The Landraces of Maize (*Zea mays* L.): Diversity and Utility

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Landraces, the germplasm maintained by the farmers over the decades or centuries, were evolved and selected to thrive under particular environmental conditions and to meet local food preferences. Although maize originated in Mexico, landraces of this crop of worldwide importance are widely spread across the continents. India too forms a rich hub of diversity for maize landraces, particularly in the North-Eastern Himalayan (NEH) region. These landraces provide immense range of useful genes that could be efficiently utilized for allele mining and population improvement. Maize landraces of Americas and Europe have been subjected to intensive molecular analyses in the last 10-15 years, leading to significant insights regarding diversity, population genetic structure and global migration routes. Comprehensive genetic and agronomic knowledge of the landraces is critical for effective management as well as utilization in breeding programmes. We review here the tremendous diversity of maize landraces worldwide and in India, and the prospects for tapping this vast genetic potential.

Key words: Maize, Germplasm, Landraces, Genetic diversity, Breeding

The diversity and the utility of maize have been a subject of appreciation since centuries. Maize stands out as one of the most important cereal crops in the world, with enormous role in food and nutritional security. Maize belongs to the tribe Maydeae of the grass family Poaceae. It is the only cultivated species of major economic importance in the entire Maydeae tribe and surpasses all other cereals in its ability to adapt to varied agroecological niches.

Maize diversified first in the highlands of Mexico soon after domestication. Matsuoka *et al.* (2002) showed that the domestication of maize is based on a unique event, and that maize accessions from the highlands of Oaxaca in Mexico are genetically the closest to the wild ancestor of maize *(Zea mays* ssp. *parviglumis).* Maize then spread in all the important agroecologies of tropical, subtropical, and temperate regions. This was possible due to the inherent genetic plasticity of the species, attributed mainly to hybridization of distinctly different races. This, in turn, led to release of significant genetic variability on which both natural and artificial selection operated. The credit must also go to the native Americans whose tireless and effective selection efforts led to the development and maintenance of diverse races of maize that could survive in a wide range of environments to sustain their civilizations. Mutations, migration and genetic drift also played their role in the evolution of racial diversity in maize. This vast diversity provided the foundation for the present-day maize, permitting cultivation from 58°N latitude to 55°S for food, feed, and fodder.

Landraces are an important component of plant genetic resources. Commonly called the 'local varieties' or the 'farmer's varieties', landraces form a genetically diverse, heterogeneous population, that are typically selected by farmers for their adaptation to specific local environment and are understood to differ in agronomic and nutritional characteristics, including plant height, prolificacy, biotic and abiotic stress resistance, maturity, nutritive value, etc. They have evolved under subsistence agriculture and are still cultivated by farmers in regions of crop domestication and diversity. Existence of a vast array of landraces in maize has given a major opening to dealing with the problem of the dwindling resources of alleles. The landraces could serve as an excellent raw material for the development of modern varieties and for crop improvement.

Definition of a 'Landrace'

The unparalleled genetic richness of maize is evident from the existence of well-described landraces from diverse countries. Although Sturtevant (1899) classified maize into six kernel types (flint, dent, flour, pop, pod, and sweet), it was Anderson and Cutler (1942) who first stressed the need for a more natural classification of variability known to exist among maize. They defined race as "a group of related individuals with enough characteristics in common to permit their recognition as a group", and in genetic terms, a race "is a group of individuals with a significant number of genes in common, major races having a smaller number in common than do subraces."

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of the kernel – Olotillo Amarillo and Olotillo Blanco, with yellow and white kernels, respectively.

Palomero Toluqueño, is well adapted to high elevations, low temperature, and was found to have resistance to the maize weevil, *Sitophilus zeamais* (Arnason *et al.*, 1994). Nal-tel is a widely distributed race in Chiapas and is particularly characterized by a short growing cycle, which makes it desirable to subsistence farmers (Ortega-Pacza, 1973).

The Hopi tribe is a native of the Southwest [states of Arizona, New Mexico, Southern Colorado (USA), and the northern part of Mexico]. They have established a reputation as superior dryland farmers. The Hopi maize landrace is native to Northeastern Arizona. This landrace survives in regions where the better known varieties fail for lack of sufficient water. Like Hopi, its neighbours, Navajos and Zunis are also drought tolerant. Factors responsible for this drought tolerance trait are their ability to force the growing shoot of seedling to the surface of the soil (because of an elongated mesocotyl), when planted deep. Hopis/Navajos/Zunis, all three are often planted at unusual depths of 6, 12, or even 18 inches. At such depths, less specialized varieties die before reaching the surface. Also, each seed produces only a single root. Thus, by concentrating the energy of the seedling into a single root, the latter is forced to greater depths into the soil that is more moist.

Maize Diversity in Asia and India

Distinct types of maize can also be found in Asia, for example, among the hill areas of Mindanao in southern Philippines. Notable among these are some small-eared, early-maturing flint or popcorn types that either have the capacity to grow and mature quickly before being devastated by downy mildew or carry genetic resistance to downy mildew. The most widely used and productive maize of Asia are mainly derived from Caribbean-type flints introduced in relatively recent times. An outstanding population is Suwan-1, derived by breeders in Thailand from composites of mostly flint and semi-flint varieties from the Caribbean islands, Mexico and central America, South America, USA the Philippines, and India (Sriwatanapongse *et al.*, 1993).

The racial diversity of maize in India is small when compared to the Americas but the selection for genetic uniformity and local adaptation indicate a potential for unique germplasm for the maize geneticists and breeders. Extensive variability in plant, ear, and tassel characteristics is observed in Northeastern and Northwestern highlands of India and relatively less varietal diversity is available in the plains. The social and cultural values of the tribes inhabiting the North-eastern Himalayan (NEH) region played an important role in the conservation of maize landraces, offering significant diversity with respect to plant type, ear characters, quality, biotic and abiotic stress resistance etc. (Figures 1 and 2).

Particularly impressed by the diversity of maize in the North-eastern Himalayan (NEH) region, Anderson (1945) considered maize to have an ancient Asiatic origin, and an early trans-Pacific migration to South America. Subsequent studies by a number of workers, including Stonor and Anderson (1949) and Suto and Yoshida (1956), showed that landraces with primitive characteristics (popcorn characters and high prolificacy) do exist in the eastern Himalayan region (Sikkim in India and Bhutan). Dhawan (1964) christened such landraces as "Sikkim Primitives", whose New World progenitors seem to have disappeared. Based on ear and kernel characters as well as geographical distribution, Bhag Singh (1977) proposed 15 distinct races and three subraces, which were assigned to three lineages, Palomero Toluqueno, Confite Marocho, and Kculli.

Describing and rechristening a popcorn variety of Sikkim as 'Sikkim Primitive' (SP1 and SP2), Dhawan (1964) is credited for arousing great interest in Himalayan maize among the concerned scientists of the world. Although Dhawan (1964) studied only two collections of primitive maize from Sikkim, landraces having characteristics of SP are distributed throughout the NEH region, including Bhutan and Nepal. Sachan and Sarkar (1986) identified 13 different strains of primitive maize from NEH region and designated them as SP strains, although these came from Nagaland, Meghalaya, Tripura and Sikkim.

The most important physiological attributes of SP maize are a complete lack of apical dominance; prolificacy (5-9 ears) with uniformity in ear size; erect leaves for developing maize varieties for high population density; top bearing habit and drooping tassel to ensure effective fertilization (Sachan and Sarkar, 1982). It stays green after maturity; thus it is also good for fodder purposes. It is resistant to stalk rot and has tremendous stem strength, which prevents lodging.

Various collections of 'Sikkim Primitive' types seem to be derivatives of a single widespread popcorn variety grown and selected by different ethnic groups in remote

Fig. 1: (A) *Ears of maize landraces hung in a traditional manner in a farmer's house in North Sikkim;* (B) *Diversity for ear characters displayed by the maize landraces grown by a farmer in the North-eastern Himalayan State of Sikkim in India*

Fig. 2: (A) *Multi-eared (prolific) maize landrace in Sikkim;* (B) *Diversity in the maize collections from the Mizoram State in North-eastern India (Photo Courtesy: Dr. DK Hore, NBPGR, Umiam, Meghalaya)*

and isolated pockets of the North-eastern Himalayas. Tillering habit was not observed in any of the collections. The increase in the number of ears is associated with the decrease in the number of internodes between the topmost ear and peduncle. It is interesting to note that in 'Sikkim Primitives' many of the ears bearing male inflorescences at the tip are all self fertilized. Such ears are completely covered with long husks, and thus silk does not come out of the husk. Apparently there is no indication of inbreeding depression in these populations.

Sikkim Primitive (locally called as 'Murli') is totally distinct and used only as offerings in ceremonial use among the Buddhistic peoples of the region. This little grown popcorn of Sikkim and adjoining areas occurs at mid-elevation, 2000-2700 m, in moist tropical cloud forest region, and has been claimed to be a primitive sort of ancestral maize. Is this a derivative of a Caribbean Flint/New England Flint from the plains below? This hypothesis needs to be verified through empirical studies.

Another area worthy of further studies is the Eastern Region of the tribal areas in the states of Arunachal Pradesh, Nagaland, Assam, Manipur, and Tripura. Much of the maize, which is not typically Indian in the region is extremely interesting. Were these maize types introduced by missionaries or were they introduced through the 'silk route'? This needs further analysis. We have a rich haul of maize germplasm from Sikkim, Nagaland, Meghalaya, Tripura, Mizoram, Manipur and Northwestern Bengal. The germplasm can be broadly classified into waxy, sugary, floury, flint, dent and popcorn types.

There are several other landraces of maize with special features, which belong to the regions spanning rest of India, other than NEH region. These could be efficiently used in maize improvement programs for their respective specialties or importance. Some of them are 'Sathi local', from Punjab, which is a very early maturing (65 – 75 days), heat and drought tolerant landrace and has excellent yield characters and adaptability; 'Basi local' (Rajasthan) has a drought tolerance trait; 'Dausa local' (Rajasthan) has excellent yield characters and adaptibilty; 'Jaunpur local' (Uttar Pradesh), is resistant to stalk rot and other diseases and is also tolerant to excess water and drought; 'Tulbulia local', from Bihar and Teenpakhia local from Uttar Pradesh, are extra early maturing.

Another area where older landraces are grown is in the foothills of South India, around 1000 to 1600 m in elevation, seasonally dry with a tropical forest vegetation cover. These appear to be modified New England Flints which are very rapid in their maturity and among tribal people in Andhra Pradesh and Orissa are called "hungry children food" because the crop is ready and eaten green (like a sweet corn) before the slower to mature rice crop is ready for harvest. This maize landrace most probably possesses germplasm for disease resistance because all the crops grown in the region show signs of fungal infections.

There is no adequate information about the landraces and no documentation of this rich diversity that could serve as a comprehensive database. It is hence important to attain an extensive genetic and agronomic knowledge of these landraces. This has been recently initiated under the ICAR National Fellow project on "Molecular characterization of Indian maize landraces and allele mining for agronomically important traits".

Global Migration Routes of Maize

It is believed that maize spread from Americas through Southern Europe and into Africa, South Asia and Northwest Himalayas in the 16th century. Since maize is a naturally open-pollinated crop, the varieties that were moved from place to place carried considerable genetic diversity, allowing farmer selection, that led to the development of a vast array of races.

Migration routes of the maize germplasm, as deduced from cytological studies, are of particular interest to anthropologists and students of maize evolution. Researchers identified a number of such routes (Kato, 1984; McClintock, 1978; McClintock *et al.*, 1981). One, described by McClintock (1978), extends along the Pacific Coast of Mexico from the Guatemalan border to the state of Sonora. Another route, a relatively recent one according to McClintock (1978), extends from the Mexican Bajio into Chihuahua. A third most interesting migration route is that extending along the east coast of Mexico from Veracruz into Tamaulipas. This route includes the highly productive race Tuxpeno, which has contributed significantly to maize improvement in the lowland tropics.

After the discovery of America by Christopher Columbus in 1492, maize moved quickly to Europe, Africa, and Asia, possibly within a span of 100 years. In Italy and Spain, early counterparts of many South American races are evident even today. From Spain, it spread northwards and north-eastwards to the short-growing-season areas of Europe, where selection for early maturity has produced some of the earliest commercial varieties of maize now available. In Europe, until the last part of the 19th century, the flints were the most prevalent type. Later, however, germplasm from highlands of Mexico, early types from Canada and northern USA, and then, some time between 1880 and 1930, the US dents were introduced. Trifunovic (1978) recognized only four racial groups in Europe, including Corn Belt Dent-like forms, South-eastern European Flints, Northern European and Alpine Flint types and the South European or Mediterranean type.

According to a study by Paterniani (2000), the Brazilian maize landraces were derived from crossing introductions from United States (at different times in the past) and maize types cultivated for a prolonged period of time by indigenous tribes and European colonizers after the discovery of the American Continent. In the middle of the 18th century, yellow dent germplasm was introduced to Brazil from the United States, and the white dent germplasm was recently introduced with the Hickory King variety. Doebley *et al.* (1988) reported that yellow dent, white dent, and Hickory King were races derived from Southern United States dent corn types.

Based on molecular analysis of European and American maize populations using SSR markers, researchers from INRA, France, concluded that maize grown in southern Spain comes mostly from the Caribbean, whereas northern European maize originates in the northeastern USA (Northern Flint). It might have been expected that most European maize would be similar to Spanish maize, having been brought back by Columbus and subsequently spread, but maize with Northern Flint characteristics was commonly observed in Germany in the 1540s, suggesting that maize was independently introduced into northern and southern Europe.

Much of the maize now found in Africa is derived from later introductions from the southern US, Mexico, and parts of eastern South America, although it was introduced into Africa soon after discovery. Africa has always preferred white maize; until recently, the varieties grown there were almost exclusively white. In contrast to the intensive studies on maize migration routes in Americas and Europe, there is little information on this aspect with respect to Africa and Asia. This gap is expected to be filled through an ongoing Generation Challenge Program (GCP) collaborative project titled "Characterization of genetic diversity of maize populations: Documenting global maize migration from the centre of origin", involving CIMMYT (Mexico), INRA (France), IITA (Nigeria) and institutions from NARS (India, China, Indonesia, Philippines, Thailand, Vietnam and Kenya).

Antiquity of Maize in India – A Puzzle Ripe for Solution

Post-Columbian introduction of maize into India by the Portuguese in the 16th century or later has been accepted by most of the maize workers. However, the peculiar features of maize being grown in remote North-eastern Himalayan (NEH) tracts adjoining Burma and Tibet have stimulated an interesting discussion among maize workers on the possible pre-Columbian introduction of maize in these hilly tracts of the Himalayas.

Jeffreys (1965) suggested that maize had been introduced by the Arabs and not by the Portuguese, in the pre-Columbian era. Kuleshov (1928) reported that varieties similar to those described from the Naga tribes are widespread in Central Asia from Persia and Turkestan to Tibet and Siberia. The deep involvement of maize in the customs, tradition and economy of tribal people in the centre NEH also led to the support for the hypothesis on the prehistoric introduction of maize in these areas (Thapa, 1966). Johannessen and Parker (1989) argued that stone carvings of maize ears exist in at least three pre-Columbian Hoysala stone block temples near Mysore, Karnataka state, India. Vocal critics of Johannessen and Parker argued that what is depicted in these sculptures is in fact not maize, but rather something else - variously muktaphala (lit. "pearl-fruit", an imaginary fruit made of pearls), some exotic tropical fruit, etc. (Veena and Sigamani, 1991; Payak and Sachan, 1993). Kumar and Sachan (1993) attempted to provide genetic evidence for the antiquity of maize in India, thus independently corroborating Johannessen and Parker hypothesis of pre-Columbian introduction of maize into India.

Kumar and Sachan (1993) proposed two sets of maize introductions in NEH (a) in pre-historic times through a sea/land route much before the discovery of America by Columbus in 1492, and (b) in the post-Columbian era by Christian missionaries, material which essentially resembles Caribbean germplasm. Empirical studies are required to validate the hypotheses related to antiquity of maize in India.

Cytological Analyses of Maize Landraces

A comprehensive classification of the indigenous landraces of Mexico based on morphological characteristics, internal cytological features and physiological characteristics such as earliness, yield and resistance to diseases, was carried out by Wellhausen *et al.* (1952).

Chromosomal knobs were used to elucidate differences among maize locals of Kashmir valley (Jotshi and Patel, 1983). Fifteen local maize varieties from three districts (Anantnag, Pulwama and Baramulla) of Kashmir valley were collected for the study. Out of these 15 varieties, four were locally known as Tripachi, four as Badeh, two as Vozij, two as Niver, one as Mishri, one as Kani, and one as Ferozpur. Knob number within the varieties of a group showed a lot of variation in the Tripachi group and within the Badeh varieties. Niver varieties did not show any difference between each other, but in Vozij varieties, significant differences were observed.

Cytological characterization of eight Sikkim Primitive (SP) maize strains collected from different parts of the NEH region was carried out by Kumar and Sachan (1992). These included three strains from Meghalaya (M-1, M-15, M-25), two from Tripura (T-2, T-26), two from Sikkim (S-27, S-44) and one from eastern Nepal (SP Nepal). Twenty-six knob forming positions have been identified altogether in different collections of NEH maize. The presence of some new and unusual knob positions in NEH maize, hitherto unknown in American maize races, had been identified in this study. The presence of these new knob positions in different regions suggested their adaptive value and indicated the uniqueness of NEH maize. On the basis of chromosome knob number, these SP strains were grouped into two categories: low knob number group (4 knobs) and high knob number group (6-11). When these two SP groups were compared with those of American primitive races, the low knob number SP group was shown to have its linkage from Confite Morocho of Peru and/or Palomero Toluqueno of Mexico. In contrast, the high knob number group of SP strains possesses close similarity to the Nal-Tel-Chapalote complex. Based on information obtained from studies on botanical, C- and Q-banding, pachytene analysis, ethnobotany, and interpretation of the archaeological findings led to a hypothesis (Sachan *et al.*, 1984) that the pre-historic wild corn, which evolved in the extreme desert environment in the Tehuacan valley of Mexico, is well preserved in the form of Sikkim Primitive.

Biochemical Characterization of Maize Landraces

Evidence of a great dissimilarity between Northern Flint and Southern Dent landraces of North America was demonstrated through isozyme diversity analysis by Doebley *et al.* (1988). Twenty-three isozyme loci representing 13 enzyme systems were used for the study. The isozyme data supported the view that Midwestern Dents arose from the hybridization of Northern Flint from New England and Southern Dent, and the Midwestern Dents contain a greater share of Southern Dent germplasm as compared to the Northern Flints.

The genetic variability among 15 populations from four indigenous races of maize - Caingang, Entrelaçado, Lenha and Moroti - that occurred historically in Brazil, and five indigenous cultivars, were analyzed by Gimenes and Lopes (2000) using five isozyme systems encoded by 14 loci. The study showed no correlation between the accessions name and the genetic relationships. Also, the genetic similarity among populations collected in different geographic regions, was sometimes higher than that among populations from the same race, collected at sites very close to each other, indicating that there is little correlation between the geographic and genetic distances among populations.

Bhat *et al.* (1998) attempted to elucidate the interrelationships between maize landraces of NEH and Mexico using the esterase, peroxidase, and acid phosphatase profiles. The study showed that maize landraces grown by the tribal people of North-eastern India are of significant antiquity as they bear a close resemblance to the prehistoric wild corn. The analysis indicated a wider diversity among the maize accessions collected from Tripura, Uttar Pradesh, Nagaland, Sikkim and Meghalaya (the four forming one sub-cluster), and Nal-tel, a Mexican landrace, was closely related to these landraces.

Molecular Analyses of Maize Landraces

Genetic variation among 15 accessions of Native American maize from the Great Plains was investigated using RAPD (Moeller and Schaal, 1999). The study revealed very high levels of polymorphism among accessions, indicating that many maize accessions were introduced through trade into those regions or migrated with indigenous tribes who had begun maize agriculture in other localities.

Using the bulk RFLP analysis, Gauthier *et al.* (2002) undertook molecular characterization of 488 European maize populations. Populations from Eastern Europe (Poland, Austria, Germany, etc.) showed the lowest genetic diversity, a lower number of unique alleles and a higher percentage of fixed loci than populations from Southern Europe. Genetic diversity was higher in the Southern regions where the first maize populations are thought to have been introduced. A correlation between allelic frequencies at some loci and latitude and/or longitude was observed. Such tendencies may reflect the direction of gene flow between different races of maize; for instance, North American (Northern Flint) and Caribbean populations were introduced, respectively, to northern and southern Europe, in the past. According to Brandolini (1970), maize was not introduced into Greece directly from Americas, but probably derived from the Balkan populations. This historical perspective of introduction may explain the relatively low diversity of Greek populations. This observation is in contrast to the allelic richness and high number of unique alleles in races from Portugal, Spain and Italy, where maize is known to have introduced form America during the 16th century (Revilla *et al.*, 1998).

A comparative characterization of farmer populations of the flint maize Italian landrace "Nostrano di Storo" was carried out by Barcaccia *et al.* (2003) using different types of PCR-based (SSR and ISSR) markers. An inbred line and three synthetics selected from as many landraces were used as reference standards. Although a high variability can be found among plants, most of the genotypes belong to the same landrace locally called 'Nostrano di Storo'. This result was also confirmed by a further molecular investigation using AFLP and RAPD markers to fingerprint pooled DNA samples from all farmer populations. Although gene flow from commercial hybrids might have occurred, the large number of polymorphisms and the presence of both unique alleles and alleles unshared are the main factors underlying the value of this flint maize landrace as a source of genetic variation.

The genetic relationships among 81 maize accessions (consisting 79 landraces and two improved varieties), maintained by farmers in southern Brazil were investigated using Random Amplified Polymorphic DNA (RAPD), with 32 polymorphic primers (Carvalho *et al.*, 2004). The highest genetic similarity was observed between the Branco Lastek Dinart and Cunha Branco landraces. These accessions have been cultivated in distinct regions by unrelated small farmers and are known by different names. In contrast, two other accessions, Astecão Branco and Asteca Branco that have been treated by similar names were less related by RAPD. The Asteca landrace, which showed the lowest similarity to the other accessions, has an uncertain origin and seems to have been derived from a sample collected a few years ago by small landholder farmer. This study also revealed that maize management adopted by small-scale farmers contributed to the maintenance of genetic variability.

Study of the populations of maize landraces cultivated in six villages of the Oaxaca region of Mexico (Pressoir and Berthaud, 2004 a,b) revealed that the morphological and agronomic characters in the field, such as ear size, kernel colour, or flowering period, vary depending on the farmer. At genome scale, microsatellite markers revealed strong homogeneity between the maize populations within the same village and, more surprisingly, between distant villages. This investigation brought the first genetic proof that cultivation practices, conducted on a small scale (village and region), are a key element in the evolution of maize and its diversity. In-situ conservation of so-called "farm" varieties of crop plants, following the example of maize, could therefore be perceived in terms not of isolation, but of dynamic means of gene flow between different populations of the same region in which the farmers play a predominant role.

The first detailed molecular characterization and a population genetic analysis of selected Indian maize landraces was initiated by Prasanna *et al.* (2005). Seventeen selected landraces from diverse agro-ecologies, including 10 accessions from the NEH region and 7 from other agro-ecologies, were analyzed using 27 polymorphic SSR markers. Population genetic analysis, including Wright's F statistics of the SSR data revealed greater genetic divergence among the NEH landraces in comparison with the landraces from other regions.

Utility of Maize Landraces in Crop Improvement

There are various reasons attributed to a farmer's selection, maintenance and retention of landraces and these include storage, cooking, nutritional, and processing qualities; historical and cultural factors such as dietary diversity and use in traditional foods or religious ceremonies. Another cause may be for agronomic reasons: some folk varieties are considered more suited to traditional intercropping patterns, have longer or shorter growing cycles, or are more resistant to local biotic and abiotic stresses (Dennis, 1987; Bellon, 1990; Brush, 1991; Brush *et al.*, 1992; Zimmerer, 1991; Ferguson and Mkandawire, 1993; Longley and Richards, 1993; Soleri and Cleveland, 1993; Soleri *et al.*, 1994). Yield stability is also an important reason for retaining these folk varieties. For example, the Hopi tribe in South America still retains the blue maize landraces because these are adapted to drought, have a short growing season and meet their cultural requirements.

Agronomic performance

Two objectives in evaluating landraces are: (a) to identify the best local populations that could be used broadly, and, (b) to identify populations that will be starting material for crop improvement. Suwan-1, the popular OPV from Thailand, has been used to develop a commercial cultivar, a composite "Parbhat" was developed by the Punjab Agricultural University, Ludhiana. This composite shows multiple disease resistance, high yield and stability in performance (Dhillon and Prasanna, 2001; Dhillon *et al.*, 2002).

Broad based pools formed using promising landraces for specific traits are excellent material for population improvement programmes. Population Improvement through recurrent selection aims at increasing the frequency of favourable genes in a population progressively over successive generations, while maintaining reasonable levels of genetic variability. For example, at Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, Uttaranchal, landraces from Jammu & Kashmir as well as the Uttaranchal states in India were effectively utilized for developing a broad-based genepool. Using this germpolasm, several inbred lines and hybrids that are well adapted to hill areas were derived. The popular hybrids include Him-129 (yellow, flint, 85-90 days maturity, highly tolerant to leaf blight); Him-128 and several 'Vivek' hybrids.

Prasanna *et al.* (2005) evaluated 27 selected landraces from diverse agro-ecologies in India, including 10 accessions from the NEH region, along with the inter-population experimental crosses, were evaluated for their agronomic performance at two locations in India (Hyderabad and Delhi) during 2003 and 2004. Significant genotype x environment interactions were observed with respect to the agronomic performance of the landraces as well as the experimental crosses. Nevertheless, Sathi local, Jaunpur local, Dausa local, Jhabua local and S51 among the landraces revealed excellent yield potential and adaptability. Evaluation of yield performance of experimental crosses, derived using the seven locals from the non-NEH region, led to the identification of Sathi local and Dausa local as the best general combiners at Hyderabad and Delhi, respectively. At Hyderabad, Sathi local x Jhabua local, Sathi local x Dausa local, and Jhabua local x Arabhavi local showed top ranks for several yield components, while at Delhi, Dausa local x Jaunpur local, Dausa local x Jhabua local, and Bhowali local x Arabhavi local were found to be highly promising. Some entries even outperformed the popular hybrid, Parkash, indicating the tremendous genetic potential of these landraces in improving maize productivity, particularly through population improvement. A more extensive agronomic evaluation of nearly 300 Indian maize landraces is in progress.

Biotic stress resistance

A number of studies in maize indicated the potential of the landraces in improving biotic stress tolerance. For example, 28 landraces of maize from Mexico were assessed for susceptibility to the maize weevil, *Sitophilus zeamais* in standardized resistance tests (Arnason *et al.,* 1994). Susceptibility parameters such as grain weight loss, number of insect progeny produced, and the Dobie index of susceptibility, were found to vary significantly by genotype, with exceptional resistance found in accessions representing the Naltel, Chapalote and Palomero landraces.

A set of the indigenous races of Mexico, differing in altitudinal adaptations, were assessed for resistance to the European corn borer, *Ostrinia nubilalis,* by Reid *et al.* (1990). Correlations of altitudinal origin with resistance were found for the Mexican races. There was an increased susceptibility to borer tunneling and stalk rot resistance in higher altitudes. Also, since tropical plants are more exposed to various species of insects than temperate plants, this could have led to the selection of maize with greater resistance to fungi in these regions than in temperate zone plants.

Abiotic stress tolerance

Michoacan 21, a collection from Mexico, which is the source of *latente* gene, has shown an unusually high recovery after a strong drought stress (Munoz, 1975). It was resistant to permanent seedling wilting and tissue desiccation, with high transpiration under irrigation and low transpiration under stress. The Hopi farmers in Arizona, USA, plant primarily landraces of field crops mainly because this germplasm exhibits considerable tolerance to drought stress. The ability of Hopi blue maize to emerge from seeds planted as deep as 25 cm is a specific adaptation to the arid climate and soils of the Hopi homelands (Soleri and Cleveland, 1993).

Studies carried out at Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, Uttaranchal, with 15 'Sikkim Primitives' collected from the NEH region, during *kharif* 1986, revealed that these landraces could serve as a potential source for drought tolerance in maize breeding programmes (Mani *et al.,* 1987).

Rodriguez *et al.* (1998) analyzed the physiological aspects of Tuxpeño maize with relevance to its drought tolerant characteristics. Physiological factors such as stomatal conductance, leaf photosynthetic rate and detectable abscisic acid levels were analyzed, besides parameters change in Tuxpeño landrace with successive generations.

Quality traits

The long-term selection experiment for kernel oil and protein content in maize was initiated at the University of Illinois, Illinois, in 1986 by C.G. Hopkins (Hopkins, 1899) and culminated in 2002 (Dudley and Lambert, 2004). This '100 generations of corn' experiment was started using the 'Burr's white' landrace of the Burr's county, Illinois, USA. The extraordinary continuity of this experiment in itself is remarkable. The original objective was to determine whether the chemical composition of the maize kernel could be changed by selection. As the experiment continued, the objective was modified to determine the limits of selection for kernel oil and protein and to select strains - Illinois High Oil (IHO), Illinois Low Oil (ILO), Illinois High Protein (IHP) and Illinois Low Protein (ILP). These strains were further used to detect QTLs for protein, oil, and fatty acid composition (Willmot *et al.,* 2006).

Fourteen accessions of three types of maize (convar. *mays,* convar. *dentiformis,* convar. *microsperma)* landraces from the germplasm collection at the Institute for Agrobotany, Hungary, differing with respect to endosperm color (yellow to orange), were analyzed for carotenoids (polyoxycarotenoids, lutein, zeaxanthin, b-zeacarotene, zeinoxanthin, cryptoxanthin) and total colour content, using high performance liquid chromatography (HPLC) [Daood *et al.,* 2003]. The study provides evidence for carotenoids differences among the maize landraces, and identified promising landraces with highest concentration of lutein, zeaxanthin and cryptoxanthin (precursor of vitamin A). Such accessions are of special interest from nutritional and biological points of view.

Managing the Vast Maize Genepool

Often, the size of germplasm collections limits their accessibility and greatly discourages effective management, evaluation and utilization of available germplasm. To improve this situation, the concept of 'core collection' was suggested by Frankel and Brown (1984). They defined a core collection as a representative sample of a collection where the diversity is retained as much as possible with minimum of redundancy. The accessions not included in the core serve as the reserve collection, composing the collection's back-up. Core subsets of landraces feature useful traits such as high yield, grain quality, disease resistance etc.

Taba *et al.* (1998) developed a core subset of Carribean maize accessions from the CIMMYT maize germplasm bank. Most accessions were from West Indies and others were from Central and South America. They evaluated and used morphological traits like, plant height, ear length, senescence, ear diameter, days to silk, days to anthesis and number of kernel rows, to cluster accessions into homogeneous groups.

Malosetti and Abadie (2001) compared three classification strategies in establishing a core collection of Uruguayan maize landraces and concluded that a combination of kernel type and geographic origin was the best classification rule since it took into account two points which were closely related to the distribution of diversity: genotypic composition and geographic origin.

At the Institute of Crop Germplasm Resources, Beijing, China, Li *et al.* (2004) have attempted to produce a core collection out of 13,521 maize landraces preserved in China National Genebank (CNG). The landraces were divided into subgroups in terms of ear type, kernel type, kernel colour, cob colour, plant height, ear height, number of leaves, days from seedling, emergence to maturity, ear length, ear width, number of rows, and 1000-kernel weight.

Creating broad-based populations could be another alternative to managing huge collections of accessions. Broad-based population refers to a heterogeneous group of germplasm accessions. It facilitates the management and use of broad diversity of landraces and also broadens the genetic base of a crop. It involves bringing together resources with as many alleles as possible, irrespective of the target trait. For example, it could combine alleles for various traits like disease resistance, drought tolerance, protein quality etc. Landraces could form the starting material for developing a broad-based population.

Concluding Remarks

Maize landraces have immense genetic diversity. Yet, it is relevant to note that genetic resources used in maize breeding programmes around the world represent less than 10% of all landraces (Dowswell *et al.*, 1996), indicating that much of the genetic diversity remains to be efficiently and effectively explored and exploited. Concerted efforts are required to utilize landraces and wild relatives in generating breeding populations, so as to derive elite germplasm with enhanced productivity and ability to adapt to a range of production environments.

This rich diversity of maize in many countries, including India, appears to be under threat due to various reasons, including the changing nature of agricultural production, and due to widespread adoption of modern varieties.

It is important to develop maize germplasm conservation mechanisms both *ex situ* and *in situ*, by strengthening the role of rural communities in the conservation of biodiversity. It is equally important to study the dynamic conservation of landraces in farmers' fields as well as the relatively more static conservation of landraces in gene banks.

In future, this genetic diversity could enable development of maize varieties that would resist insects and diseases and tolerate drought, saline and infertile soils, and endure other stresses. Landraces possessing these traits are essential for helping people in the developing world to feed their families and improve their economic well-being. Hence, it is now time to take measures to conserve, characterize and utilize these valuable genetic resources. Integration of morphological and molecular surveys is advisable for the study of landraces, and building up genetic resources management strategies.

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