Plant Breeding: Aims, Scope and Importance

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Abstract

Plant breeding is as old as Agriculture. Plant breeding started with man bringing desirable wild type plants under cultivation. The continuous selection under both natural and artificial settings led to domestication and evolution of plants that were unable to survive under wild environments. The land races have higher yields than their wild type counterparts. Through breeding, yields of crops have been tremendously improved. The increase in yield has been a result of implementing findings from numerous scientific discoveries since 1900. Plant breeding has been employing conventional breeding techniques before, it now combines it with advanced modern breeding technologies such as genome editing, marker assisted selection, genomic assisted selection, genomic prediction. In addition, rapid generation advancement and high-throughput phenotyping technologies are also being implemented to shorten breeding cycle and increase selection accuracy, and increase the rate of varietal development.

Key word: Domestication, Plant breeding, crop evolution, cultivars, land races, Mendel’s contribution, breeding objectives, breeding achievements

1.1 History of Plant Domestication and Plant Breeding

The periods from around 10,000 – 1,000 B.C., is the era when the first farmers began introducing the best wild species under cultivation. The earliest domesticated crops occurred in Mesopotamia, which today comprises the modern nations of Iran, Iraq, Turkey, and Syria. These included cereals such as wheat and barley, and legumes as lentils and many kinds of peas. In addition, people domesticated plants in other regions of the world, such as eastern Asia, parts of Africa, and North and South America. During the domestication process, humans selected for unique or unusual phenotypes and maintain them in their cultivars for aesthetic reasons, whereas synchronous ripening or the avoidance of seed shattering (a dispersal mechanism) are selected for to facilitate harvest. The first type of cultivar and the outcome of domestication are the landrace variants. Landraces are varied because they were chosen for subsistence farming circumstances when modest, reliable yields were necessary, and a large genetic base was needed owing to natural environmental unpredictability.

Humans' attempts to learn about how plants survive and reproduce, as well as how to make use of the variations that already exists, may be seen between 700 BC and 1900. Assyrians and Babylonians were intentionally pollinating Date palms by 700 BC. Date palms has separate male and female plants (*Phoenix dactylifera* L.), thus, good seed set could only be attained by human intervention. Rudolf Camerarius working with monoecious plants (e.g., mulberry, castor-bean, and Indian corn) demonstrated the existence of sex in plants in 1694. He removed the silks from corn and proved that pollen of corn was necessary to fertilize the ovules in order that the kernels might develop. Thomas Fairchild (1717) crossed sweet william (*Dianthus barbatus*) and carnation (*Dianthus caryophyllus*), creating the first interspecific hybrid flower variety known as Fairchild's mule. Between 1760 and 1766, Joseph Koelreuter conducted one of the most systematic studies on plant hybridization of a variety of species. Using 138 distinct species, he conducted nearly 500 different hybridization experiments and studied the pollen traits of more than 1000 different plant species. He observed heterosis among interspecies crosses, male sterility within species and among interspecies crosses, and self-incompatibility phenomena.

An observation of natural cross-pollination was first reported by Cotton Mather in 1716. He observed cross pollination between large yellow corn field planted along with a row of blue and red corn maize. Cobs from yellow corn plants contained a mixture of yellow, blue and red coloured kernel. Robert Reid and his son James Robert Reid made contributions to the creation of Reid Yellow Dent in 1846 and 1847. Reid Yellow Dent corn was created by combining Gordon Hopkins and Little Yellow Corn with a continual mass selection process where it was later carried forward by several breeders' year after year. In 1727, the Vilmorin Breeding Institute in France was established by Louis Leveque de Vilmorin. The institute focused on enhancing sugar content, size, and shape of sugar beets. The progeny test was invented at the institute to assess breeding potential of a single plant. In 1899, just before the rediscovery of Mendel's work, the concept of ear to row selection method was laid down by Hopkins for maize breeding.

The era from 1900 to today marks the post-mendelian era. The modern plant breeding era evolved upon the foundation laid by the fundamental laws of Mendel in 1865. But his work went unnoticed and then it started with the rediscovery of Mendel's work. Mendel described how traits pass from one generation to the next. The genetic principles that were developed continue to guide crop improvement. In 1903, the Danish botanist Wilhelm Johannsen put forth the pure-line theory while working on French bean and it marked the first example of application of genetics in the field of plant breeding. The study of wheat pericarp colour inheritance by Nilsson-Ehle formulated the multiple factor hypothesis. Morgan gave the famous chromosomal theory of inheritance in 1910 and his student Sturtevant in 1913 developed the first ever linkage map in drosophila. In 1919, the idea of a single cross was extended further by D. F. Jones who proposed the concept of double cross which essentially involves the cross between the products of two separate single crosses. The first commercial hybrid was from corn breeding, was released in the 1926. Hayes and Garber gave idea on recurrent selection and also suggested the use of synthetic maize varieties for commercial applications. The similar idea about recurrent selection was given by East and Jones. The extensive studies on *Nicotiana sanderae* by East and Mangelsdorf resulted in the discovery of gametophytic system of self-incompatibility while its counterpart called Sporophytic system was later discovered by Hughes and Babcock in 1950 while working on *Crepis foetida*.

In the 1930s, mutagenesis where used in mutation breeding. Stadler used X-rays for inducing mutations in barley in 1928. The agent is employed on genetic resources to increase genetic diversity and speed up novel trait development and discovery. In 1934, Dustin discovered the effect of colchicine on mitosis in mice and it was further successfully applied in plants by Nebel and Balkeslee who discovered the polyploidy induction in plants due to application of colchicine. The use of single seed descent method in self-pollinated crops for advancing the segregating generations was suggested in 1939 by Goulden. In the 1945, using the knowledge from the works of Mendel, Norman Borlaug and his team in Mexico developed semi-dwarf varieties that were more productive, and higher-yielding across a number of crop species including wheat and rice.

DNA structure was discovered in 1953 by James Watson and Francis Crick. This helped explain how hereditary information is coded and replicated in living being. This was one of the most significant discoveries of the 20^{th} century, and helped advance molecular biology to this day. Then scientists began to apply tissue and cell culture technologies to create genetic variability and increase the number of desirable germplasms available to the plant breeder. One of the most significant achievement in this aspect was the development of MS media in 1962 by Murashige and Skoog which revolutionized the field of tissue culture. The introduction of recombinant DNA technology in 1973 by Paul Berg, Stanley Cohen and Herbert Boyer opened a new window for development of novel organisms. In 1983, scientists developed the first plants using biotechnology to introduce a trait from nature to help them better survive their environment. Monsanto utilized this genetic engineering approach to develop the first ever transgenic cotton in 1987. But the use of such genetically modified crops remained a debatable topic and hence the use of this GM technology was restricted.

The discovery of Restriction Fragment Length Polymorphisms (RFLPs) by Beckmann and Soller in 1983 initiated marker-based era in the biotechnology which was further accelerated with the invention of Polymerase Chain Reaction by Karry Mullis for which he was awarded the Noble Prize in 1993. This led to the beginning of the new era of plant breeding which was laid upon the foundation of principle called Marker Assisted Selection (MAS). MAS is the indirect selection process where a trait of interest is selected based on a marker linked to a trait of interest. Genomic selection, which was proposed by Meuwissen in 2001, is a form of MAS in which genetic markers covering the whole genome are used. The advancements in sequencing led to various sequencing projects and currently the most of the majorly cultivated crops have been sequenced. The rice genome was sequenced in 2002 while recently the chickpea genome sequencing was done. The development of various genome editing tool, as an alternative to putatively hazardous GM technology has shown the great potential in developing superior crops. Various tools such as ZFNs, TALENs and CRISPR has revolutionized the field of gene editing and in the year 2020 the Noble Prize for chemistry was awarded to Jennifer Doudna and Emmanuelle Charpentier for the discovery of CRISPR-Cas9 technology.

1.2 Nature of Plant Breeding

Plant breeding is an art or science and is as old as agriculture started since man learnt to cultivate the plants. In earlier days, man depended on his skill and judgement in selecting better plants. His knowledge about the plant was very limited. Knowledge about inheritance of characters, role of environment in producing them and the basis of variation in various plant characters were unknown. During the primitive time plant breeding was largely an art and very less science was involved. After the rediscovery of Mendel’s work and the advancement in science, breeding methods became entirely based on the scientific principles of plant sciences, particularly of genetics and cytogenetic. Science is the knowledge gathered through scientific method. The scientific method consists of observation, formulation of hypothesis, experimentation, and conclusion either to accept or reject the hypothesis.

Selection of desirable plant today combines art and science. Successful breeder should understand principles of difference disciplines viz. genetics, cytology, Morphology and

Taxonomy, plant Physiology, Plant Pathology, Entomology, Agronomy, and Soil Science, Biochemistry, Statistics, and Biometrics, Computer and Plant biotechnology.

1.3 Understanding of plant breeder

Plant breeder applies genetic principles to produce plants that are more useful to humans. Plant breeder usually has in mind an ideal plant that combines a maximum number of desirable characteristics. These characteristics may include resistance to diseases and insects; tolerance to heat, soil salinity, or frost; appropriate size, shape, and time to maturity; and many other general and specific traits that contribute to improved adaptation to the environment, ease in growing and handling, greater yield, and better quality.

There has been a substantial transformation in how genetics relates to plant breeding. Until recently, the focus was on plants and phenotypes, and phenotypic selection. Plant breeders relied on disciplines such as statistical genetics that, in some vague but nonetheless effective manner, helped improve germplasm. The operational model was that of form follows function; that is, select based on phenotype (function), and changes in the underlying genotype (form) would follow. The focus of current plant genetics is mostly on genes and genotypes. We are in the era of gene sequencing, mapping, transformation, functional genomics, proteomics, and metabolomics. The underlying assumption of most current plant geneticists is that if the genotype is well enough understood, improved plants and phenotypes will follow without undue exertion. The new vision of a plant breeder is that of a true engineer who assembles the appropriate set of nucleotide sequences in the construction of an ideal genotype. The engineering approach to plant improvement most closely follows the function follows form model. The goal is to engineer plants from the sequence up, locus by locus, rather than, as some would claim, work backward by using plants and their phenotypes to modify the underlying genotype.

1.4 Objectives of Plant Breeding

Developing high yielding varieties: Increase in yield is an ultimate goal of plant breeding. This increase has been achieved using a variety of techniques, such as; recurrent selection, hybrid development, backcross breeding. Advanced "*omic*" tools are being used to complement conventional breeding techniques, such includes utilization of genetic maps, marker assisted selection, genomic assisted breeding, genomic prediction etc.

Enhancing nutritional value of crops: breeding for quality aspects is an important traits of crop improvement. Successful achievement has been attained in golden rice development, development of high-quality protein maize, enhanced malting quality in barley, prolonged shelf life of fruits and vegetables, reduction of gluten in wheat, BOAA free khesari, breeding for high lysine content in sorghum, aroma in rice etc. Reducing or eliminating undesirable toxic compounds of the product is also considered with almost importance. For instance, sorghum breeding programs all over the world have been aiming to reduce the amount of anti-nutritional factors such as; hydrogen cyanide in fodder, lignin content in cell-wall, tannin content in grain.

Mitigating biotic and abiotic stresses: over 50% crop losses are attributed to biotic and abiotic events. The most prevalent abiotic stress event is drought, salinity, heat, and biotic stresses are fungal, bacterial and viral diseases. Deployment of resistant cultivars is considered more affordable, practical, and environmentally friendly than any other methods.

Developing early maturating varieties: development of early maturing varieties aims to reduce food insecurity, escape terminal drought and allow for at least two cropping seasons per year. Through breeding, early maturing varieties have been developed in rather late maturity groups of crops. Such include, pigeon-pea where maturity has been reduced from 270 days to 120 days, 360 days to 270 days in sugarcane and 270 days to 170 days in cotton.

Incorporating photo and thermo-insensitivity: cultivation of some crops across different seasons and locations is constrained by their photo- and thermo-sensitive behaviour. Sorghum is a tropical crop, its utilization in temperate environments was greatly hindered. Being photo-insensitive, the crop grows more vegetative during vegetative growth stage taking longer to flower in the field. Through backcross conversion programs, photoperiod sensitive cultivars were developed and used in temperate crop improvement programs.

Minimizing plant lodging: Plant lodging affects plant stand and grain yield. Stem or root lodging is associated to plant height, yield productivity, stem thickness and stem and root diseases especially soil borne diseases. Dwarf and semi-dwarf varieties of rice and wheat were developed during the green revolution with low lodging capabilities. The focus has been aimed at developing resistant varieties against soil born diseases such as charcoal rot in a number of crops.

Overcoming dormancy: dormancy is an internal condition of the chemistry or stage of development of a viable seed that prevents its germination. A period of dormancy for some crops would prevent the losses due to pre-harvest rain. On the other hand, it may be desirable to eliminate dormancy.

Developing input use efficient varieties: Development of hybrids has led to increased use of fertilizers. Breeding programs have been developing varieties with increased nutrient uptake and utilization efficiency to reduce on soil and water pollution from the excessive application.

Breeding for climate resilience: increase in global temperature due to elevated CO_2 levels in the past few decades has been recorded. The increasing temperature, depleting water resources, increasing sea-level is significantly affecting yield of crops across the world. Development of climate resilient varieties, with greater plasticity and recovery from climate shocks is paramount.

Yield stability and adaptability: Due to the differences in genotype adaptability to various climate, pedologic, and agronomic factors, genotype-environment interactions frequently occur, complicating variety recommendation and impacting genetic improvement in breeding programmes for a specific location. The efficiency of cultivar recommendation can be maximised by taking into account genotype adaptation trends.

1.5 Activities in Plant Breeding

The complete breeding cycle may include the following activities/stages; (a) defining breeding objectives; (b) creating/assembling variation; (c) selection; (d) germplasm evaluation; (e) cultivar release; (f) cultivar seed multiplication and (g) cultivar dissemination.

Objectives: the breeder should define a clear purpose for the breeding program, taking consideration of the growers, processors and end-user demands.

Creation/Assembly of genetic variation: The necessary germplasm to initiate the breeding program is collected based on the objectives of the study. The germplasm is evaluated for the desired traits. Desirable traits may be available in more than one genotype, such that, crossing program is initiated to introduce the set of traits in a cultivar. Artificial crossing between suitable parents is the most popular approach for introducing the desired gene into the base population. If the gene does not already exist, additional variability may be induced through mutagenesis, interspecific crosses and or genetic engineering and gene editing technologies.

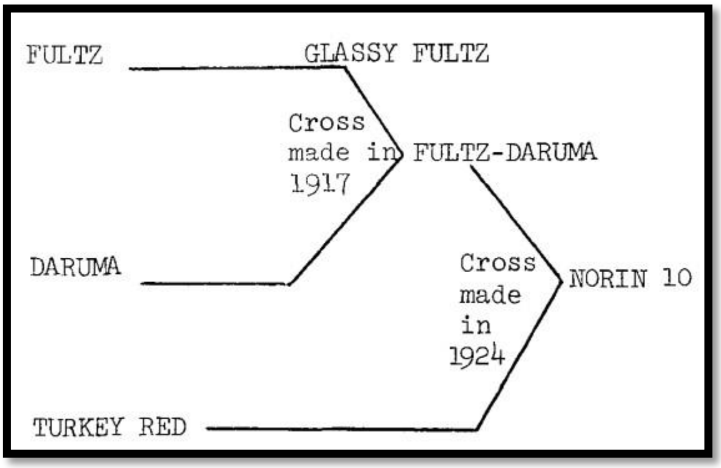
Selection and Evaluation: Genetic selection is the process of discriminating among the available or created variability to identify individuals with the desired combination of genes (genotype) or expressed trait(s). These genotypes are identified through extensive testing, which must account for the environmental factors under which the final cultivars will be cultivated (Borojevic 1990). A final selection cycle in breeding usually yields a small number of genotypes that are candidates for advancement as cultivars for release to producers.

Certification and Cultivar Release: Plant breeders use certification to make sure that their seeds are of the highest quality, have their original genetic identity, and are genetically pure. In every country, there is national agencies that oversee the process of seed certification for different crops (Agrawal, 1998).

Multiplication and Distribution: Certified seed is produced by certified seed growers, who are contracted by independent breeders and seed corporations to mass-produce released cultivars for sale to growers (Allard 1960). Consumers can purchase new cultivars from a wide variety of different retailers.

1.6 Achievements of Plant Breeding

Development of semi-dwarf wheat and rice: The development and spread of semi-dwarf cultivars of wheat and rice was the driving force behind the green revolution. The entry of Norin 10 marked the beginning of wheat revolution. The story of Norin originates from Japan where the local cultivar “Glassy Fultz” was isolated and further crossed with short cultivar “Daruma” to yield “Fultz-Daruma” in 1917. The cultivar was crossed with another cultivar called “Turkey Red” in 1924 followed by generation advancements across various stations in Japan. In 1935, Norin 10 was developed. The short stature of Norin 10 is attributed to *Rht* genes which makes the shortened internodal length due to less responsiveness of tissues towards endogenously encoded gibberellin (Sial, 2002). This property was utilized to develop winter wheat varieties in US by Orville Vogel and then those varieties were exploited by Norman Borlaug. This led to development of revolutionary Sonoro 64 and Lerma Rojo 64 which were the propellant behind the green revolution in India. The technology led to development of Sonalika and Kalyan Sona wheat varieties that were introduced all over the wheat growing belt of India in 1963. These varieties were high high-yielding and disease-resistant wheat rust. Consequently, this led to an increase in wheat production from 11 million tonnes to 75 million tonnes in the same year.



Genealogy of Norin 10 (Reitz and Salmon, 1968)

Similarly, the rice revolution was also initiated due to contribution of dwarf stature of rice. The short stature is governed by a recessive gene *sd1*. The *sd1* gene encodes a truncated inactive enzyme called GA20ox which have a 383bp deletion (Spielmeyer *et al.*, 2002). Dr. Peter Jennings made several crosses at IRRI in 1962 and out of all those crosses, the eighth cross was promising. That cross was made between a Chinese dwarf variety "*Dee-geo-woo-gen*" and a tall Indonesian variety "Peta". Henry Beachell joined this programme in 1963 and advanced it further. Beachell went on selecting best promising lines in further generation where in the row 288, he selected the third plant and named it as IR8-288-3 and this plant in the F5 generation made history and popularly termed as IR8. This IR8 was further used by Beachell and G.S. Khush to develop several superior rice varieties such as IR36 and IR72. Other varieties developed using the same technology were Jaya and Ratna. As a result of the development, in India, rice production rose from 35 million tonnes to 89.5 million tonnes.

Nobilization of sugarcane: pioneering works of Dutch breeders established the concept of nobilization. They termed *Saccharum officinarum* as noble cane owing to the good appearance of the cane. Jesweit, a Dutch sugarcane breeder in Java coined the term nobilization. Indian canes, originating from *Saccharum barberi* had hardy and robust growth nature. However, the yield and sugar content of the sugar cane was negligible as compared to noble cane. In addition, low winter temperature also restricted direct use of these noble canes in northern Indian region. In 1912, Imperial Sugarcane Breeding Research Institute was established at Coimbatore. Dr. C.A. Barber was the first in charge of this institute who carried out the work of nobilization along with T.S. Venkatraman. It resulted in high yielding sugarcane cultivars with higher sugar content as well.

Quality improvement in crops: the goal of plant breeding is not just limited to yield enhancement but it also focuses on quality improvement aspects. This may include enhancing quantity of beneficial compounds or reducing/ eliminating toxic substances. A wide range of undesirable toxic compounds such as saponins in alfalfa, haemagglutinin in faba beans, CN glycosides in cassava, gossypol in cotton, trypsin inhibitor in cowpea, antivitamin E factor in field pea, erucic acid in mustard, phytic acid in pearlmillet etc. Many varieties have been developed to address these constraints. For example, barley cultivars Karan 15, Karan 92 and Karan 280 have good malting quality, sugarcane varieties Co 671 and Co 7314 have high sugar content, soybean cultivar Lee has high protein and oil content, khesari cultivar Pusa 24 have low neurotoxins and maize cultivars Protein Shakti and Rattan has a considerable lysine level in the grain.

Enhanced stress tolerance: the application of various breeding strategies along with advanced molecular techniques have helped to develop various stress tolerant varieties. In India, drought tolerant varieties such as rice varieties Vandana, Satyabhama and Sahbhagi Dhan, chickpea varieties Pusa 362, Vijay and BGM 4005, Sorghum varieties CSV 18, CSH 19R and CSH 15R, groundnut varieties Ajaya and Girnar 1 and cotton varieties Suraj, Surabhi and Veena; waterlogging tolerant varieties such as rice varieties Swarna Sub-1, Varshadhan and JalaMani, maize varieties HM-5 and HM-10 and sugarcane cultivars Co 0239 and Co 0118 have been developed and released. Development of disease resistant varieties has also helped to boost yields in disease prone areas in India. Such varieties developed included DRR Dhan 47 having blast resistance, DRR Dhan 48 with BLB resistance, wheat variety Malviya 838 resistant against rust, maize varieties such as Shweta resistant against brown stripe downy mildew and Tarun resistant against pythium stalk rot.

Marker Assisted Selection (MAS): The discovery of Polymerase Chain Reaction (PCR) inaugurated the era of modern plant breeding. The development of various marker systems such as RAPD, RFLP, SSRs made a tremendous contribution in plant breeding. The marker assisted breeding approaches such as Marker Assisted Backcrossing (MABC) and Marker Assisted Recurrent Selection (MARS) are generally employed in selection of desirable plant and advancing it for the further generations. It has been employed I selection of recessive traits, traits expressed in later stages of plant growth, traits that are expensive for direct phenotyping and in gene pyramiding. Rice varieties such as Swarna Sub1 having flooding tolerance, Samba Mahsuri having bacterial leaf blight resistance genes xa5, xa13 and Xa21, high lysine and tryptophan maize Vivek QPM 9, groundnut with high oleic acid to linoleic acid ratio, Super

Annigeri 1 and Improved JG74 for fusarium wilt resistance in chickpea are some of the example of successful utilization of MAS in plant breeding.

Aesthetic crop improvement: Breeding for ornamental crops is gaining a lot of attention owing to their aesthetic nature. Breeding is focus on introduction of novel traits such as colour, form and shape, vase life of flower, multiple blooming, photo-insensitivity and growth habit. Breeding techniques such as alternation in ploidy level and mutation breeding are the chiefly utilized approaches. Polyploidy is exploited for developing cultivars of various crops such as marigold, lily, rose, jasmine, carnation, narcissus, tulip, gladiolus and anthurium. Triploid cultivars such as Cypheri of bougainvillea, Mukta and Manisha of gladiolus, Prema and Surekha of rose, Showboat and Nugget of marigold have been developed. Tetraploid cultivars such as Riverbend and popcorn of orchid, Samrat of amaryllis, Tetra Peach and Bill Norris of day lily, Princess and Mahara of bougainvillea are notable examples. Along with this, the major mutant varieties such as Abhisarika, Sukumari and Madhosh are developed in rose by induced mutations while Winter Holiday, Coral Cluster, Better Times are bud sport derived mutant cultivars in rose. Gladiolus cultivars such as Shakti and Triplex *via* induced mutations while Salmon's Sensation by spontaneous mutations have been developed. Rajat Rekha and Swarna Rekha are the example of mutant cultivars of tuberose.

Transgenic crops: transgenic technologies offers' gene transfer from one species to other species without any sexual compatibility barriers. In India, the apex biotechnology regulatory body "Genetic Engineering Appraisal Committee" (GEAC) regulates all activities revolving around genetically-engineered organisms. Bt cotton was the first transgene approved in India in 2002. Another example of transgenic variety is DHM-11 mustard developed by the Delhi University by harnessing the "barnase/barstar" system. Maharashtra Hybrid Seed Company (Mahyco) also developed a transgenic variety of brinjal using Cry1Ac gene for fruit and shoot borer resistance.

Hybrid crop varieties: Hybrid varieties were initiated in maize. Beal in 1878 suggested the specific varietal crosses for commercial use based upon heterosis. The idea of double cross scheme given by Jones in 1918 was later exploited at commercial level to release a first commercial hybrid maize variety "Butt Leaming Dent" in 1922. In India, the Coordinated Maize Improvement Project was launched in 1952. In 1961, Ganga 1, Ganga 101, Ranjit and Deccan varieties were released. The first jowar hybrid CSH1 and hybrid bajra variety HB1 was released in 1964. The first hybrid cotton variety H4 was developed in 1970 by Gujarat Agricultural University. The GMS based first pigeonpea variety ICPH-8 was released in 1992.

Photoperiod sensitive conversions: Photoperiod sensitivity is a major constraint in adoption of varieties on wide scale. Hence incorporation of photo-insensitivity increase adaptability of crop varieties to new environments. Photoperiod insensitivity is closely related to early flowering. Daylength insensitive chickpea cultivars has helped its spread in central and southern India. In sorghum, photoperiod sensitivity is useful in promoting vegetative growth for fodder production in temperate climate. Sorghum conversion program was initiated to ensure the utilization of tropical gene pool of sorghum in temperate sorghum improvement. The Sorghum Conversion Program (SCP) successfully derived strains for temperate zones which were of short stature, early maturing and photo-insensitive nature (Quiles-Belén and Sotomayor-Ríos, 1983). Recessive day-neutral lowering alleles and dwarf-height genes were introduced into exotic backgrounds using a backcrossing strategy to recover the exotic genome in an early-reducing, combine-height inbred population (Stephens *et al.*, 1967).

Consequences of Plant Breeding

Narrow genetic base: Many of the successful varieties in early era of green revolution were having one common parent which led to considerable uniformity and reduced genetic base. This narrowed genetic base has caused the susceptibility of the crops towards a wide range of pests and diseases which is referred to as genetic vulnerability. For example, susceptibility of maize hybrids to southern leaf blight due to CMS-T parent of hybrids and downy mildew and ergot in early pearl millet hybrids developed using Tift23A cytoplasm source.

Genetic erosion: Harlan stated that the varietal wealth of the plants that feed and clothe the world is slipping away before our eyes and the human race simply cannot afford to lose it. The large number of heterogeneous local landraces are getting replaced by the handful, limited number of modern cultivars which has comparatively better yield but having homogeneous background. This replacement is depleting the variability in the cultivars which are present since the ages, leading to genetic erosion.

Increase in susceptibility to other biotic or abiotic constraints: diseases that were considered of minor constraints have produced severe epidemics. Notable examples are the grey mold outbreak in chickpea during 1980s, *Trichoderma Afroharzianum* Ear rot in maize, stem rot in bajra, southern rice black-streaked dwarf virus (SRBSDV) in rice, highly virulent stem rust variant of race TTTTF in wheat and geminivirus producing stay-green disease in soybean. Along with diseases, emergence of minor pests has also been a threat to crop production. Notable examples are sugarcane aphid of sorghum in North America, fall armyworm in bajra, exotic mealybug species in cotton, four spotted fall armyworm in maize and leaf-mining moth in soybean.

Lack of general acceptability of improved varieties by the end users: cultivars developed by genetic improvements are generally less accepted by consumers due to technophobia and lack of knowledge of principles behind varietal development. Primary goal of plant breeding is improvement for grain yield. Farmers preferred traits are often compromised during the selection process, probably because of lack of breeders' knowledge about these traits. Selection of a variety by a farmer depends upon various components. The results reported by Awio *et al.* (2017) on participatory farmers' selection of common bean varieties revealed several influential factors such as environmental conditions, yield components, harvest quality parameters like time required for cooking and its quality. The report also underpinned gender-based orientation towards the selection of variety where male farmers especially preferred market demand while cooking quality was the preferred criteria for female farmers (Awio *et al.*, 2017). High prices of hybrid seeds compared to regular varieties also is considered a major constraint to its adoption. Adoption of transgenes are constrained by issues revolving around ethical principles, chances of horizontal gene transfer and risk of environmental sustainability. As a result of these constraints, land races of various crops have been popular with the farmers with minimal replacement with modern varieties.

1.7 Future Prospects

The ever-increasing population has resulted in a massive demand for food. There has also been a shift in the dietary patterns that underlined the importance of the inclusion of a wide range of food crops like millet and minor pulses into daily diets. Food security is facing challenges due to the rapidly growing climate change crisis. The goal of modern breeding must be concerned with yield stability, sustainability, and quality. Increasing the productivity will require combination of conventional along with advanced high throughput phenotyping and genotyping to maximize the chances of better plant selection. Technological advancements such as somatic hybridization, genetic engineering, genetic markers, marker-assisted selection, RNA interference, gene editing, and nanotechnology have a great role to play in the current crop improvement.

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