Indian Journal of Agricultural Sciences **84** (4): 517–22, April 2014/Short communication
https://doi.org/10.56093/ijas.v84i4.39471

Digitization of collecting mission data to enhance plant genetic resource management in maize (*Zea mays*) in India

ANJULA PANDEY[1], D P SEMWAL[2], D C BHANDARI[3] and SHASHI KANT SHARMA[4]

National Bureau of Plant Genetic Resources, New Delhi 110 012

Received: 4 January 2013; Revised accepted: 20 February 2014

Key words: Collecting mission data, Digitization, Diversity rich pockets, GIS, Landrace diversity, Trait-specific germplasm

Maize (*Zea mays* L.) (tribe Maydeae of family Poaceae) is one of the three important cereal crops after wheat and rice consumed as staple food (Mukherjee 1989). Due to wider adaptability to varied agro-ecology this multipurpose cereal crop is cultivated globally (Ahloowalia and Dhawan 1963, Iltis and Doebely 1980). The center of origin for maize has been established as the Mesoamerican region, now Mexico and Central America (Iltis and Doebely 1980). Cultivated maize was introduced into the old world in the sixteenth century (Beadle 1980, Doebley and Iltis 1980). It was introduced in India by the Portuguese during the seventeenth century (Mukherjee *et al.* 1971, Mangelsdorf 1974, Wilkis 1981).

In India, maize is largely grown as *kharif* crop across all the states, more so in the north-east hill (NEH) region and north-western Himalaya. Unique topographic conditions of maize growing regions, socio-economic attributes among the ethnic groups, seed movement among farmers, cultural knowledge and use have greatly influenced the pattern of diversity distribution in maize in different regions beyond their primary habitats. Consequent upon cultivation over long period amazing diversity has got developed in different growing regions of India. This variability has regional significance and is prominently available as local cultivars being utilized for specific uses. This is especially true for maize from Sikkim Himalaya which is considered to be the secondary centre of diversity in maize (Rahman and Karuppaiyan 2011).

Collection mission data generally include eco-geographic, environmental, biotic, climatic, use pattern that can be used to improve knowledge about accessions and facilitate their utilization (Thormann *et al.* 2012). The present paper is an update on information on distribution and germplasm collection on maize genetic resources diversity especially of local cultivars in light of efforts made by the National Bureau of Plant Genetic Resources (NBPGR) through the collecting missions undertaken during last three decades. This comprehensive information on the specific traits available in germplasm will be useful for effective management of plant genetic resource as well as in utilization by the plant breeders to develop improved varieties. Collecting mission data (passport data) of 8 089 accessions collected from over 2 000 collection sites under different agro-ecological regions during last three decades were examined based on information available in published literature (NBPGR 1976-2012, Singh *et al.* 1990, NBPGR 2000-10 a, b, Plant Exploration Databases up to 2012). Short-listed germplasm (6 368 accessions) with details on state, district, village, collector number and latitude (N) - longitude (E) of collection sites were used for mapping of collection sites. DIVA-Geographical Information System (GIS) tool was used to analyze passport data to generated maps on distribution pattern and survey, collection sites, altitudinal variation pattern with the help of point to grid analysis using simple methods (Hijmans *et al.* 2000, 2001, Sunil *et al.* 2009; Abraham *et al.* 2010). Information on names of local cultivars/landraces, known traits and ethno-botanical uses were drawn mainly from passport data records and authors' experiences. In view of fast movement of cultivars from region to region and phenotypic variation developed under different climatic conditions, distinct cultivars were identified with variable local names and henceforth treated as local cultivars in the text of local germplasm and landrace diversity.

Areas of collection and mapping of diversity

Eco-geographic mapping of the collection sites and overall topographic configurations have been shown below (Fig 1). For the interpretation of results and discussion, agro-ecological areas of concentration of diversity were arbitrarily classified into five major zones.

[1]Principal Scientist (email: anjula@nbpgr.ernet.in), [2]Senior Scientist (email: semwal@nbpgr.ernet.in), [4]Technical Assistant (email: sksharma@nbpgr.ernet.in), Division of Plant Exploration and Germplasm Collection; [3]Principal Scientist (email: bhandaridc@yahoo.com), CAZRI, Jodhpur

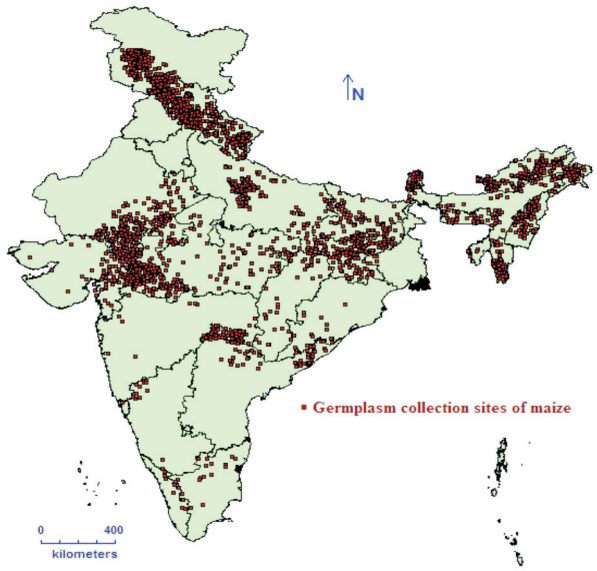

Fig 1 Germplasm collection sites of maize in India

Diversity assembled in maize

Prior to 1976 organized exploration activities were executed under joint collection mission of Indian Council of Agricultural Research (ICAR) and Rockefeller Foundation project to various maize growing states (Rachie 1963, NCA 1973). Since 1976-2012, a total of 8 089 accessions of indigenous maize germplasm have been collected by NBPGR through crop-specific and multi-crop explorations in collaboration with crop-based institutes of Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs). A total of 28 states covering 297 districts in five major agro-ecological regions of the country were explored. Among these states (accessions collected in parenthesis) of Himachal Pradesh (1062), Arunachal Pradesh (760), Uttarakhand (550), Mizoram (402), Jammu & Kashmir (387), Rajasthan (368), Meghalaya (366), Madhya Pradesh (362), Uttar Pradesh (325), Nagaland (324), Jharkhand (298), Sikkim (274), Gujarat (191) and Andhra Pradesh (116) were well-explored. Trend of germplasm collections *vis-a-vis.* agro-ecological zone showed that the highest number of accessions representing local cultivar diversity were gathered from the north-eastern hill (NEH) regions and western Himalaya (WH) followed by the western and central plains (WP), eastern plains (EP) and the peninsular region (PR).

Local cultivars/ landrace diversity collected

Collection, characterization and classification of maize diversity are the foremost and time consuming activities that are essentially required for assessment of quality germplasm and its utilization. Numbers of landraces described globally for maize collections from different regions are estimated to be much lesser than projected (Brown and Goodman 1977). Globally this assessment could be done of maize accessions from the Latin American (Mangelsdorf 1974, Brown and Goodman 1977), Japan (NIAS 1979) and Europe (Leng *et al.* 1962, Brandolini 1969, Brandolini and Avila 1971, Trifunovic 1978). Characterization data revealed wide variability in Saharan maize population adapted to temperate conditions (Djemel *et al.* 2012). However, this activity has received little attention for Asian and African germplasm. Characterization of maize from the Indian region mainly from NEH region have been done using morphological as well as molecular tools (Prasanna and Sharma 2005, Prasanna *et al.* 2009 a, b).

Over 280 accessions of local cultivars/ landraces were collected from different diversity rich regions. Majority of the germplasm was named after locality name (Jaunpur local, Bhagalpur local, Jalandhar local, etc.), kernel colour (yellow, black, white, red) and by the maturity period (number of days; Sathi matures in 60 days), name of the month in Hindi calendar in which crop matures (Asaujya, Katigya are late maturing types). Botanically different cultivars are classified into seven principal groups or botanical forms (pod corn, popcorn, flint corn, dent corn, soft corn, sweet corn and waxy corn) on the basis of endosperm and floral bract (glume) characters (Singh 1969).

Indigenous variability was observed for plant height, adaptation to varying altitudinal ranges, leaf orientation, height at which ear arise, silk colour, cob size, cob orientation, shank colour, number of kernel rows/cob, kernel type (dent, flint, waxy, popping type, etc.), kernel shape/ size and colour and crop maturity period (NBPGR 2000-10a). Variation in traits like lodging resistance, stiffness of straw and rachilla and crude protein content was sporadically represented in the collected germplasm. Considerable polymorphism and variations in grain size, shape and colour was reported by many workers (Singh *et al.* 1990, Prasanna and Sharma 2005, Plant Germplasm Reporter 2000-10a). Regional variation in traits was apparent among the collected diversity. North-eastern hill region was richer in popcorn, flint corn and dent corn, sweet corn, sticky and waxy type. Mostly the popcorn type kernels, big-smallest cob size, early to medium types and tall-dwarf types were more prevalent among the collected diversity. In the north-western Himalayan region mostly flint kernel type (sometimes dent), late maturing, tall types and medium cob size were common. Similar observations were reported by Dhawan (1964) and Singh (1977).

Diversity collected from North-eastern hill region

In the north-eastern hill (NEH) region intensive collections were made during crop specific exploration. Collected diversity from this region represented 36 per cent of the total collection. Maximum collections (accessions in parenthesis) were made from Arunachal Pradesh (760) from West Kameng (162), West Siang (140) and East Siang (107) districts. Other states of the NEH region explored for collection of diversity were Manipur (111), Asom (87) and Tripura (29). In general the diversity collection sites were located in the altitude range from 50m (Asom, Tripura) to 2200m (Arunachal Pradesh) with intensive collection at 100m (Tripura) to 2000m (Arunachal Pradesh). Interesting

landraces of maize were earlier collected and discussed by others from all parts of north-eastern hill region (Singh 1977, Prasanna 2005).

Out of 165 local cultivars/landraces of maize reported from this region- Ambo, Badam, Chujak, Fingdong, Finthang, Mimban, Mimpui, Murli, Nabo, Oshum, Poakzo, Riewhadem, Sappa, Seti, Tanee, Tepeh, Topo and Viamin were the most common. Highest numbers of landraces were collected from Lohit, Tawang and West Kameng district in Arunachal Pradesh. Tribal areas of Arunachal Pradesh, Nagaland, Asom, Manipur and Tripura had rich variability in primitive cultivars with primitive popping type of kernels, smaller and more number of ears and relatively high placed ears, fewer kernel rows, prolific tillering, tassel with fewer branch, smaller internodes and narrower leaves. Variability in primitive local-maize called Murli and Darikincho (medium tall, high tillering, 4-5 cobs/plant, short cobs-6cm, small yellow elongated, hard kernels) and Phensong (cob up to 30cm long) was recorded from north Sikkim. Among local landraces, Sikkim Primitive maize (locally called Murli) was very distinct having characteristic small lemon yellow popcorn type kernels arranged in cob of size 3-6cm, prolific bearing, prolificacy (multiple-ear bearing) and has its religious importance among the Buddhist community. This landrace was earlier collected from Sikkim (Ahloowalia and Dhawan 1972) and subsequently from Arunachal Pradesh (Plant Germplasm Reporter 2000-10a, Pareek *et al.* 2006). Sikkim Primitive maize strains (Sikkim Primitive-1 and Sikkim Primitive-2) were reported to be different from the primitive Mexican races (Mukherjee *et al.* 1971, Prasanna 2005). Some of the landraces like Sethi and Pahenli had thick husk coverage and oblong cob orientation which impart resistance against earrot in rainy season. Extra-earliness is a rare trait in mid and high altitude maize. The high altitude maize Tempo Ringing attains maturity in 85-90 days in mid-hills before the other maize cultivars complete silking. Very interesting local germplasm with potential traits- Murli, Tempo Ringing and Sethi are being utilized in on-going breeding programme at the ICAR, Sikkim Centre, Tadong (Rahman and Karuppaiyan 2011).

Some of the trait-specific local types/ landraces reported from this region were: aromatic and sticky kernel types- Fingdong (aromatic pop corn), Chujak (aromatic, pop corn), Chakhou chujak (aromatic, soft, sticky), Kholakitthi (sticky); pop corn type- Badam topo, Tanee; flint kernel type - Kukidolong, Kuchungdari, Bacherey, Kuchungtamar, Kukharey (dwarf, high altitude); dent kernel type, Gadbade, Seti, Chaptimakai (soft opaque cap) and, Pahenli (light dent). Sporadic collection of early local types- Ambo, Riewhadem (early maturing), Vaimin (three months), Pahari makai (adapted to mid-to high-altitude, cold hardy), Nepali Sappa (3 cobs/plant) and modern cultivars/new introduced landraces (Mampokmendi, Taminlamendi, Maromendi) were also made. Lachung maize exhibited para-mutation (multi coloured cob, tolerant to cold weather). Some outstanding landraces reported from this region- Sikkim Primitive, Tirap, Naga Sahyup (Arunachal Pradesh) and Tistamehdi (Sikkim) were collected and evaluated (Prasanna 2005).

North-western Himalayan region

In the north-western Himalayan region the surveyed areas are given in Fig 1. More than 31 per cent accessions of the total diversity were collected from Himachal Pradesh (1062), Jammu & Kashmir (387) and Uttarakhand (550). Highest collections were made from Chamba (354), Sirmaur (166) and Mandi (161) districts of Himachal Pradesh. In Uttarakhand mainly two districts, viz. Dehradun (121) and Almora (119) had maximum collections, whereas in Jammu and Kashmir, Poonch (51), Kathua (37) and Jammu (57), districts were explored well. The collection sites were located between the altitudinal range 500m (Himachal Pradesh) to 1800m in Uttarakhand with intensive collections made from 700-1600m (Jammu & Kashmir and Uttarakhand).

Among the total of 54 local cultivars/landraces Chirku, Mishri makki and Sathi were the most commonly reported from this region. Within the area highest numbers of landraces were collected from Chamba and Mandi districts in Himachal Pradesh and Almora and Chamoli districts of Uttarakhand. Maize is cultivated in this region from foothills to high hills at an elevation of about 2500m (Sharma and Rana 2005).

Distinct local types/ landraces collected from the region were popcorn type- Chitku/chitkanu (small white kernel), Pinjori, Mudhe-ke-Makki; dent type- Gada (greenish yellow kernel); flint type- Rhodu, Bachheli local, Jaunsari maize (early type); sweet kernel-Mishri makki; tolerance/resistance to biotic/ abiotic stresses- Pahari makki (resistance/tolerance to lodging and insect pests), Bhogru (tall plant, resistant to diseases), Chhoti panjabi (dwarf, lodging resistance, pest resistant); early type- Chhoti pinjori, Lal kukudi, Sathu/ Sathi and fodder type- Chari (*Zea mays* spp. *mexicana*) (in tribal tracts of Tharus, Buxas in Uttarakhand). In Uttarakhand region, a local cultivar named 'Murli' with distinctly 3-6cm sized cobs with small kernel from Pithoragarh and Almora districts was noteworthy due to it similarity with a primitive landrace from NEH (also called in NEH region as 'Murli'). Improved maize hybrids (Ganga-1, Ganga-5, Vijay, Pratap, Himsuper) were not much popular in the area (NBPGR 2000-2010a). In general local tall types showed lodging susceptibility, borer attack and sporadic incidence of loose smut. The maize landraces diversity collected from this region was mainly of the flint and dent types (Chandel and Bhat 1989, Dhillon *et al.* 2006). Landrace Chitkanu was suspected to be no more under cultivation in the Himachal region (State of Plant Genetic Resources for Food and Agriculture in India- 1996-2006, A Country Report 2007).

North-western and central plains

Areas surveyed and diversity collected from the north-western and central plains are given in detail. In north-western and central plains collection sites were located in the range from 50m (Gujarat) to 800m (Rajasthan) with intensive areas falling between altitudinal ranges of 100-

800m. Out of the total germplasm collections, nearly 15 per cent accessions were collected from five states, viz. Gujarat (191), Haryana (35), Rajasthan (368) and western parts of Madhya Pradesh (200) and Uttar Pradesh (125). Maximum collections were made from Banswara (68), Rajsamand (43), Bundi (42) and Udaipur (41) districts of Rajasthan. While in Gujarat, variability was mainly collected from Narmada district (74) followed by Panchmahal (Godhra) (31) district.

A total of 32 local cultivars/landraces were collected from this region; most commonly represented types included Bharda, Dudhmogar, Malan, Pilli and Sathi makki. Within the area highest numbers of landraces were collected from Dungarpur, Rajsamand and Udaipur districts of Rajasthan. Studies showed that north-western plains had moderate diversity in maize with traits that were different from those available in other part of India. Local types collected with traits like stay green habit/ fodder type (Jharkhand, Uttar Pradesh) and dual types (Bihar, Jharkhand) were interesting genetic resources collected from this region (NBPGR 2000-2010). Cultivar 'Sathi local' was collected across different maize growing regions indicating its wider preference and adaptiveness. Recently, promising germplasm of landraces Malan makki-4 and Sathi makki- 5 were collected from Rajasthan under the National Agriculture Innovation Project (NAIP) executed by the NBPGR. Sathi and Basi local (Rajasthan) were earlier collected and evaluated (Prasanna 2005).

Some of the local cultivars/landraces from the region included: flint types- Doodhmogar (early maturity, drought tolerant), Sameri (early maturity, drought tolerant), Gulla (drought hardy); early types- Chandan (drought tolerant), Sathi (insect-pest resistance), and Bari hati and Malan (kernel arranged in zig-zag manner). Dhillon *et al*. (2006) have reported significant landraces - Sathi local (Punjab) with very early maturing (65-75 days), heat and drought tolerance, excellent yield and high adaptability, Basi local (Rajasthan) with drought tolerance trait and Dausa local (Rajasthan) excellent yield characters and wider adaptability from this region.

Eastern plains

Major part of the eastern plains was broadly surveyed but intensive collections were made only from few districts. Maize was collected from the altitudinal range 50- 800m but intensive collection sites were located between 200-400m. Diversity collected from this region represented nearly 14 per cent of total collected diversity. Germplasm was assembled (accessions in parenthesis) mainly from Jharkhand (298), Bihar (113), Chhattisgarh (81) and West Bengal (14). Out of 43 local cultivars/landraces of maize collected from this region, Deshila, Dhibria and Jondra were the most common types. Within the area, highest numbers of landraces were collected from Katihar and Bhagalpur districts in Bihar, Chapra and Hazaribagh districts in Jharkhand and Bastar and Sarguja districts of Chhattisgarh.

Some local types/ landraces collected from this region included Jaunpuria local (resistant to stalk rot, tolerant to excess water and drought) from Uttar Pradesh, Tinpakhiya local and Tulbulia local (both with extra early maturity) from Uttar Pradesh and Bihar respectively. These landraces have been earlier collected and evaluated from this region (Prasanna and Sharma 2005). The characteristic known traits in some of these were- pop corn types- Bhadra (irregular shape kernels, 100 days maturity); Jharkhand tipri (white-cream-yellow, angular shaped kernels), Tinpakhiya (very sweet kernel, extra early maturity); flint type- Desi purple (anthocyanin colouration on tassel and silk); early maturing types- Ushvan, Mamu-bhaigna makka (white-violet kernel, very old cultivar from last 80 years); medium maturity- Jaunpuria local (maturity 80-90 days), late maturing type- Chhota safed (small, round shaped kernels), Deshila (tasty, medium sized kernel); resistant/ tolerant to biotic and abiotic resistance- Akbarnagar local (drought, waterlogging, diseases and insects, maturity in 75 days); Bhagalpur local (resistant/tolerant to drought, water logging, pests, maturity 75 days); Jethualal (highly tolerant to waterlogging), Kabri (maturity 90 days); Sabour local (resistance to drought, waterlogging, diseases/insects, maturity early); Sonatikkar (drought and waterlogging tolerant, maturity 80-90 days); Tilbulia (tolerant to waterlogging); and Putali (transposon-induced pericarp variegation).

Peninsular region

This region is a major site of maize production. In the Peninsular region, only few districts were surveyed. Altitudinal range from 100-1000m was covered for collection of maize with intensive collections made from 200-500m. From genetic resources collection point only 4 per cent of the germplasm was collected from six states representing Andhra Pradesh (116) followed by Odisha (93), Maharashtra (25), Tamil Nadu (21) Karnataka (14) and Kerala (10). Maximum accessions were collected from tribal tracts of Adilabad (41) district. Out of 22 local types/ landraces Jonna pottulu and Makka jonna were the most common types reported from this region, mainly from Vishakhapatnam district in Andhra Pradesh, Wayanad district in Kerala and Coimbatore district in Tamil Nadu. Maize is mostly cultivated around 1000-1600m altitude and landraces grown in the foothills of south India are early maturing types (Prasanna and Sharma 2005). They are popular among tribal people of Andhra Pradesh and Odisha (called "hungry children food"). This appears to be the potential area for higher adaptability and tolerance to fungal diseases as compared to other growing regions (Prasanna and Sharma 2005).

Among landraces diversity collected from this region, Beli govina jola (a 40 year old local cultivar), cold tolerant types- Kattu cholam, Kullan cholam, Kathiru; hill maize (drought tolerant); rainfed type-Mokka jonna and Nattumakka cholam (suitable to poultry feeds) were the most interesting. Besides improved/newly introduced

types- Baby corn (released type), Paras local-2; Deccan-1 and Deccan-2 were available in parts of Kerala and Karnataka.

Conservation and use

A total of 8 736 accessions of maize germplasm have been conserved for long-term in the genebank including 687 exotic collections (NBPGR 2000-2010b) including trait-specific materials (landraces, elite material, varieties, obsolete cultivars, elite populations, synthetics and lines). Out of exotic collections majority were introduced from CIMMYT, Mexico (Singh *et al.* 1990).

In India maize is used as food for human consumption, seed/ cobs eaten raw, roasted or boiled. Other uses include livestock/ poultry feed, raw material for corn starch, oil etc. (Dhillon *et al.* 2006). During explorations to different parts of the country, particularly tribal dominated areas of north-eastern hill regions, Rajasthan, Himachal Pradesh and Uttarakhand, ethnobotanical information on use of maize was gathered (Vasal and Taba 1988, NBPGR 1976-2012, NBPGR 2000-2010a, b). In the north-eastern hill region, maize is extensively used for brewing. The bear (beverages) is used by several tribes using grain mixture of maize, rice and millets boiled in an earthen pot (Singh 1977). Use of mature kernels ground into flour is in wide preference across the regions, more so in the western and eastern plains, in particular in Punjab and Uttar Pradesh consumed with leafy vegetable prepared from *Brassica juncea* (sarson ka saag).

SUMMARY

The data gathered on germplasm collection of maize evidently showed is a preliminary attempt on digitization of collecting mission data of maize genetic resources to enhance its use in plant genetic resource management in maize in India through quality passport data, eco-geographic location, availability of germplasm site description, geographic coordinates for crop improvement programme. Identification of collection sites located in distribution maps would allow: pinpointing of directed collection plans in under represented and identified sites that are rich in landraces/ trait-specific diversity. Since these sites are highly vulnerable to genetic erosion due to spread of hybrids/ genetically modified crops (GM), such areas need to be given special attention in genetic resource management. Broadly all maize growing areas have been surveyed in the past and diversity augmented from different parts of the country. However, based on gaps identified in the genebank holdings of trait specific germplasm and unique material needs to be augmented. Grouping of local cultivars/ landraces of maize based on geographical distribution, morphology, field and molecular characterization is a major challenge that needs special address by the maize breeders and users.

ACKNOWLEDGEMENTS

The author expresses sincere thanks to the Director, NBPGR for valuable guidance and support for undertaking this work. Acknowledgements are also due to Dr E R Nayar, Ms Rita Gupta and Sh O P Dhariwal for providing help in all respect.

REFERENCES

Abraham B, Kamala V, Sivaraj N, Sunil N, Pandravada S R, Vanaja M and Varaprasad K S. 2010. DIVA-GIS approaches for diversity assessment of pod characteristics in blackgram (*Vigna mungo* L. Hepper). *Current Science* **98**: 616–9.

Ahloowalia B S and Dhawan N L. 1972. A synapsis in maize from Sikkim. *Indian Journal of Genetics and Plant Breeding* **3**2(2): 229–3.

Ahloowalia B S and Dhawan N L. 1963. Effect of genetic diversity on combining ability of inbreds of maize. *Indian Journal of Genetics* **23**: 158–62.

Beadle G W. 1980. The ancestry of corn. *Scientific American* **245**: 112–9.

Brandolini A. 1969. European races of maize. *Proceedings of Annual Corn, Sorghum Research Conferences* **24**: 36–48.

Brandolini A and Avila G. 1971. Effects of Bolivian maize germplasm in south European maize breeding. *Proceedings of Sixth Meet on Maize, Sorghum Section,* pp 117–35. VIth EUCARPIA General Congress, Cambridge, UK.

Brown W L and Goodman M M. 1977. Races of maize. *Corn and Corn Improvement,* pp 49-88. Sprague, G F (Ed). American Society of Agronomy, Madison, Wisconsin.

Chandel K P S and Bhat K V. 1989. North-western Himalaya - a centre of maize diversity. *Indian Journal of Plant Genetic Resources* **2**(1): 12–17.

Dhawan N L. 1964. Primitive maize in Sikkim. *Maize Genetic Coop Newsletter* **38**: 69–70.

Dhillon B S, Sharma A K, Dinesh Kumar, Malhi N S and Singh N N. 2006. Maize. *Plant Genetic Resources*, pp 90–136. Dhillon B S and Sharma A K (Eds.). Narosha Publishing House, New Delhi,

Djemel A, Revilla P, Hanifi-Mekliche L, Malvar R A, Álvarez A and Khelifi L. 2012. Maize (*Zea mays* L.) from the Saharan oasis: adaptation to temperate areas and agronomic performance. *Genetic Resources Crop Evolution* **59**(7): 1 493–4; doi 10.1007/s10722-011-9778-82.

Doebley J F and Iltis H H. 1980. Taxonomy of *zea*. I. A subgeneric classification with key to taxa. *American Journal of Botany* **67**(6): 982–93.

Hijmans R J, Garrett K A, Huaman Z and Zhang D P, Schreuder M and Bonierbale M. 2000. Assessing the geographic representativeness of genebank collections: the case of Bolivian wild potatoes. *Conservation Biology* **14**: 1 755–65.

Hijmans R J, Guarino L, Cruz M and Rojas E. 2001. Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genetics Resource Newsletter* **127**: 15–9.

Iltis H H and Doebely J F. 1980. Taxonomy of *zea* (Gramineae) II. Subspecific categories in the *Zea mays* complex and generic synopsis. *American Journal of Botany* **67**(6): 994–1 004.

Leng E, Tavcar R A and Trifunovic V. 1962. Maize of south eastern Europe and its potential value in breeding programmes elsewhere. *Euphytica* **11**: 263–72.

Manglesdorf P C. 1974. *Corn: Its Origin, Evolution and Improvement*. Harvard University Press, Cambridge, Massachusetts, USA.

Mukherjee B K, Gupta N K, Singh S B and Singh N N. 1971. Meteroglyph analysis of Indian and exotic maize. *Euphytica* **20**: 113-8.

Mukherjee B K. 1989. Maize. (*In*) *Plant Breeding*, pp 199–12. Chopra V L (Eds). Oxford & IBH, New Delhi, India.

NBPGR. 1976-2010. *National Bureau of Plant Genetic Resources* (NBPGR), New Delhi, India.

NBPGR 2000–10a. *Indigenous Collections*. National Bureau of Plant Genetic Resources, New Delhi.

NBPGR. 2000-10b. *Exotic Collections*. National Bureau of Plant Genetic Resources, New Delhi.

NBPGR. 2007. State of Plant Genetic Resources for Food and Agriculture in India 1996-2006. *A Country Report* 2007. National Bureau of Plant Genetic Resources, Indian Council of Agricultural Research, New Delhi.

NCA. 1973. *Maize Report of the Study Team of National Commission on Agriculture.* New Delhi.

NIAS. 1979. *Characteristics of Races of Maize in Japan*. National Institute of Agricultural Sciences, Series D no. 3, Tokyo, Japan.

Pareek S K, Bhandari D C, Pandey Anjula and Dhillon B S. 2006. Sustainable Development of Plant Genetic Resources: a Success Story. *Agro-biodiversity (PGR)-59*. National Agricultural Technology Project on Sustainable Management of Plant Biodiversity, National Bureau of Plant Genetic Resources, New Delhi.

Prasanna B M. 2005. Diversity of Maize Landraces of India. *Proceedings of International Conference*, Beijing, China 8–10, December, pp 1–26.

Prasanna B M and Sharma L. 2005. The landraces of maize (*Zea mays* L.)- Diversity and utility. *Indian Journal of Plant Genetic Resources* **18**(2): 155–68.

Prasanna B M, Pixley K, Warburton M L and Xie C X. 2009a. Molecular marker-assisted breeding options for maize improvement in Asia. *Molecular Breeding* **26**(2): 339–56.

Prasanna B M, Sharma Lata, Wasala S K, Singode A, Kumar R, Guleria S K, Sekhar J C, Karuppaiyan R, Srinivasan K and Gupta H S. 2009. Maize landraces in India- phenotypic and molecular characterization. Indian Council of Agricultural Research *Newsletter* **15**(1): 1–3.

Rachie K O. 1963. *The Systematic Collection of Sorghum, Millet and Maize in India (mimeographed)*. The Rockfeller Foundation, New Delhi.

Rahman H and Karuppaiyan R. 2011. *Biodiversity of Sikkim, Agro-biodiversity of Sikkim: Exploring and Conserving a Global Hotspot,* pp 403-26. Arrawatia M L and Tambe S (Eds). Information & Public Relation Department, Govt. of Sikkim, Gangtok.

Sharma B D and Rana J C. 2005. Plant Genetic Resources of Western Himalaya. Bishen Singh and Mahendra Pal Singh, Dehradun, Uttarakhand.

Singh B. 1969. Evaluation of primitive cultivars from north-eastern Himalayan region in relation to lineages. *Indian Journal of Genetics* **37**: 103–13.

Singh B. 1977. *Races of Maize in India*. Indian Council of Agricultural Research, New Delhi.

Singh B, Pant K C, Sharma B D, Sapra R L and Rana R S. 1990. *Catalogue on Indigenous and Exotic Maize (Zea mays) Germplasm*. National Bureau of Plant Genetic Resources (NBPGR), New Delhi.

Sunil N, Sivaraj N, Anitha K, Abraham B, Kumar V, Sudhir E, Vanaja M and Varaprasad K S. 2009. Analysis of diversity and distribution of *Jatropha curcas* L. germplasm using geographic information system (DIVA-GIS). *Genetic Resources Crop Evolution* **56**: 115–9.

Thormann I, Gaisberger H, Mattei F, Arnaud E. 2012. Digitization and online availability of original collecting mission data to improve data quality and enhance the conservation and use of plant genetic resources. *Genetic Resources and Crop Evolution* **59**(5): 635–44.

Trifunovic V. 1978. Maize production and maize breeding in Europe. *Maize Breeding and Genetics,* pp 41–58. Walden D B (Ed). John Wiley, New York.

Vasal S K and Taba S. 1988. Conservation and utilization of maize genetic resources. *Plant genetic resources- Indian perspective*, pp 92–7. Paroda R S, Arora R K and Chandel K P S (Eds). Proceedings of the National Symposium on Plant Genetic Resources, New Delhi, India.

Wilkis H G.1981. Maize in India. *Maize Genetic Coop Newsletter* **55**: 13–5.