boricha district of Southern Ethiopia with Kayyo seed producer cooperative (SPC). Based on the preferences of the farmers, the early maturing varieties of red and red-mottled common bean were introduced in the region. Thereafter, farmer’s preferences were ascertained using focus group discussions (FGD) held with 30 randomly selected households from seed producers and their customers. Farmers were given the center stage by taking their opinion on the traits they considered as important for selection of a given variety at a particular developmental stage. The cultivars were then evaluated on the suggestions of the farmers at the vegetative, maturity, and postharvest stages. Cultivators were asked to give a score for major common bean traits on a scale of 1 to 6, viz., 1 for excellent and 6 for bad. The common bean traits like maturity period, number of seeds per pod, growth habit, and height of pods from the soil were at the forefront in the farmers’ mind as the selection criteria. It was interesting to note that most of the farmers selected uniformity of seed color (red) as the major criteria for accepting and rejecting the variety after harvest. It was concluded that introduction of new varieties through participatory varietal evaluation aids the cultivators to choose the varieties efficiently as per their and the market requirement.

### Table 9.2

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Local white pea bean (Mex 142)</td>
<td>13.7</td>
<td>9.7</td>
<td>14.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Local cream type bean</td>
<td>16.3</td>
<td>11.8</td>
<td>17.2</td>
<td>12.4</td>
</tr>
<tr>
<td>PPB line: G87</td>
<td>25</td>
<td>16.5</td>
<td>27</td>
<td>16.8</td>
</tr>
<tr>
<td>Price increase: PPB/local</td>
<td>+53.83%</td>
<td>+40.70%</td>
<td>+57.88%</td>
<td>+35.63%</td>
</tr>
</tbody>
</table>

9.3 Mung Bean

Mung bean [Vigna radiata (L.) R. Wilczek var. radiata], commonly known as “green gram,” is an important food and cash crop in several parts of the world especially the tropical and subtropical regions of the developing countries. The plant has a diploid chromosome number of \(2n = 2x = 22\) and a genome size of 579 Mb (1.2 picogram per 2C). The legume is cultivated on small farms in Asia, Africa, South America, and Australia with India being the largest producer followed by China, Myanmar, and Indonesia, which together account for approximately 90% of the world’s mung bean production. India is considered to be the center of origin of mung bean where the legume originated from its putative progenitor, \(V.\ radiata\) var. sublobata. Thereafter mung bean underwent multiple rounds of domestication and selection and migrated to Asia and Africa. Mung bean is a drought-tolerant, warm-season crop that flowers in response to short-day conditions and has a short life cycle of about 60 days. Mung bean is nutritionally rich since it is a rich source of carbohydrates and superior-quality digestible protein, folate, and iron.

Mung bean is a favored legume in Nepal but is almost wholly imported from India since the released varieties are not popular among the Nepalese farmers due to traits like short pods, small grains, virus susceptibility, unpleasant smell, and requirement of manual labor for multiple harvesting. Participatory evaluation of short-duration \(V.\ radiata\) varieties obtained from the Asian Vegetable Research and Development Centre (AVRDC) was initiated in 2002 across 13 districts in the low hills and Terai regions of Nepal and comprised of the following activities that were a joint effort of Rural Welfare and Agricultural Reform for Development (FORWARD) and Local Initiatives for Biodiversity, Research, and Development (LI-BIRD):

1. **Mother trials:** breeder-designed, farmer-managed, multiple cultivars in many locations; yield and maturity measured by breeders while consultative evaluation done for other agronomic traits.

2. **Baby trials:** farmer-managed, 1–2 new cultivars/farmer compared with local cultivar or second new variety; evaluation of farmers’ perceptions form the basis for assessment of entries.

3. **Informal research and development (IRD):** this was an alternative form of participatory varietal selection, less intensive, designed to improve the flow of new genetic materials to cultivators and facilitate their dissemination through farmer-to-farmer networks.

4. **Multiplication of farmer-preferred varieties.**

The cultivators played a key role in the implementation of the project and almost completely managed the crop trials by deciding the inputs, time, and method of planting and agronomic practices. The monitoring of the crop and its evaluation was the combined task of the breeders and the farmers through farm walks and focus group discussions. Most of the farmers preferred the improved varieties obtained from AVRDC to the existing local varieties for agronomic and postharvest traits. It
was observed that improved mung bean varieties have high potential for cultivation as a catch crop in diverse cropping patterns.

*V. radiata* is an important food crop in eastern and northern regions of Uganda, a landlocked country in East-Central Africa with an area of 241,038 km² and a population of around 41 million people. However, the productivity is quite low (less than 300 kg/ha) in these areas. A two-phase study was conducted in the country that aimed at exploring the farmers’ preferences and selection criteria for the crop and their utilization for selection.

1. Phase I – This phase emphasized the use of interviews and focus group discussions in Amuria and Soroti districts for analyzing and comparing the traits considered as important by the farmer.

2. Phase II – This phase involved on-farm participatory selection and performance evaluation trials at 4 locations, viz., Kumi, Soroti, Kitgum, and Alebtong districts, for the 11 high-yielding advanced breeding mung bean genotypes obtained from AVDRC, Taiwan, along with a local check (Echoroko lodidi). Of the 25 traits under study, the cultivators gave preference to the following 6 traits for selecting the best genotypes:

   (i) Yield
   (ii) Overall performance
   (iii) Seed size
   (iv) Seed color
   (v) Marketability
   (vi) Early maturity

Nine out of 11 introduced genotypes that were selected during on-farm trials had early maturity and had large-sized seeds which were readily marketable at premium prices. It was observed that many traits are simultaneously used by the cultivators for adopting a particular genotype, and these should be considered in the mung bean genetic improvement program directed for the study area. It is possible to develop new genotypes that are acceptable to both men and women since there is lack of genetic differentiation, and both sexes do not have specific trait preferences.

### 9.4 Faba Bean

Common names: Broad bean, Faba bean, Horsebean, Windsorbean, Tickbeans, Bakela, Boby kurnouvje, Faveira, Ful masri, Feve, Yeshil Bakla.

Faba bean (family: Fabaceae; 2n = 12) is one of the most globally important legume crops that stands next in importance after garden pea, chickpeas, and lentil. The legume is cultivated primarily in the temperate and subtropical regions of the world as a cool-season annual crop with China being the biggest producer followed by Ethiopia, Egypt, and the United Kingdom. The global production of the crop in
2014 was 4.1 million tons. The fresh and dry seeds are highly nutritious due to high protein content and range of minerals like K, Ca, Mg, Fe, and Zn along with a number of bioactive compounds like vitamins, polyphenols, and carbohydrates. *V. faba* is thought to have been domesticated in the Eastern Mediterranean region, close to Afghanistan and the Eastern Mediterranean, while Nile Valley, South America, and Central and Eastern Asia form the secondary centers of diversity. Faba bean has a large genetic diversity with about 38,000 accessions being conserved globally in numerous gene banks around the world.

Ethiopia is considered as one of the secondary centers of diversity of faba bean and is also the largest producer in Africa accounting for 56% of the production. Here the legume is grown as a cold-season crop in the highland and mid-highland areas and is most common in Woyina Dega, the central temperate high belt of the Ethiopian plateau, with elevations of 1700–2400 masl and an average precipitation of 1500–2000 mm per year. However, the productivity of faba bean is low in the region (0.7 t/ha) due to absence of disease-resistant, stress-tolerant, and high-yielding improved varieties coupled with an outdated production system. This peculiar problem can be changed by introduction of varieties that can withstand the stress conditions and give high yield. A participatory variety selection program was initiated in Wollo at Geregera, Legambo, and Kutaber districts on station and farmers’ site to evaluate *V. faba* germplasm in coordination with the farmers to recommend high-yielding varieties that have the capacity to withstand most of the stresses prevalent in the region. The trial was executed as:

- Mother trials – all the three replications are on one site.
- Baby trials – only one replication on one site trial form.

The experimental material comprised of seven improved faba bean varieties released previously by different research centers. Both male and female farmers evaluated and selected the germplasm from the baby trial on the basis of the criteria finalized by them, viz., earliness, pod setting, and disease-free seeds. The study enabled the recommendation of best-performing varieties for different districts and enabled both the breeder and cultivator to select the best variety which can meet their specific requirement.

Another participatory program was initiated in Enda Mekoni Woreda, the northern part of Ethiopia where agriculture is the mainstay of the economy, to evaluate and select faba bean varieties for high yield and other agronomic traits. Four released varieties (Gora, Dosha, Hachalu, and Tumsa) with one local check were used in the study. Farmers assessed the varieties and exercised selection depending on the following criteria:

1. Ground cover
2. Vigor
3. Earliness
4. Pod setting
5. Lodging
6. Diseases
Farmers ranked each variety based on the selection criteria that was ranked from 1 to 5. Twenty-four farmers representing both sexes (11 females) were part of the study group since they were the primary beneficiaries in a participatory variety selection program. Dosha (4.67) scored the highest value followed by Tumsa (4.16) both in the farmer’s evaluation and researcher’s selection indicating that they were the most promising under the test conditions of the study area.

Faba bean is cultivated as a minor crop in Germany (acreage: 16,000 ha), but a large portion (39%) of it is under organic farming. Although some improved varieties have been released in Europe, these cannot be considered the best ones since organic farming is quite similar to farming in marginal areas like having heterogeneous environments, diverse needs of farmers, and lack of adapted varieties.

A study was conducted in Germany with 49 genotypes at 5 locations (4 organic and 1 conventional) during 3 years (2004, 2005, 2006) that aimed to combine organic farmers and researchers in a participatory breeding approach to develop faba bean cultivars that efficiently fitted into the requirements of a set of organic farms in Germany. Three organic farmers performed on-farm activities such as management of the trials, scoring of agronomic parameters, visual estimation of yield at maturity, and personal appreciation of the material through a visual score. It was observed that personal appreciation was strongly influenced by different stresses since high prevalence of diseases in some locations led to higher appreciation scores being given to disease-free healthy germplasm. The organic farmers gave greater weightage to uniformity. The highest yielding inbred line was better than the predicted highest yielding synthetic lines and ranked among the most appreciated genotype. The significance of the study is evident since the combined efforts of cultivators and the breeders led to new information and identification of best genotypes for organic farming.

9.5 Potato

Potatoes (Solanum tuberosum L.; family: Solanaceae) are the fourth most important food crop in the world with the global production of potatoes amounting to approximately 376.83 million metric tons in 2016. Potato plants are herbaceous perennials having a basic chromosome number of 12 and the diploid potato having a genome size of 844 Mb. Potato exhibits polyploidy in wild and cultivated forms ranging from diploid \((2n = 2x = 24)\), triploid \((2n = 2x = 36)\), tetraploid \((2n = 4x = 48)\), and pentaploid \((2n = 5x = 60)\) to hexaploid \((2n = 6x = 72)\), the cultivated potato being a tetraploid. Potato has high content of carbohydrates, significant amounts of quality protein, and substantial amounts of vitamins, especially vitamin C. The crop probably originated in the mountainous west-central region of Peru (South America), and is widely distributed throughout the Andes from Colombia to Peru and also in Southern Chile. Potato exhibits substantial phenotypic and physiological diversity as is evident in Fig. 9.2. The genebank at the International Potato Center (CIP) has an extensive collection of about 4727 accessions including 4354 traditional landrace cultivars from 17 countries (primarily of the Andean region) and improved varieties.
In Rwanda, a small landlocked East African country having an area 26,338 km², potato is the second major food crop after banana with the highlands in southwest and north of the country having the most favorable climatic conditions for its cultivation. The country has about 70,000 potato farmers grouped in 30 cooperatives which make it one of the largest potato producers in the region with an annual production of 2.3 million tons. Rwanda has recently become one of the major potato exporters in the region. However, in spite of its immense usage, several constraints like lack of high-yielding varieties, postharvest losses, poor storage facilities, insufficient clean potato seed tubers, inadequate seed distribution system, inefficient production technologies, and enormous incidence of diseases like late blight (Causal organism: *Phytophthora infestans*) and bacterial wilt (Causal organism: *Ralstonia solanacearum*) severely limit crop production. Sporadic attempts to involve the local farmers using participatory approach in potato variety evaluation failed since the farmers were not fully integrated into the whole breeding process. Muhinyuza et al. (2012) initiated a study for the identification and analysis of the constraints faced by the farmers in potato production and with a broader objective of including preferences of the farmers in cultivar development and variety selection. A participatory rural appraisal (PRA) study based on a questionnaire presented to the farmers was conducted through structured survey involving 144 households and 22 focus groups with 258 participants in 3 districts of Rwanda. Farmers were encouraged by group discussions to identify and express their opinion on the preferred traits to be included in selection of potato varieties. Inadequate credit facilities, lack of high-yielding varieties, insufficient clean planting materials, and incidence of late blight were some of the factors that negatively affected potato production. It was
concluded that farmers should be actively involved in the breeding process in the crop to have an effective and successful breeding program.

Potato is also an important crop in Uganda which ranks ninth in potato production in Africa. However, the potato yield is about 4.8 t/ha which is quite low against a potential of about 25 t/ha. This is due to crop infestation by pathogens (late blight and wilt diseases being most common), abiotic stress, socioeconomic constraints, and poorly adapted varieties. Most of the available improved varieties are adapted to the highlands and give good yield at around 2000 masl (meter above sea level) but result in low yield at low and mid-altitudes. Several varieties released by the National Agricultural Research Organisation (NARO) in collaboration with the International Potato Center (CIP) have found less acceptability among the farming community since they prefer their own varieties due to special attributes. Keeping this in mind, a participatory rural appraisal was initiated in three major potato-growing regions of the country, namely, Central, Eastern Highlands (Mount Elgon) and South Western Highlands (Kigezi region) to identify key potato production constraints, varieties grown, and farmers’ knowledge of potato diseases. A semi-structured questionnaire containing open-ended questions was provided to 577 potato farmers (mostly between 21 and 55 years of age) along with direct interaction to extract their knowledge and experience regarding potato cultivation. High yield was identified as the most preferred attribute across the three potato-growing regions followed by marketability, resistance to diseases, and early maturity (Table 9.3).

Potato was introduced in Ethiopia in 1958 by a German immigrant, Wilhelm Schimper. Ethiopia had immense potential for potato production among the African countries since 70% of its cultivable land situated mainly at altitude above 1500 m was best suited for potato cultivation. Since the highlands are also home to almost 90% of Ethiopia’s population, the potato could play a key role in ensuring national food security. The country has four distinct crop seasons:

1. Belg: also known as the short rainy season; starts in January and continues to May or June
2. Meher: also known as the rainy season; starts in May or June and ends in October
3. Belmehr: overlaps the Belg and the Meher seasons; starts in March or April and lasts in August
4. Mesino: also known as the residual production season, starts in September and continues through December or January

According to the FAO estimates, potato production increased from 280,000 tons in 1993 to around 525,000 tons in 2007 showing its immense importance in Ethiopian agriculture. However, the average yield of potato in the country was low (9 t/ha) as compared to the world average (16.8 t/ha). To mitigate this problem, the government introduced nine new varieties from CIP, Peru, since the year 1987 that were high yielding, blight resistant, early maturing, and had good adaptability. However, these varieties were less popular among the farmers in most potato-growing regions of the country with the farmers depending on conventional “local
<table>
<thead>
<tr>
<th>Attributes</th>
<th>District</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kabale</td>
</tr>
<tr>
<td>High yielding</td>
<td>84.8</td>
</tr>
<tr>
<td>Marketable</td>
<td>53.1</td>
</tr>
<tr>
<td>Resistant to late blight</td>
<td>28.1</td>
</tr>
<tr>
<td>Early maturing</td>
<td>16.5</td>
</tr>
<tr>
<td>Good for eating</td>
<td>15.9</td>
</tr>
<tr>
<td>Resistant to pests and diseases</td>
<td>0.0</td>
</tr>
<tr>
<td>Resistant to bacterial wilt</td>
<td>0.0</td>
</tr>
<tr>
<td>Red skinned</td>
<td>40.8</td>
</tr>
<tr>
<td>Yellow flesh</td>
<td>0.0</td>
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</tbody>
</table>
varieties.” This was due to the fact that while the farmers’ selection traits were multivariate in nature, the formal varieties relied on only 3–4 traits. In potato, other accessory traits like culinary quality, color, and storage quality also need to be considered for successful acceptance of a variety. Therefore, a study was undertaken in two agroecological zones (districts: Laigaint and Yilmana) and two growing seasons of northwest Ethiopia to identify the traits that farmers considered more important when selecting potato varieties. The germplasm tested included 12 potato varieties consisting of 9 local varieties and 3 widely distributed new varieties selected from CIP-bred clones. A participatory variety selection (PVS) scheme adopted from the Africa Rice Center, along with field experiments, was conducted on the cultivators’ plots in each district. Farmers’ research groups (FRGs) organized in each village evaluated the varieties at the time of flowering, at harvest, and after 3 months of storage as per the methodology stated in the “Technician’s Manual” for participatory variety selection. Farmers were asked to rate the best five and worst five varieties at each stage giving suitable reasons for the same. Farmers selected 23 traits for selection of a variety of which 14 were agronomic, 6 related to stress tolerance (both biotic and abiotic), and 3 related to utilization and marketability (Table 9.4).

Table 9.5 compares the traits considered important in the breeding programs with the traits of importance recognized by the farmers. It was strange that the farmers did not give much emphasis to wider adaptability of the varieties which was considered as a very important trait in the conventional breeding programs. In fact the selection criteria followed by the farmers was unique and diverse as per their local needs along with differences in the gender perception of traits to be selected. The selection criteria also differed between growing seasons and locations. It was amply clear that although the local varieties had unique traits not present in the researcher-bred varieties, these traits were not given due weightage in the national potato breeding program.

A farmer participatory research-farmer field school (FPR-FFS) program was carried out from 1999 to 2002 in San Miguel, Cajamarca, Peru, by the International Potato Centre (CIP) with the support of the International Fund for Agricultural Development (IFAD) and the OPEC Fund for International Development. The primary objective of this program was to address the pressing problem of late blight of potato that assumes explosive proportions and is the cause of about 15% crop losses. Initially the farmers were surveyed to determine their existing knowledge of late blight of potato, its causes, dissemination, and control. Ten to 25 farmers met every 2 weeks and worked with a facilitator as well as an extension worker who was an expert in agriculture and participatory research. The benefits to participants of FPR-FFS programs were initially evaluated by measuring the knowledge of late blight management of the participants and nonparticipants. It was observed that the participants have more knowledge than the other group with respect to blight disease, and this was further enhanced after a year of participation. The benefits of FPR-FFS programs for better blast resistance was also indirectly assessed in terms of better estimates of performance for a particular cultivar or technique which became more accurate by inclusion of data from more sites for assessment. One important
Table 9.4  Average ratings of potato variety trait importance by district and gender

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Prob &gt; $\chi^2$</th>
<th>Male</th>
<th>Female</th>
<th>Prob &gt; $\chi^2$</th>
<th>Laigaint</th>
<th>Yilmana</th>
<th>Prob &gt; $\chi^2$</th>
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</thead>
<tbody>
<tr>
<td>Biotic and abiotic tolerance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought tolerance</td>
<td>3.00</td>
<td>3.00</td>
<td>NS</td>
<td>2.79</td>
<td>3.00</td>
<td>NS</td>
<td>3.00</td>
<td>2.85</td>
<td>0.005</td>
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<tr>
<td>Low soil fertility adaptation</td>
<td>2.90</td>
<td>2.36</td>
<td>0.029</td>
<td>2.43</td>
<td>2.57</td>
<td>NS</td>
<td>2.70</td>
<td>2.47</td>
<td>0.038</td>
</tr>
<tr>
<td>Bird damage tolerance</td>
<td>2.45</td>
<td>2.36</td>
<td>NS</td>
<td>1.54</td>
<td>2.00</td>
<td>NS</td>
<td>2.41</td>
<td>1.65</td>
<td>0.000</td>
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<tr>
<td>Late blight tolerance</td>
<td>2.90</td>
<td>3.00</td>
<td>NS</td>
<td>2.93</td>
<td>3.00</td>
<td>NS</td>
<td>2.95</td>
<td>2.94</td>
<td>NS</td>
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<tr>
<td>Wind and hail damage tolerance</td>
<td>2.65</td>
<td>2.86</td>
<td>NS</td>
<td>2.61</td>
<td>2.86</td>
<td>NS</td>
<td>2.76</td>
<td>2.68</td>
<td>NS</td>
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<tr>
<td>Tuber spoilage tolerance</td>
<td>2.65</td>
<td>2.57</td>
<td>NS</td>
<td>2.57</td>
<td>2.86</td>
<td>NS</td>
<td>2.65</td>
<td>2.65</td>
<td>NS</td>
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<td>Agronomic traits</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Long shelf life</td>
<td>2.95</td>
<td>3.00</td>
<td>NS</td>
<td>2.93</td>
<td>3.00</td>
<td>NS</td>
<td>2.97</td>
<td>2.94</td>
<td>NS</td>
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<tr>
<td>Long root and stolon system</td>
<td>2.10</td>
<td>2.21</td>
<td>0.047</td>
<td>1.46</td>
<td>1.29</td>
<td>NS</td>
<td>2.16</td>
<td>1.38</td>
<td>0.000</td>
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<td>Large plant height</td>
<td>1.75</td>
<td>1.71</td>
<td>NS</td>
<td>1.32</td>
<td>1.14</td>
<td>NS</td>
<td>1.78</td>
<td>1.26</td>
<td>0.001</td>
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<tr>
<td>Large leaves</td>
<td>2.25</td>
<td>2.14</td>
<td>NS</td>
<td>2.04</td>
<td>1.57</td>
<td>NS</td>
<td>2.22</td>
<td>1.94</td>
<td>NS</td>
</tr>
<tr>
<td>Early flowering</td>
<td>2.35</td>
<td>1.93</td>
<td>NS</td>
<td>2.14</td>
<td>1.86</td>
<td>NS</td>
<td>2.14</td>
<td>2.06</td>
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<td>Thick stems</td>
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<td>2.50</td>
<td>NS</td>
<td>2.43</td>
<td>2.14</td>
<td>NS</td>
<td>2.70</td>
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</tr>
<tr>
<td>Strong leaves</td>
<td>2.25</td>
<td>2.50</td>
<td>NS</td>
<td>2.57</td>
<td>2.14</td>
<td>NS</td>
<td>2.35</td>
<td>2.47</td>
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<tr>
<td>Large number of leaves</td>
<td>2.15</td>
<td>2.36</td>
<td>NS</td>
<td>2.29</td>
<td>2.57</td>
<td>NS</td>
<td>2.27</td>
<td>2.32</td>
<td>NS</td>
</tr>
<tr>
<td>Large number of sprouts</td>
<td>2.60</td>
<td>2.43</td>
<td>NS</td>
<td>2.50</td>
<td>2.86</td>
<td>NS</td>
<td>2.57</td>
<td>2.59</td>
<td>NS</td>
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<tr>
<td>Early maturity**</td>
<td>2.55</td>
<td>2.29</td>
<td>NS</td>
<td>2.50</td>
<td>2.29</td>
<td>NS</td>
<td>2.41</td>
<td>2.44</td>
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<tr>
<td>Sequential harvesting</td>
<td>2.95</td>
<td>3.00</td>
<td>NS</td>
<td>2.75</td>
<td>2.86</td>
<td>NS</td>
<td>2.97</td>
<td>2.79</td>
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<tr>
<td>High yield</td>
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<td>3.00</td>
<td>NS</td>
<td>3.00</td>
<td>3.00</td>
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<td>3.00</td>
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<td>Tuber size</td>
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<td>2.59</td>
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<td>Tuber number</td>
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<td>2.18</td>
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<td>2.26</td>
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<tr>
<td>Utilization</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Suitability for boiling</td>
<td>3</td>
<td>2.93</td>
<td>NS</td>
<td>3.00</td>
<td>3.00</td>
<td>NS</td>
<td>2.97</td>
<td>3.00</td>
<td>NS</td>
</tr>
<tr>
<td>Suitability for stew</td>
<td>2.95</td>
<td>2.79</td>
<td>NS</td>
<td>3.00</td>
<td>3.00</td>
<td>NS</td>
<td>2.86</td>
<td>3.00</td>
<td>0.009</td>
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<tr>
<td>Market demand</td>
<td>2.75</td>
<td>2.29</td>
<td>0.0372</td>
<td>2.82</td>
<td>2.86</td>
<td>NS</td>
<td>2.57</td>
<td>2.82</td>
<td>NS</td>
</tr>
</tbody>
</table>

Reprinted from Kolech et al. (2015)

*Twelve very important traits are shown in bold; **only important for Meher season production

*P value associated with $\chi^2$ test using Kruskal’s rank test. Ratings are on a scale of 1 to 3, where 1 is less important and 3 is very important.
outcome of the FPR-FFS program was that it enabled the cultivators to eliminate the undesirable germplasm and recommend the best ones by coordinated work of the farmers and the breeders.

9.6  Sweet Potato

Sweet potato (Ipomoea batatas (L.) Lam.) ranks seventh among food crops in the world after wheat, rice, maize, potato, barley, and cassava and fifth for its caloric contribution in developing countries (Fig. 9.3). Sweet potato originated in the region between Yucatan peninsula of Mexico and the mouth of the Orinoco River in Venezuela about 10,000 years ago. The crop was distributed throughout the Americas by New World inhabitants through migration routes and introduced to Europe after the first trip of Christopher Columbus to Americas in 1492 via Spain. Scientific studies have confirmed that for sweet potato, two independent domestication events have occurred: one in Mesoamerica and the other the northwestern part of South America. Sub-Saharan Africa is considered to be a secondary center of diversity. It is a member of family Convolvulaceae (2n = 6x = 90) popularly known

<table>
<thead>
<tr>
<th>Traits</th>
<th>Participatory variety selection</th>
<th>Current breeding programa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biotic and abiotic tolerance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought tolerance</td>
<td>+++</td>
<td>++</td>
</tr>
<tr>
<td>Adapted to low fertility soil</td>
<td>++*</td>
<td>+</td>
</tr>
<tr>
<td>Late blight resistance</td>
<td>+++</td>
<td>+++</td>
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<tr>
<td>Lodging tolerance due to wind</td>
<td>++</td>
<td>+++</td>
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<tr>
<td>Tuber spoilage tolerance</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Wide adaptation</td>
<td>Not</td>
<td>Not</td>
</tr>
<tr>
<td><strong>Agronomic traits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long shelf life</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Sequential harvesting</td>
<td>+++</td>
<td>Not</td>
</tr>
<tr>
<td>High yield</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Early maturity</td>
<td>Depends on rainfall distribution</td>
<td>+++</td>
</tr>
<tr>
<td><strong>Utilization</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suitability for boiling</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Suitability for stew</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Market demand</td>
<td>++**</td>
<td>+++</td>
</tr>
</tbody>
</table>

*Very important at Laigaint; **very important at Yilmana; Not, not important; “+,” least important; “++,” somewhat important; “++,” very important trait

aCompiled from characteristics of new varieties and from the literature (Woldegiorgis 2013; National variety release procedures and guidelines document)
as the “bindweed” or the “morning glory family.” It is a herbaceous perennial vine treasured for its large, starchy, sweet-tasting, tuberous roots although young leaves and shoots are sometimes eaten as vegetable. The crop has received recent attention due to adaptability to different agroecological zones and its nutritional superiority. Sweet potato is a rich source of carbohydrates, dietary fiber, sugars, proteins, minerals (mainly iron and calcium), and vitamins (mainly vitamin A and C). Thus, the crop can play an important role in combating the vitamin deficiency in particular zones around the world. The International Potato Center (CIP) maintains one of the world’s largest cultivated sweet potato genebanks with over 5500 accessions and about 1092 wild sweet potato accessions corresponding to 67 species from 19 countries.

Uganda is the largest producer of sweet potato in Africa which is spearheaded by the Sweet Potato Programme (USPP) based at Namulonge Agricultural and Animal Production Research Institute (NAARI) in coordination with Serere Agricultural and Animal Production Research Institute (SAARI) in Eastern Uganda and Kalengyere Agricultural Research Development Center (KARDC). Scientists and

**Fig. 9.3** Different floral morphotypes in sweet potato. (Reprinted from Current Biology, Vol 28, Muñoz-Rodríguez P, Carruthers T, Wood JRI, Williams BRM, Weitemier K, Kronmiller B, Ellis D, Anglin NL, Longway L, Harris SA, Rausher MD, Kelly S, Liston A, Scotland RW, Reconciling conflicting phylogenies in the origin of sweet potato and dispersal to Polynesia, 1246–1256, 2018, with permission from Elsevier)
farmers in Uganda identified preferred sweet potato both through participatory varietal selection (PVS) and using new clones from seedling populations through a participatory plant breeding (PPB) approach. The participatory varietal selection (PVS) trials were incorporated into activities of two farmer groups in Masaka and Rakai districts of Uganda during three rainy seasons. NASPOT 1, a released variety, was most favored among the farmers due to traits like earliness, moderate resistance to sweet potato virus disease (SPVD), higher yield, and sweet and mealy roots. It was noticed that some of the traits desired by the farmers were not incorporated by the breeders due to reasons like being labor consuming and not for sure prediction of both biotic and abiotic stresses.

In continuation of the concerted breeding of Ugandan Plant Variety Release Committee (UPVRC), “NASPOT 11” (Namulonge Sweetpotato 11) was approved for release in 2010 which represented the first sweet potato cultivar bred by participatory plant breeding (PPB) for Africa. The main features of “NASPOT 11, a progeny of ‘New Kawogo,’” as the female parent from open-pollinated seed have been provided below:

(a) Excellent root yields exceeding 10 t/ha
(b) Long elliptic shape of roots
(c) Intermediate purple-red storage root skin color
(d) Cream root flesh color
(e) High dry matter (approximately 34%)
(f) Moderate to high field resistance to sweet potato virus disease (SPVD) and *Alternaria bataticola* blight
(g) High consumer acceptance

Côte d’Ivoire, with an area of 322,500 km², is a French-speaking country in West Africa where agriculture contributes 20% of the GDP and employs almost 50% of the population. Cocoa and coffee are the main crops grown in the country besides yam, rubber, cotton, plantains, pineapple, sweet potatoes, peanuts, minor cereals, and some oil-yielding crops. However, out of a population of 22.7 million people, over 23% of the country’s population lives below the international poverty line of US$1.25 per day, and the country’s Global Acute Malnutrition (GAM) rate among babies and young children is 7.1%. Sweet potato, due to its nutritional characteristics mentioned previously, can play an important role in mitigation of malnutrition especially of vitamin A in countries like Côte d’Ivoire. The flesh color of sweet potato is a reflection of the β-carotene content since a lot of diversity is seen for this aspect in the crops:

(a) White-fleshed varieties: having no β-carotene
(b) Yellow-fleshed varieties: having moderate content
(c) Orange-fleshed sweet potatoes (OFSP): containing high amounts of this vitamin A precursor
The flesh color assumes significance in countries like Côte d’Ivoire where vitamin A deficiency is rampant among the people in general and children in particular. Thus, OFSP can be an effective tool as a productive, low-cost source of provitamin A for the resource-deficient people. However, lack of OFSP planting material in Côte d’Ivoire has resulted in growth of only genotypes with white or yellow flesh. To mitigate this problem, 17 OFSP varieties were introduced from the Institut de l’Environnement et de Recherches Agricoles (INERA, Burkina Faso), Kenya, and Uganda through CIP and KEPHYS. These introduced varieties were evaluated through on-farm participatory approach conducted with 2769 women farmers in 42 villages in Bondoukou, Nassian, Korhogo, and Bondiali over a 2-year period (2014 and 2015) with the following objectives:

1. Selection of specific OFSP that are adapted to targeted regions
2. Enhancing the accessibility of cultivators to OFSP varieties
3. Creating awareness among the cultivators on the benefits of OFSP especially with reference to consumption
4. Training the farmers in newly developed agronomic practices so that they are able to take maximum benefit from the introduced varieties

It was observed the farmers primarily relied on higher yield, dry texture, good taste, and the external appearance of boiled roots. The PPB approach also helped in raising awareness among the cultivators with the advantages of varieties with orange-colored flesh along with efficient ways to cultivate it. The study showed that the variety “Irene” was most acceptable among the farmers followed by TIB-440060 and “Bela bela.”

9.7 Quinoa

Common names: Quinoa, Kinwa, Kinuwa, Kvinoa, Reismelde.

Quinoa (Chenopodium quinoa Willd.; family Amaranthaceae) is an underutilized Andean crop that is cultivated in South America primarily for its nutritious grain that is rich in high-quality protein having an excellent amino acid spectrum, essential vitamins, and minerals and has an excellent fatty acid profile. The crop is quite resilient and has the ability to grow in agricultural systems with minimum inputs. Quinoa has gained worldwide attention in recent decades due to its ability to grow in various stress conditions, such as salinity, acidity, drought, and frost, with the species exhibiting a high level of resistance to these environmental stresses. Quinoa is an allotetraploid (2n = 36) annual, predominantly self-fertilized crop with the 4C DNA amounts ranging from 6.34 to 6.47 pg. Although the crop has been cultivated for more than 5000 years in the Andean region, it was domesticated by ancient civilizations in different geographic zones like Peru (5000 BC), Chile (3000 BC), and Bolivia (750 BC). Ancient farmers in the Andes were the first to domesticate quinoa from its wild or weedy forms until the current known types in a domestication/
cultivation period of about 5000 years. In spite of the enormous potential of quinoa, the crop was never accorded importance by the breeders in formal programs due to varied reasons. Breeding work was initiated in earnest in the 1960s but picked up quite late in the Andean countries of Peru, Bolivia, and Ecuador when several organizations like Wageningen University, McKnight Foundation, and the PROINPA accorded due importance to the crop. However, formal breeding programs that focused on the release of cultivars having wide adaptation on large homogeneous high-input areas were futile since quinoa was cultivated by low-resource farmers in marginal environments where modern varieties of maize, barley, or wheat performed poorly. It was realized that participatory plant breeding was a viable alternative for improvement of quinoa in diverse environments prevalent in the region. A participatory varietal selection program was initiated for small farmers in the Ecuadorian highlands which had the following objectives:

1. To evaluate the participatory breeding techniques to small quinoa farmers in the country
2. To assess the evaluation capabilities of the farmers, both on farm and on station
3. To compare the gender-related variations among quinoa farmers and assess its impact on participatory trials
4. To determine the knowledge base of the cultivators with respect to disease in the plant and its impact on evaluation capabilities

The methodology entailed interviewing the farmers in two communities in the villages of Ninín Cachipata (Cotopaxi province, 3300 masl) and La Esperanza (Imbabura province, 2660 masl) to select farmers who were willing to be a part of the program. The selected farmers were informally interviewed over a period of 4 months on various aspects like:

- Seed origin
- Familiarity with quinoa cultivars
- Crop management practices like fertilizer use, intercropping, sowing density, etc.
- Disease and pest problems and their management
- Importance of saponin content and seed color
- Quinoa consumption pattern
- Cost of production
- Accessory income-generating activities

The results showed the predominance of women in quinoa cultivation since they interacted freely and showed greater interest in field work and quinoa evaluations. It was interesting to note that although the farmers were interested in sweet quinoa, the officially released low saponin cultivars by INIAP were not available with the farmers indicating that germplasm from formal breeding programs have not reached the actual stakeholders. Crop failure as a fallout of drought and frost reduced the availability of seed for the following year making the farmers “seed insecure.” The
breeders and the farmers differed in the selection criteria which were most evident in the importance accorded by the farmer to color. Similarly breeders gave preference to stem diameter for ease in mechanical threshing, while small farmers did not give due importance to this trait since they perform threshing by hand. Likewise farmers were not much concerned for downy mildew (caused by *Peronospora* sp.) resistance, but this formed an important selection criterion by formal plant breeders. It was observed that the on-station evaluations were not of much significance in quinoa improvement since the farm conditions rarely mimic actual field conditions leading to wide variation between the performance of the germplasm on-station and in on-farm trials. The study was important since it was a pioneer study regarding participatory studies in quinoa and pointed out the differences in the evaluation criteria followed by the farmers and the breeders.

Quinoa is also associated with an evolutionary participatory breeding (EPB) program that merges evolutionary breeding with participatory breeding for developing high-yielding, disease-resistant cultivars of desired quality while maintaining a high degree of genetic variation to allow for adaptability to fluctuations in environmental conditions. This long-term participatory development project started using ten biparental quinoa populations derived from the US Department of Agriculture’s National Genetic Resources Program, and private seed companies are intended to implement a collaborative European-North American EPB program for the crop with on-farm trials in several countries spread across continents. The pilot Global Collaborative network on quinoa (GCN-Quinoa) is the first step in moving forward with EPB in quinoa. The aim is to create a collaborative space to facilitate exchanges between farmers, processors, distributors, policy makers, and other persons involved in quinoa development for the promotion and sustainable use of quinoa genetic resources. Members of the GCN-quinoa interested in testing quinoa through the evolutionary participatory approach are gradually increasing, and the members can derive support and benefit from this association.

9.8 Cassava

Common names: Manioc, Yuca, Mandioca, Brazilian arrowroot.

Cassava (*Manihot esculenta* Crantz) (family: Euphorbiaceae), a perennial shrubby crop, is one of the three major tuberous crops consumed by nearly 600 million people in Africa, Asia, and Latin America. The crop is vital for food security as well as income generation for rural communities who grow cassava on marginal land for starch, biofuels, and alcohol production. The plant is allopolyploid in nature having a diploid chromosome number of 36, and a genome is 161,453 base pair in length. Cassava is an ancient crop species, and its domestication began about 5000–7000 years ago with most of the conventional domestication hypotheses considering the crop to be a “compilospecies” derived from one or more species complexes, either in Mexico and Central America or throughout the Neotropics. Christian
Isendahl (2011) has put forward the following points with respect to the origin and domestication of cassava:

1. *Manihot esculenta* subspecies *flabellifolia* (Pohl) Ciferri can be considered as the strongest taxa for the origin of cassava.
2. The savannas, the Brazilian Cerrado, to the south of the Amazon rainforest can be considered as probable area where cassava progenitor evolved.
3. The Brazilian Cerrado is also the most probable region of its initial cultivation.
4. Domesticated cassava spread from the agricultural origin by the early Holocene, possibly as early as 10,000 years ago, but certainly by 7000 B.C.
5. Domesticated cassava became distributed in most regions of the Neotropics by the mid-Holocene sometime around 6500 years ago.

Cassava is cultivated in the following two regions of Colombia:

1. Dry northern area characterized by poor soils and 800–1000 mm annual rainfall
2. Highlands of Southwest Colombia

CIAT and the Corporación Colombiana de Investigación Agropecuaria (CORPOICA) initiated a participatory research program in cassava on the following aspects:

(a) To obtain information regarding farmer criteria for choosing varieties along with the production and marketing systems
(b) Generation of better cassava germplasm that is acceptable to farmers by enabling the cultivators to evaluate characters within a non-preselected genetic base
(c) Increase cassava biodiversity by facilitating selection of a wide range of accessions having wide adaptation to different stresses

In 1986, the study started in Northern Columbia in a region where cassava was grown by poor farmers on nutrient-deficient soil. Initially cassava was used for own consumption, and a little was sold in the market, but in later years, a suitable market emerged, and the crop found its way for forage, livestock feed, and starch. These developments necessitated detailed studies to assess the farmers’ needs and a suitable participatory program to evaluate the potential of cassava clones derived from a formal breeding program. Eight to 10 farmers from 28 communities who evinced interest in the history of the crop, its usage, and their participation were chosen to evaluate the crop. The programs resulted in the release of three new cassava varieties in the region which were an outcome of the evaluation made by the cultivators. The study enabled the formal breeders to understand the farmers’ criteria in a better way and utilize some of these criteria in their own breeding program.

Cassava is an important crop for the poverty-stricken people in Northeast Brazil who produce about 58% of country’s output. However, the productivity in this arid and semiarid zone having low fertility soils and small farms (70% less than 10 ha in area) is quite low (10.7 t/ha) which is far below the national average of 17.1 t/ha.
The cassava yield has been limited in this region for decades due to frequent dry spells, diseases like root rots and witches’ broom, lack of suitable planting material, and limited research been undertaken in these resource-deficient areas. Since the late 1980s, participatory plant breeding came into prominence in the region and involved association between the small-scale farmers in marginal areas and the formal plant breeders. The objective was to develop crop varieties as per the needs of the resource-poor farmers in these stressful conditions to develop their skills leading to economic empowerment. A formal project was initiated in the mid-1990s by Wania Maria Goncalves Fukuda, a cassava breeder at the Empresa Brasileira de Pesquisa Agropecuária/Centro Nacional de Pesquisa de Mandioca e Fruticultura Tropical (EMBRAPA/CNPMF) with funding from the International Fund for Agricultural Development (IFAD), and technical support from CIAT. Within a span of 8 years, the participatory cassava breeding program conducted about 300 trials and released 10 varieties. A detailed study was conducted in the year 2002 in four communities in Northeast Brazil, viz., Lagoa do Barro, Tanquinho, Cajueiro dos Potes, and Muniz, to assess the reasons and the extent of adoption of cassava varieties introduced through PPB and the benefits they accrued to the cultivators. An average of 30 farmers were interviewed in each community that added up to a sample size of 122. The survey showed the willingness of the cassava farmers to pay for the planting material which was generally not a practice in the region. Also there was a demand for clean planting materials, even of those discarded clones that were considered less desirable to the existing planting material. It was interesting to note that for most of the respondents (both participating and nonparticipating), the main reason for trying the clones was the need for new varieties followed by a general sense of curiosity. Although the adoption of cassava clones was high in the region, there was no major yield improvement in production or income. However, this should be considered as the success of the PPB program since it stemmed the continuous trend of decrease in cassava yields in the experimental area.

Kenya is a major cassava-producing country in Africa with the crop being cultivated in western, eastern/central, and coastal regions intercropped with beans, maize, and bananas. The crop is most important in the western regions of the country which accounts for about 60% of the country’s cassava production. A participatory study was conducted in three major cassava growing regions of western Kenya, viz., Mumias, Teso, and Busia, located in diverse agroecological zones to generate information regarding the qualitative methods used by farmers to evaluate cassava varieties, the effectiveness the farmers’ qualitative, and the breeder’s qualitative methods of evaluating cassava varieties for preferred traits. Fifteen varieties that included 6 landraces and 4 improved varieties based on their usage and popularity were chosen for the study. An exhaustive focused group discussion (FGD) was carried out that involved farmers as well as members of the farmer groups. It was observed that the farmers evaluated plant material primarily on the basis on diverse traits in contrast to the breeders who evaluated the germplasm on the basis of scientific knowledge and expertise. High yield of storage roots, clean plants, and disease
resistance were considered as the most preferred traits in all the study areas. Both the evaluation methods showed significant correlation between related traits and exhibited differences between varieties for most of the traits under study. The taste of boiled roots was an important character for the farmers but was not given due preference by the breeder due to lack of evaluation methods. An interesting finding of the study was that despite the differences in traits preferences and variety ranking between the cultivators and the researchers, both had effective evaluation methods. However, both the groups had gaps in evaluation that indicated the requirement of effective participatory variety selection program.

9.9 Coffee

Common names: Arabian coffee, Mountain coffee, Arabica coffee.

Coffee (Coffea Arabica; family: Rubiaceae), introduced in Rwanda in 1904 by German missionaries, is an important cash crop in Rwanda and a source of income for about half million small farmers. Rwandan coffee is considered as one of the best in the world due to features like aromatic richness, complexity, balance, elegance, aroma intensity, and strength. In an agricultural centered economy of the country, coffee is a major export item and contributes more than 45% of the exports. Rwanda fetched $58.5 million from coffee exports in the financial year July 2016–June 2017. Despite the impressive progress, coffee productivity index is constrained in Rwanda due to lack of high-yielding and disease-resistant varieties, along with low soil fertility and extensive soil erosion. Diseases like coffee rust caused by Hemileia vastatrix (order: Pucciniales, Basidiomycota) and coffee berry disease caused by Colletotrichum kahawae (order: Glomerellales, Ascomycota) lead to severe losses in coffee-growing areas of Rwanda. H. vastatrix is believed to cause losses to the tune of 30–90% depending on the prevailing environmental conditions. To mitigate this problem, a participatory adaptive breeding program was initiated in 2009 with the objective to develop improved coffee varieties within a short span of time that show high degree of resistance to leaf rust and berry disease. The program led to the development of a promising coffee variety RAB C 15 that was not only resistant to both the fungal diseases but was high yielding and had quality attributes at par with the fine cup quality of the commercial varieties.

Coffee cultivation is a major economic activity in Columbia, a country situated in northwest of South America where agriculture is an important source of livelihood, providing employment to about one fifth of the country’s work force. Although commercial production began in 1808 in Columbia, coffee has been documented in the country since 1730 when it was mentioned by Jesuit priest, José Gumilla, in his book *The Orinoco Illustrated*. Today Columbia stands third in coffee production with about 11.5 billion bags and is next only to Brazil and Vietnam. Columbia is also the highest producer of Arabica coffee in the world. The coffee-growing axis or
the coffee triangle is a part of the Colombian Paisa region comprising a meager 1.2% of the territory and comprises three departments (administrative units in Colombia):

1. Caldas
2. Quindío
3. Risaralda

*Hypothenemus hampei*, the coffee berry borer (CBB), first detected in Nariño in 1988, is a major pest in coffee plantations and has spread throughout the major coffee-growing regions in the country leading to massive losses. Due to enormity of the problem, the National Coffee Research Centre (Cenicafé) developed an integrated pest management (IPM) program for controlling the CBB. The program laid emphasis on monitoring the disease and implementing biological control of the pest. However, subsequent studies showed that majority of the coffee growers were using the chemical insecticides like endosulfan (organochlorine insecticide) and chlorpyrifos (organophosphate pesticide), while only 18% used biological control. Also, the farmers only sporadically used cultural harvesting practices that were possibly due to the inadequacy of these practices in controlling the CBB. This necessitated the initiation of a participatory project with small-scale coffee growers. An integrated management program against the CBB was initiated on 34 small farms in 3 municipalities, viz., Quimbaya, Montenegro, and Buenavista, from 1998 to 2001. This IPM program comprised of aspects like workshops and hands-on training sessions to the farmers and associated field-workers wherein they were appraised about the cultural management practices along with inculcating awareness about the use of parasitoids and entomopathogenic fungus in the control of CBB. A decrease in the CBB populations was observed in all the three experimental areas after growers improved harvesting practices and released ten million *Cephalonomia stephanoderis* and five million *Prorops nasuta* over a period of 2 years.

### 9.10 Cotton

Cotton (*Gossypium* spp.; family: Malvaceae) is one of the most important fiber-producing plants distributed in arid to semiarid regions of the tropic and subtropics. It is also considered as a good source of oil that is used as an animal feed and for soap production. *Gossypium* includes about 50 species that show large variation in vegetative and reproductive structures and are distributed across Africa, Australia, Central and South America, the Galapagos Islands, Hawaii, the Indian subcontinent, and Middle East Asia (Fig. 9.4). Cotton is the fifth largest fiber-producing plant in the world.

Cotton cultivation is carried out in the Indian subcontinent in rotation with oilseeds, pulses, and millets. India is the biggest cotton producer in the world with approximate cotton yield for the 2017–2018 season being estimated at 365 lakh bales of 170 kg each. However, displacement of conventional cotton species by
genetically modified hybrids has put a severe stress on organic cotton cultivation in India. Since PPB offers immense opportunity for developing locally adapted cultivars, a study was conducted with the following objectives:

1. Introduction of participatory approaches for organic breeding
2. Inculcating team work among the different stakeholders, viz., farmers, breeders, extension agents, and industry personnel
3. Evaluation of improved germplasm in smallholders’ fields

Fig. 9.4  Centers of origin or primary geographic distribution sites of cultivated cotton species *G. hirsutum* L. (a), *G. barbadense* L. (a), *G. arboreum* L. (b), and *G. herbaceum* L. (b) and their wild relatives (a and b). (Reprinted from Mammadov et al. 2018)
4. Assessing the suitability of different types of cotton germplasm for organic and low-input farming in India

The project was initiated in 2011 and is a joint effort of the following organizations:

(a) bioRe Association, Madhya Pradesh
(b) Chetna Organic, Orissa
(c) University of Agricultural Science (UAS) Dharwad, Karnataka
(d) Research Institute of Organic Agriculture (FiBL), Switzerland

The Cotton Cultivar Evaluation Project laid emphasis on the evaluation of traditional cultivars using on-station and on-farm participatory trials, which focused on the re-establishment of cotton seed supply chain under control of the farmers to safeguard the organic cotton production. The farmers were quite enthusiastic about the project and shared their field experience along with active participation in workshops, cross breeding, and the selection process. G. arboreum and G. hirsutum were the major species tested. It was noticed that the performance of the germplasm depended on the climate, edaphic factors, and availability of irrigation. An effective collaboration among various stakeholders allows identification of genotypes that exhibited better performance in marginal environments and could be of use to the small farmers. The on-farm trials were extremely beneficial since they enabled the farmers to take up seed production of the best germplasm and kept the farmers engaged.

In Africa, Uganda is an important cotton-producing nation (largest organic cotton producer in Africa) where the crop was introduced by British Cotton Growing Association in 1903. In the year 2010, about 80,000 hectares of land was under cotton cultivation in the country, and it was a major source of revenue for both rural households and the national economy. Uganda followed the one variety policy for decades under which the variety Bukalasa Pedigree Albar (BPA2002) developed by the Government Breeding Station was cultivated throughout the country, mainly by the small farmers. A collaborative program was initiated in 2010 by the Wageningen University, cotton breeders, and cotton farmers in Uganda that aimed at development of cotton varieties suited to the local low-input farming environments. Marginal farmers and formal breeders held workshops where the germplasm performance was evaluated after two farmer field trials. Although both the groups gave high importance to yield, they differed slightly on the preference to be given to other traits. For example, the breeders recommended a fast-maturing crop, while the cultivators gave more importance to a short and bushy plant habit making it easier to pick bolls and reducing the labor cost. The cultivators also expressed the desire for the following information:

(a) Information on the best period for sowing cotton
(b) Best planting distance between planting holes
(c) Row-to-row distance
Both the stakeholders, viz., smallholder farmers and breeders, preferred testing of germplasm on farmers’ plots and jointed workshops to exchange ideas that would lead to improved variety. A participatory breeding approach using the mother-baby trial principle was envisaged as a promising option to achieve better adaptation to low-input farming systems (Table 9.6).

### Table 9.6 Pedigree and seed yield of ten populations in two locations (Pullman, high-heat environment, and Quilcene, low-heat environment) in Washington State, USA, in 2014

<table>
<thead>
<tr>
<th>Population designation</th>
<th>Female parent</th>
<th>Male parent</th>
<th>Seed yield (g/400 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>High-heat environment</td>
</tr>
<tr>
<td>QUP11WA-101</td>
<td>Biobio</td>
<td>Colorado 407D</td>
<td>7.5</td>
</tr>
<tr>
<td>QUP11WA-102</td>
<td>Colorado 407D</td>
<td>QQ74</td>
<td>94.9</td>
</tr>
<tr>
<td>QUP11WA-103</td>
<td>Cherry Vanilla</td>
<td>Black</td>
<td>1.3</td>
</tr>
<tr>
<td>QUP11WA-104</td>
<td>Kaslaca</td>
<td>QQ74</td>
<td>8.5</td>
</tr>
<tr>
<td>QUP11WA-105</td>
<td>QQ065</td>
<td>QQ74</td>
<td>7.8</td>
</tr>
<tr>
<td>QUP11WA-106</td>
<td>QQ065</td>
<td>Black</td>
<td>20.8</td>
</tr>
<tr>
<td>QUP11WA-107</td>
<td>QQ74</td>
<td>Black</td>
<td>10.1</td>
</tr>
<tr>
<td>QUP11WA-108</td>
<td>QQ74</td>
<td>Cherry Vanilla</td>
<td>No seed</td>
</tr>
<tr>
<td>QUP11WA-109</td>
<td>Temuko</td>
<td>Biobio</td>
<td>No seed</td>
</tr>
<tr>
<td>QUP11WA-110</td>
<td>Oro de Valle</td>
<td>Black</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Reprinted from Murphy et al. (2016)

(d) Number of seeds to be sown in a planting hole  
(e) Number of stems per planting hole

Participatory methods have immense potential for the involvement of farmers in the designing of the agroforestry systems. Participatory agroforestry is increasingly being promoted to enhance watershed function and development of livelihood for the local populations. Generally, the selection involves identifying and prioritizing farmers’ needs and preferences in forest tree management and utilization. Furthermore, by taking local environmental knowledge into consideration, a participatory approach helps to identify tree species for selection that can meet both social and environmental needs.

Democratic People’s Republic of Korea (North Korea) used the participatory approach for empowering local user groups to develop their preferences for agroforestry species. Local knowledge of the multiple functions of agroforestry species ensured that the tree selection criteria included the value of timber, fruit, fodder, oil, medicines, fuel wood, and erosion control. Involving 67 farmers from 3 counties,
this participatory selection process resulted in *Prunus armeniaca*, *Castanea cre- nata*, and *Ziziphus jujube* being selected as the top 3 species for the development of sloping-land agroforestry in North Hwanghae Province. These trees embody what the region’s farmers value most: erosion control, fruit production, and economic value. The participatory approach in agroforestry could help to meet both local needs for food security and the national objective of environmental conservation and has great potential for wide adaptation in North Korea and beyond.

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Future of Participatory Plant Breeding

Abstract

The Green Revolution was a huge success especially in cereals and had a tremendous impact on food production, socioeconomic conditions, and environmental sustainability. However, this success story seemed incomplete since Green Revolution created islands of prosperity in vast stretches of low productive areas. To mitigate this problem, participatory plant breeding was conceived and extensive work carried out in this new field. PPB is extremely advantageous in those geographic areas where classical breeding efforts have been less successful and failed to leave a positive impact on farmers’ conditions. PPB can be resorted to for multiple uses like increasing productivity, preserving diversity and benefits for specific end users. However, most of these goals are not mutually compatible leading to trade-offs when any one option is given priority. Participatory approaches have certain limitations when compared to the conventional breeding methodologies especially the cost that is sometimes exorbitant and lead to selection of conventional methods as way of improvement. Thus, it is important that one should have total clarity regarding the objective of participatory research as to whether it is being used for improving the efficiency of agricultural research or merely being used as a tool for empowering farmers or partner organizations. Plant breeding institutions need to focus on the functional components of participatory breeding along with the empowerment of intermediate/partner organizations rather than the direct empowerment of large numbers of farmers.

10.1 Introduction

The purpose of conventional plant breeding is the creation of new varieties having improved agricultural traits. Classical breeding utilizes the natural diversity prevalent in the germplasm as a source of valuable economic traits and creates new varieties using selection and intra- and interspecific crosses. The advent of the Green
Revolution greatly improved agricultural productivity in many developing countries, saving billions of people from famine and starvation. The Green Revolution was a huge success especially in cereals and had a tremendous impact on food production, socioeconomic conditions, and environmental sustainability (Fig. 10.1). The outcome of Green Revolution was that in several places production surpassed the population growth leading to increased per capita availability of cereals and better consumption. Many Asian countries reaped the benefits of Green Revolution to meet the growing needs of food supply using productive lands. However, this success story seemed incomplete since Green Revolution created islands of prosperity in vast stretches of low productive areas. This was due to the fact that Green Revolution mainly looked into the productivity aspect of crops rather than the producers. To mitigate this problem, participatory plant breeding was conceived, and extensive work carried out in this new field.

PPB is extremely advantageous in those geographic areas where classical breeding efforts have been less successful and failed to leave a positive impact on farmers’ conditions. Some of the areas having this specific situation have been provided below:

1. Marginal agricultural areas: In these areas the environment is highly variable that results in less adaptation of modern varieties. As a result the farmers in these areas are not benefitted. Some such areas are the hilly regions, rainfed zones, and abiotic stress-affected soils.

2. Rural areas: These areas are plagued with little or no formal seed supply systems along with predominance of subsistence-based farming.

3. Areas where local crops are neglected: Small farmers give a lot of emphasis on cultivation of local crops which are mainly noncommercial in nature. These local crops once widely cultivated before the advent of Green Revolution have never been the target of plant breeders. As a result these crops have not shown improvement in agronomic parameters and have lagged behind in usage. Thus, participatory farming is more suited to areas where these neglected crops have not been at the helm of breeding efforts.

4. Major crops in highly productive ecosystems where cultural preferences and biotic stresses have not been given due preference by the plant breeders: Example

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**Fig. 10.1** The impact of Green Revolution. (Reprinted by permission from Springer Nature: Green revolution: the way forward, Khush GH, Nature Review Genetics, 2:815–822, 2001)
of this type is the red rice that is used in special dishes and cultural ceremonies. Another example is the preferential use of secondary plant products like long straw for animal feed, flowers for vegetable soups, etc.

5. Loss of consumer preferences like specific taste in some areas which are lost in conventional breeding due to low preference being given to them.

6. Specific agronomic conditions like organic agriculture and mixed cropping in which the modern varieties have not been fruitful.

7. Drastic changes in the environment like occurrence of a natural disaster or after armed conflicts.

10.2 Setting Right Goals for PPB

One area that requires greatest attention is the explicit goal setting in PPB programs, i.e., defining in clear terms for what purpose is PPB being used. This assumes importance since PPB can be resorted to for multiple uses like increasing productivity, preserving diversity and benefits for specific end users. However, most of the abovementioned goals are not mutually compatible leading to trade-offs when any one option is given priority. The research design should be managed in such a way that the goal to be followed is given primacy which is often not the case. Thus, most PPB programs in a way become modifications/extensions of the formal breeding programs that focus mainly on the productivity aspect. A surprising aspect is the maximal use of PPB in cases when conventional breeding has failed to live up to the expectations which points to the fact that significant gap exists in our understanding of cases where PPB offers greater advantages over conventional breeding. This has resulted in complete absence of many crops and cropping systems from the realm of PPB with virtually no field studies in them.

10.3 Challenges with Respect to Conventional Breeding

Participatory approaches have certain limitations when compared to the conventional breeding methodologies with respect to logistics. The cost of maintaining participatory approaches is sometimes exorbitant and lead to selection of conventional methods as way of improvement. In spite of the cultivators lessening the burden of cost through their own labor and involvement, the major operational constraints are the difficulties in regular monitoring leading to problems of trial maintenance and protection. Also the skills and techniques used by the farmers may be new to the breeder leading to gaps in planning and execution. Another major challenge is to incorporate input from multiple farmers in multiple environments into a single breeding program which is a difficult task. Also raising the skills of the farmers in selection and breeding methodology is a major challenge and also a limitation in participatory breeding.
10.3.1 Social Challenges

Most of the PPB studies exhibit lack of information on the nature of participation especially with respect to gender participation in such studies. It has been observed that several PPB studies have lack of participation and inputs from women and illiterate farmers. The question of who participated and why was the group chosen has a significant bearing on the expected outcome of the study.

10.3.2 Lack of Farmer Interest

Some PPB studies exhibit a decline in participation by the farmers as time passes by. This is due to the fact that in some cases the farmers may need to spend a great deal of time, energy, and resources on maintaining quality and production since they share responsibilities and decision-making along with playing a major role in administrative and technical part. This results in loss of interest among the farmers and the development of more varieties or spreading the experience may not be feasible at all times.

10.4 Plant Breeder’s Rights and Seed Laws

PPB presents an interesting challenge for the regulators. Varieties developed through participatory approaches are rarely uniform and are less likely to pass national multi-location trials for varietal release. Even the farmers are not enthusiastic about the registration of these varieties since they are likely to share it with neighboring farmers. The cultivators want the selected varieties to evolve in their specific environment in which they will be grown. These farmers in all probability will not be able to register the varieties or release them after trials. They are also not interested in protection on such varieties. Also, seed laws are often contrary to such initiatives for increasing diversity through breeding. Although there are some examples like the European Union’s concept of “conservation variety” that creates policy space for the marketing old, heterogeneous, varieties having specific adaptation and qualities, this can rarely be used for outputs of participatory breeding.

10.5 Other Technical Issues

There are several other technical issues associated with PPB which need further attention.
10.5.1 PPB and Genetic Diversity

When one assumes that PPB enhances genetic diversity, one important question relates to how the genetic diversity is assessed in a realistic manner. Thus, one needs make a correct assessment of genetic diversity and its actual alteration.

10.5.2 Innovative Approaches for Different Cultivation Systems

Novel approaches are required for crops that are sown by broadcasting, as seed mixtures or by mechanized equipment and machinery.

10.6 The Future of PPB

Green Revolution has been an astounding success in tropical and subtropical areas with assured irrigation systems and has led to enormous increase in crop yield that was mainly attributed to the adoption of modern high-yielding crop varieties and new agricultural practices. However, this agricultural miracle has been of limited relevance to farmers living in marginal areas since breeders focused mainly on homogeneous agroecological and socioeconomic conditions. The researchers ignored the smallholder farmers residing in areas with low agricultural potential having low soil fertility, resistance to biotic and abiotic stresses, and inadequate storability of grains and seed.

Participatory breeding aims to enhance the efficiency and impact of agricultural technology by effective diffusion in agriculture utilizing the feedback loops that link the formal systems with the informal ones. However, one should have total clarity regarding the objective of participatory research as to whether it is being used for improving the efficiency of agricultural research or merely being used as a tool for empowering farmers or partner organizations. While a lot has been said about the internal rates of return and cost-benefit analyses of PPB, the future of participatory breeding hinges on the assessment of a much broader range of impact, particularly in the realm of rural innovation capacity and poverty alleviation.

Rural innovation can occur in two ways:

1. More accessibility of new technology due to lower costs of adoption
2. Development of a novel local technology as a result of increased adaptability

Therefore, a coordination of the researchers, farmers, industry, and consumers is required through participatory breeding approaches for rapid uptake of new cropping technologies that entails a shift in focus of agricultural research from
commercial farms to the local level by directly involving the actual stakeholder at different stages of the breeding process. This realization has resulted in realignment of several formal plant breeding programs toward issues that affect the resource deficient farmers in marginal areas. This has resulted in an increasing demand for plant breeders to find problems faced by the poor farmers throughout the world.

Participatory research would, therefore, lead to empowerment of the poor farmers which have hitherto been neglected in the research carried out by research institutions which cater to resource rich farmers. Farmer empowerment can be best generated by research institutions that can undertake long-term interaction with marginal farmers to ensure that greater benefit to this group. Therefore, plant breeding institutions need to focus on the functional components of participatory breeding, especially in terms of policy and technology development, along with the empowerment of intermediate/partner organizations rather than the direct empowerment of large numbers of farmers.

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