Maize Breeding in India – Retrospective Analysis and Prospects

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Maize is one of the three most important food grain crops in the world. It is utilized as human food, livestock and poultry feed, industrial raw material and as fodder. In India, it occupies third position among food grains with respect to production and productivity, and ranks fifth for the area under cultivation.

The All-India Coordinated Maize Improvement Project, the first multi-centre, multi-disciplinary project of unique nature, was established in 1957. The project has made outstanding contributions not only in maize improvement but also in the development of similar research projects in other crops/disciplines. The project focused on hybrid breeding and released eight hybrids during 1961 to 1964. However, due to less than expected impact of these hybrids and the problems faced in their seed production, the breeding strategy was reassessed, and composite breeding was prioritized. A first set of composites (six) was released in 1967. Up to 1972, 21 cultivars were released which generally possessed late maturing. During 1970s the breeding programme was again assessed and reoriented towards early maturity. Further, intra-population improvement was undertaken on a vast scale to develop composites particularly early maturing. Consequently, hybrid breeding was discontinued with the exception of a few research centers. During 1980s emphasis was shifted back to hybrid breeding with a focus on the single crosses. Apparently there have been sharp turns in the breeding strategies and priorities.

Indian maize breeding programme has a very strong linkage with the International Maize and Wheat Improvement Center (CIMMYT), Mexico, and CIMMYT's maize germplasm has been extensively used by the Indian programme. CIMMYT has not only liberally supplied germplasm but has also significantly contributed in the development of human resources and has, thereby, markedly influenced breeding strategies and objectives of the Indian programme. To exploit the emerging opportunities, maize breeding needs to be focussed on specific adaptation, for example, development of input responsive hybrids (specifically single crosses) for favourable environments, and early maturing hybrids and composites possessing tolerance to stresses like low nutrient supply and extreme moisture and temperature regimes for other environments. The cultivars must possess high yield, stability of performance, multiple resistance/tolerance to biotic/abiotic stresses and appropriate maturity. Breeding efforts in special maize types (high oil, quality protein, pop, sweet, baby, specialized starch) and more specifically in winter maize and in fodder maize need to be strengthened and streamlined. Last but not least, there is an urgent need to upgrade the research in maize biotechnology in the areas like development of transgenics for biotic and abiotic stresses, marker assisted selection and prediction of hybrid performance; and integrate the same with maize breeding.

Key words: Maize, Hybrid breeding, Population improvement, Germplasm utilization, Biotechnology

Maize is one the three most important foodgrain crops in the world, the others being rice and wheat. It is utilized as human food, livestock and poultry feed, raw material for a large number of industrial products and as fodder. It is a staple food in 22 countries, two-thirds of the produce is consumed as feed, and a very large number (>3500) products/by-products can be derived from it. In India, maize ranks fifth with respect to the area under cultivation and third for production as well as productivity. There has been an impressive growth in maize production and productivity in India. The production increased from 1.73 to 11.1 million tonnes and productivity from 547 to 1920 kg/ha during 1950-51 to 2002-03. But the production in the years to come is not expected to be sufficient to meet the growing demand for maize for various uses, particularly with the expansion of dairy, piggery, poultry and maize-based industries.

Maize is a cross-pollinated crop. Its populations comprise freely interbreeding individuals, and are heterozygous and heterogeneous. The species is, therefore, adapted to heterozygosity, which is an essential feature of maize cultivars. The cultivars may be open-pollinated (OP) population or hybrid. Hybrid cultivars have the advantage of higher performance and uniformity, whereas the populations are expected to have wider adaptation. Further, the seed production of OP cultivars is easier and less costly. Before the advent of hybrids all maize acreage was cultivated with heterozygous and heterogeneous populations (races, landraces, farmers' varieties or their improved versions).

The exploitation of hybrid vigour or heterosis in maize through the use of hybrid cultivars is one of the major achievements in plant breeding. Beal (1880) was the first to propose commercial cultivation of inter-varietal hybrids. However, the exploitation of hybrid

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vigour had to wait for the pioneering studies by Shull, East and Jones. Shull (1909) gave the 'pureline method of corn breeding', which involved the development of inbred lines and commercial single cross (inbred x inbred) hybrids. However, there was no good response as inbred lines were weak and there were problems in commercial seed production of single crosses. Jones (1918) suggested the commercial cultivation of double cross (single cross x single cross) hybrids, and their commercial use began in 1922. The adoption of hybrid maize was initially slow, but starting in the mid-1930s, the area planted to hybrids began to increase rapidly and after15 years, 95 percent of the maize acreage in the US Corn Belt was under hybrids (Duvick, 1999).

Among various types of hybrids, single crosses have the highest performance potential and are the most uniform. The maize breeders, particularly in North America continued their efforts to develop vigorous inbred lines so as to make seed production of single-cross and other simple hybrids economically viable. The cultivation of single crosses started in late 1950s and early 60's, and at present almost entire area in the USA is covered by single crosses. The productivity has increased from 1.5 t/ha in 1930 to 8t/ha by the beginning of 21st century. Similar success was obtained in Europe, where also initially double crosses and other complex hybrids were adopted and then these were replaced by single and other simple crosses.

In India, the maize improvement work was earlier largely confined to the State Departments of Agriculture. During 1940s and early 50s, the work basically involved isolated efforts on mass selection in local varieties in Punjab, Uttar Pradesh, Bengal and Central Provinces. These varieties were collected, evaluated and the seeds of promising ones were multiplied and distributed to the farmers. The cultivars that were released included KT 41 in Uttar Pradesh, Basi in Rajasthan, Pusa Yellow in Bihar and Farm Sumeri in Gujarat (Singh *et al.*, 1996). These showed only marginal improvement because of narrow intrapopulation genetic diversity and inefficient selection procedure.

Realizing the success of hybrids in developed world, isolated efforts were made in India also after the Second World War by various state departments to introduce commercial maize hybrids developed in the USA, Australia and other countries. In 1948, the Indian Council of Agricultural Research in collaboration with the state departments extensively evaluated introduced hybrids at the maize research stations at Delhi, Naraingarh (Punjab) and Almora (Uttaranchal). The evaluation of introduced hybrids was continued in early 1950s. A few hybrids from USA like US 13, Dixie 18, Texas 26, NC 27 and Illinois 1656 showed marked superiority ranging (30 to 50%) over local varieties. These were, however, not accepted by the farmers due to their unattractive (dent) grain type and late maturity. These hybrids also had problems in seed production because their parental lines were not adapted to the prevalent environment. The lines were late maturing, susceptible to pests and even failed to produce pollen. Above all, at that time, there was no seed industry which was vital for the success of hybrid cultivars.

At some stations inbreeding was carried out in the indigenous populations to derive inbred lines and develop hybrids. In Punjab, a scheme on hybrid maize was started in 1955. Four orange flints, double cross hybrids, with all parental lines derived from indigenous germplasm, were developed in Punjab. These included Punjab Hybrid 1 [(Pb68-66 x Pb72-103) x (NW12-580 x Kash2-597)] that was released in 1956. But it did not become popular due to seed production problems. A three-way hybrid was also developed at Arbhavi, Karnataka.

Coordinated Maize Improvement Project

In 1957, the All India Coordinated Maize Improvement Project (AICMIP) was established which is a landmark in maize improvement research in India. The establishment of this project greatly organised and strengthened the maize research and development in the country. The project facilitated better planning, coordination and monitoring of research activities; and in rapid generation of more precise data on the performance and stability of experimental hybrids or composites through simultaneous testing at a number of locations and, thereby, also reducing the time required for evaluation. Later on the disciplines of agronomy, pathology and entomology were added and multi-disciplinary teams devoted to maize improvement started working at many centers in the country. Maize improvement research since 1957 can be discussed under three phases.

Phase I: Hybrid Breeding

With the establishment of the coordinated project, a large number of germplasm including inbred lines were introduced from USA and Caribbean region and many locals were collected; and large-scale inbreeding was initiated in the promising introduced and indigenous germplasm. The inbred lines were crossed with varietal testers to produce top-crosses (inbreds x OP populations) which were evaluated in multilocation trials along with indigenous and exotic checks. As a result 28 inbred lines were identified and used in hybrid breeding. The first set of hybrids was released in 1961. These were Ganga 1, Ganga 101, Deccan and Ranjit, and all these were double crosses (Table 1).

For economical seed production, a short-term approach of developing non-conventional hybrids, namely double top-crosses (single cross x non-inbred parent) was adopted. As a result, in 1963, two double top-cross hybrids (Hi-starch, Ganga Safed 2) were released. The parents of these hybrids included CM202, which later on was used as a parent of other commercial hybrids;

Table 1. Maize Hybrids developed and released in India since the inception of All India Coordinated Maize Improvement Project

S. No.	Hybrid	Year of release	Area of adaptation*	Centre**
1.	Ganga 1	1961	Northern Plains	DMR
2.	Ganga 101	1961	Northern Plains	DMR
3.	Ranjit	1961	Southern Raj. and Central India	DMR
4.	Deccan	1961	Kar. and A.P.	Hyderabad
5.	VL 54	1962	Himalayan region	Almora
6.	Ganga Safed 2	1963	Across the country except hilly areas and Kar.	DMR
7.	Hi-starch (R)	1963	Bihar & U.P.	DMR
8.	Ganga 3	1964	Northern plains	DMR
9.	Him 123	1964	Himalayan region	DMR
10.	Ganga 5	1968	Northern plains and Peninsular India	DMR
11.	Ganga 4	1971	M.P., U.P. and Bihar	Pantnagar
12.	Ganga 7	1971	U.P.	Pantnagar
13.	Deccan 101	1975	Peninsular India	Hyderabad
14.	Ganga 9	1979	Himalayan region, U.P. and Bihar	DMR
15.	Him 128	1979	H.P. and U.P.	DMR
16.	Sangam	1981	Pb.	Ludhiana
17.	DHM 103	1982	Across the country	Hyderabad
18.	VL 41	1986	High elevation areas of H.P. and U.P.	Almora
19.	Sartaj	1988	Across the country	Ludhiana
20.	DHM 1 (R)	1988	Across the country	Dharwad
21.	VL 42	1988	U.P. hills, Himalayan region and Peninsular India	Almora
22.	Ganga 11	1988	Across the country except hilly areas	DMR
23.	DHM 105 (R)	1990	Across the country except hilly areas	Hyderabad
24.	Trishulata	1991	Across the country except hilly areas	Hyderabad
25.	DHM 107	1992	Across the country	Hyderabad
26.	CoH 2	1993	T.N.	Coimbatore
27.	DHM 109	1994	Across the country	Hyderabad
28.	Rajendra Makka 1 (R)	1994	Bihar, Orissa and W.B.	Dholi
29.	Paras	1995	Pb.	Ludhiana
30.	Rajendra Makka 2	1995	Bihar, Orissa and W.B.	Dholi
31.	DHM 1	1996	Kar.	Dharwad
32.	CoH 3 (R)	1996	T.N.	Coimbatore
33.	Him 129	1997	Himalayan region, Raj., Guj., and M.P.	Almora
34.	Pusa Hybrid 1	1997	Peninsular India, Raj., Guj., and M.P.	Delhi (IARI)
35.	Pusa Hybrid 2	1997	Peninsular India, Raj., Guj., and M.P.	Delhi (IARI)
36.	Parkash	1998	Across the country except hilly areas	Ludhiana
37.	Vivek Hybrid 4	1998	Raj., Guj., and M.P.	Almora
38.	Pusa Hybrid 3	2000	A.P., Mah., Kar. and T.N.	Delhi (IARI)
39.	JH 3459	2000	Pb., Har., Delhi and U.P.	Ludhiana
40.	Vivek Hybrid 9	2000	Uttaranchal, J&K, H.P., North East Hill region, Hills of W.B., A.P., Kar., Mah. and T.N.	Almora
41.	HHM 1	2000	Har.	Karnal
42.	HHM 2	2000	Har.	Karnal
43.	DHM 2	2001	Kar.	Dharwad
44.	Vivek Hybrid 5	2001	Uttaranchal, H.P., North East region and J & K	Almora
45.	Shaktiman 1	2001	U.P.	Dholi
46.	Sheetal	2002	Pb.	Ludhiana
47.	Shaktiman 2	2002	Bihar	Dholi
48.	Buland	2002	Delhi, Har., Pb., Western U.P.	Ludhiana

* Raj.=Rajasthan, Kar. =Karnataka; A.P.=Andhra Pradesh; U.P.=Uttar Pradesh; M.P.= Madhya Pradesh; H.P.=Himachal Pradesh; T.N.=Tamil Nadu; Mah.=Maharashtra; Pb.=Punjab; Har.=Haryana; J&K = Jammu and Kashmir; W.B.= West Bengal; Guj.=Gujarat.

** DMR=Directorate of Maize Research, New Delhi; IARI=Indian Agricultural Research Institute, New Delhi and CM104 and CM105, which later on showed durable resistance against leaf blights (Sharma and Payak, 1990). Among indigenous collections the most important example is Rudrapur local (CM600), the male parent of hybrid Ganga Safed 2. Inbreeding in indigenous collections showed these to be poor source germplasm for inbreeding.

The National Seeds Corporation was established in 1963 to facilitate hybrid maize seed production. Yet problems were faced in seed production (poor performance of inbred lines and lack of seed industry) and hybrid maize did not become popular on the expected scale. Other reasons were extremely low frequency of good inbred lines and lack of financial resources and infrastructure for hybrid breeding. This resulted in the reorientation of the programme with greater emphasis on composite breeding.

Phase II: Composite Breeding

The shift towards composite breeding has been due to various limitations associated with hybrid breeding and seed production as discussed above, and equally important due to the expectation of wide adaptation of composites and their seed by farmers. In 1967, six composites (Amber, Jawahar, Kisan, Vijay, Vikram, Sona) were released in the country (Table 2). On the whole the performance of these composites was encouraging. Composite Vijay became popular not only in India but also in adjoining countries. It was released in Pakistan under its experimental name J1 and in Nepal as Rampur Yellow. It is still grown as a fodder crop in some states. However, these composites could not cover large area. The major limitation was their long duration. About 85% of the crop was rainfed where early maturing locals were under cultivation. Realising this, the development of early maturing composites got prioritized in 1970s, and Makki Safed 1 (an improved local) was released in 1973, and Ageti 76, Tarun and others later on. So far, 85 composites have been released for general cultivation in different agro-climates in the country (Table 2). These covered substantial area in the country. The important ones are Vijay, Kisan, Ageti 76, Tarun, Parbhat, Navjot Arun, Type41, Shweta, Navin, Pusa Comp 1, Parvati, Azad Uttam, Mahi Kanchan, Megha, Mahi Dhawal and Devaki. Navjot has been commanding the largest breeder seed indent for more than a decade. During 1970s and 80s, large scale intra-population improvement was undertaken to develop better composites as discussed later. In this era of composite breeding and population improvement, certain centers including Punjab Agricultural University (PAU), Ludhiana, ANG Ranga Agricultural University (ANGRAU), Hyderabad and Vivekananda Parvatiya Krishi Anusandhan Shala, Almora, continued their hybrid breeding programmes in an isolated manner.

Phase III: Single Cross Hybrid Breeding

In view of the experiences with hybrids at world level and that of composites in India, and the emergence of private sector, national breeding programme was again reoriented in late 1980s with a focus on single cross and other simple hybrids. First three-way hybrid, Trishulata, was released for general cultivation in 1991 and first single cross, Paras, in 1995. These were followed by release of other single cross hybrids like Pusa Early Hybrid Makka 1 and 2, Parkash, Sheetal and Buland. In this endeavor, development and formation and improvement of heterotic pools got emphasis as discussed later.

Since 1961, 33 open-pedigree hybrids (18 double crosses, 9 double top-crosses, 4 three-way crosses, 2 varietal crosses) have been released for general cultivation (Table 1). The hybrids that played a role in increasing the maize productivity in the country include Ganga Safed 2, Hi-starch, Ganga 5, Sartaj, Ganga 11, Deccan 103 and Deccan 105. The number of cultivars released decade-wise since 1957 are given in Table 3.

Special Breeding Programmes

Breeding Maize for Winter Season

The cultivation of maize in winter season started in 1960s in some pockets in South India (Singh, 1974). Over time it has covered an area of about 0.65 million ha in different states – about 0.35 million ha in Bihar, about 0.10 million ha in Andhra Pradesh and about 0.05 and 0.07 million ha in each of Tamil Nadu and Karnataka. Maize during winter season yields higher than the traditional monsoon season particularly in Bihar and Andhra Pradesh.

It is generally believed that maize can be cultivated during winter season if it is frost free and temperature does not fall below 13°C. The climate of the above mentioned states generally qualifies the above defined climatic requirements. In North-western plains, however, the average temperature sometimes falls below 10°C and the minimum temperature may even be sub-zero; and there is frequent frost incidence in the months of December and January. The germination is delayed and it may be very low if seed quality is poor. The plant growth is

Table 2. Maize Composites released in India since the inception of All-India Coordinated Maize Improvement Project (Directorate of Maize Research since 1994)

S.No. (1)	Hybrid (2)	Year of release (3)	Area of adaptation* (4)	Centre** (5)
1.	Amber	1967	Himalayan Hills and Peninsular India	Hyderabad
2.	Vijay	1967	Across the country except Kar.	Ludhiana
3.	Sona	1967	Across the country except Kar.	DMR
4.	Jawahar	1967	Indogangetic plains and Peninsular India	DMR
5.	Kisan	1967	Indogangetic plains	DMR
6.	Vikram	1967	Indogangetic plains	DMR
7.	Protina	1971	Throughout India	DMR
8.	Rattan	1971	Throughout India	Ludhiana
9.	Shakti	1971	Throughout India	DMR
10.	Makki Safed 1	1973	Pb.	Ludhiana
11.	Ageti 76	1976	Pb.	Ludhiana
12.	Moti	1982	Throughout country except Kar. & T.N.	Udaipur
13.	KT 41	1978	Raj State release	DMR
14.	C 1	1978	U.P.	Srinagar
15.	C 2	1978	J & K	Srinagar
16.	C 3	1978	J & K	Srinagar
17.	Mandsar	1978	J & K	Srinagar
18.	Trikuta	1978	J & K	Srinagar
19.	Nishat	1978	J & K	Srinagar
20.	Tarun	1978, 1982	U.P. & Indogangetic Plains	Pantnagar
21.	VL Makka 16	1980	U.P. Hills	Almora
22.	L 4	1980	H.P.	Bajoura
23.	Partap	1980	Pb.	Ludhiana
24.	Shweta	1980	U.P.	Pantnagar
25.	Manjari	1980	Mah.	Kolhapur
26.	V L Amber	1981	U.P.	Almora
27.	Chandan Makka 1	1982	M.P.	Chhindwara
28.	Chandan Safed 2	1982	M.P.	Chhindwara
29.	Makka			
30.	Navin	1982	U.P.	Pantnagar
31.	Amber popcorn	1982	A.P.	Hyderabad
32.	Lakshmi	1982	Pb.	Dholi
33.	Navjot	1982, 1988	Across the country	Ludhiana
34.	Partap 1	1983	Pb., Har.	Ludhiana
35.	African Tall	1983	Across the country for fodder	Rahuri
36.	Hunius	1983	J&K, H.P., U.P., Guj., Mah., Sikkim, Kar.	DMR
37.	Diara 3	1984	East & Central U.P.	DMR
38.	D 765	1984	Across the country except. Pb. Har., Sikkim & Kar.	Pantnagar
39.	Farm Sameri	1985	Guj.	Godhra
40.	Suwan	1985	Bihar	Dholi
41.	NLD	1985	Sikkim, W.B. NE region except Assam	DMR
42.	Kanchan	1986	U.P.	Pantnagar
43.	Early Composite	1986	H.P.	
44.	Hemant	1986	Bihar	Dholi
45.	Co 1	1986	Tamil Nadu	Coimbatore
46.	Renuka	1986	Kar.	Dharwad
47.	MCU 508	1987	U.P.	DMR
48.	Arun	1987	Pb., Har., U.P., Raj., & Bihar	N. Delhi (IARI)
49.	Kiran	1988	Across the country	Ludhiana
50.	Parbhat	1988	Pb. U.P., Bihar, M.P., Guj., Mah., Kar., T.N.	Ludhiana
51.	Pusa Composite 1	1988	M.P. and Guj.	N. Delhi (IARI)
52.	Pusa Composite 2	1988	Indo-Gangetic Plain	N. Delhi (IARI)
53.	Parvati	1988	H.P.	Bajoura
54.	Harsha	1988		Dharwad
55.	VL 88	1988	Uttaranchal	Almora
56.	Dhawal	1988	U.P., Bihar, A.P., T.N., Mah., Orissa, Kar. Guj., Pb., Raj.	DMR
57.	Surya	1988	U.P.	Pantnagar
58.	J-1006	1989	Pb. (For fodder)	Ludhiana
59.	Prabha	1990	Kar.	Dharwad

Contd.

(1)	(2)	(3)	(4)	(5)
60.	Madhuri	1990	A.P.	Hyderabad
61.	Varun	1990	H.P., A.P., Mah.	Hyderabad
62.	Azad Uttam	1991	Raj.	Kanpur
63.	Kesari	1992	Pb.	Ludhiana
64.	Mahi Kanchan	1992	Raj., Guj., M.P., Pb., A.P. and Kar.	Udaipur
65.	Panchganga	1993	Mah.	DMR
66.	C-6	1994	J&K	Srinagar
67.	C-8	1994	J&K	Srinagar
68.	Punjab Sathi 1	1994	Punjab	Ludhiana
69.	Gujarat Makka 1	1994	Guj.	Godhra
70.	Megha	1994	Pb., Har., Raj., U.P., Bihar, W.B., Orissa, M.P., Guj	Ludhiana
71.	Gujarat Makka 2	1995	Guj.	Godhara
72.	Pearl Popcorn	1995	Pb.	Ludhiana
73.	Mahi Dhawan	1995	Raj.	Udaipur
74.	Birsa Makkai	1995	Jharkhand	Ranchi
75.	C 14	1995	J&K	Srinagar
76.	Devaki	1995	Bihar	Dholi
77.	Jawahar Makka 8	1996	M.P.	Chhindwara
78.	Shakti 1	1997	Throughout India	DMR
79.	Gujarat Makka 4	2000	Guj.	Godhra
80.	Aravali Makka 1	2000	Raj.	Udaipur
81.	Amar	2000	A.P., T.N., Mah., Kar. and Guj., Raj & M.P.	Pantnagar
82.	NAC 6004	2001	Kar.	Nagenhalli
83.	Narmada Moti	2002	U.P., Pb., Har., Mah., Kar., Kerala, T.N., Raj., Guj., & M.P.	Banswara
84.	Jawahar Makka 216	2003	M.P.	Jabalpur
85.	Gujarat Makka 6	2003	Guj.	Godhra

* Raj.=Rajasthan, Kar. =Karnataka; A.P.=Andhra Pradesh; U.P.=Uttar Pradesh; M.P.= Madhya Pradesh; H.P.=Himachal Pradesh; T.N.=Tamil Nadu; Mah.=Maharashtra; Pb.=Punjab; Har.=Haryana; J&K = Jammu and Kashmir; W.B.= West Bengal; Guj.=Gujarat.

** DMR=Directorate of Maize Research, New Delhi; IARI=Indian Agricultural Research Institute, New Delhi

Table 3. Number of hybrids and composites of maize released in India during different periods

Period	Hybrids (no.)	Composites (no.)
1957 - 1966	9	0
1967 - 1976	4	11
1977 - 1986	5	34
1987 - 1996	14	31
1997 - 2003	16	10

slowed and there is yellowing, graying and drying of leaves (non-freezing injury) due to low temperature and mild frost, and burning of leaves (freezing injury) when there is severe frost incidence (Khehra and Dhillon, 1984). Low temperature at flowering restricts the pollen dehiscence resulting in poor or no seed set, and extreme low temperature even leads to an abnormal development of tassel. Under such environments, the cultivars should have a high level of tolerance to low temperature/frost. Further, crop production technology, particularly the method of sowing and the schedule of input (nutrient, irrigation) application, has to be such that the plant is not exposed to stress at the critical stages of growth and development, such as flowering and pollination, and is able to withstand stress. Intensive studies were carried out on the development of cold tolerant cultivars and agronomic practices for their production at PAU. Field and laboratory methods were developed to screen germplasm for cold tolerance (Khehra *et al.*, 1987; Dhillon *et al.*, 1988); and germplasm evaluation for cold tolerance under field conditions has been undertaken on an extensive scale. These efforts resulted in the development and release of cold tolerant cultivars, namely Partap and Partap 1, and their production technologies for cultivation of winter maize in Punjab in 1983, and these were later adopted in Haryana. Partap was identified to be promising among the available germplasm and intra-population improvement in it for cold tolerance, grain yield and other traits resulted in the development of Partap 1 (Dhillon *et al.*, 1984). Two heterotic pools, discussed later, were synthesized and improved for cold tolerance, grain yield and other traits; and used to derive inbred lines using which two cold tolerant hybrids, namely Sheetal and Buland, have been developed.

Breeding Speciality Maize

Special types of maize include quality protein maize (QPM), popcorn, sweet corn, baby corn, specialized starch (waxy, amylo) types and high oil maize.

Quality Protein Maize: The nutritional quality of maize is poor mainly due to high proportion of zein (prolamin) protein fraction in the endosperm that has low contents of lysine and tryptophan, two essential amino acids, and imbalanced ratio of leucine to isoleucine contents. However, the discovery of association of recessive opaque-2 (*o2*) gene with improved lysine and tryptophan contents and leucine to isoleucine ratio by Mertz *et al.* (1964), opened up new vistas in maize quality improvement. Opaque-2 maize has, however, soft grain and many other undesirable traits. Three *o2* composites (Shakti, Rattan, Protina) were released for general cultivation in 1971. But, these had low yield, soft endosperm, unattractive grain type and susceptibility to stored grain pests. Breeding efforts were continued at New Delhi to develop QPM, that carries *o2* gene along with genetic modifier genes for hard endosperm. As a result, Shakti 1, a hard endosperm version of Shakti, improved for grain appearance, yield and other agronomic traits, was released in 1997. Recently, the work on QPM has been strengthened with the introduction and utilization of QPM inbred lines developed at the International Maize and Wheat Improvement Center (CIMMYT), Mexico; and two hybrids, Shaktiman 1 and Shaktiman 2, have been released during 2001 and 2002, respectively, using these lines. Many other mutants have also been reported for improved amino acid pattern but these have received a little attention in maize breeding.

Popcorn: Popcorn is an extreme hard endosperm type flint maize with small kernel having high expansion volume on popping, and it is used as a snack food. Amber Popcorn, VL Amber Popcorn and Pearl Popcorn are the released composites.

Sweet Corn: It has high sugar content in kernel. In comparison to 3% in normal maize, 20% of dry matter in sweet corn is sugar. Sweet corn is eaten in the immature stage, and is harvested at about 70% moisture in kernels. Kernels are high in sugar when they are eaten on the cob, or are canned or frozen. Madhuri and Priya sweet corn composites have been released for general cultivation.

Baby Corn: Baby corn is the young ear of maize at or before silk emergence and is consumed as a vegetable, salad, in soup and some other preparations. Early maturity, prolificacy, yellow cob colour and regular arrangement of kernel-rows are some desirable traits. Also relevant is quality of stalk which is used as green fodder after the cobs are picked up. Though, no cultivar has been developed specifically as a baby corn, early maturing hybrids, namely Parkash, Vivek 4 and 5, Pusa 1 and 2 are being cultivated as baby corn.

Specialized Starch Type Maize: Normal maize starch has 78% amylopectin and 22% amylose. A recessive gene, *waxy (wx)*, results in the starch that has 100% amylopectin and waxy appearance of the kernel. Waxy maize is grown to supply raw material for specialty products of the wet milling starch industry and the separation cost of amylose and amylopectin is avoided. Waxy experimental hybrids are under evaluation. Amylo-maize has *amylose extender (ae)* gene which doubles the amylose content in the kernel's starch and possesses normal kernel appearance. It is used in preparation of cellophane, films, fibres, plastics, food and other products.

High Oil Maize: Maize oil has high proportion of unsaturated fatty acids and is an excellent cooking medium for human beings. It is also a source of high energy cattle feed. Some work on breeding for high maize oil has been initiated and germplasm with 6-7% oil content in the kernel have been identified.

Breeding for Resistance to Pests

Maize has number of serious diseases, such as stalk rots, leaf blights and downy mildews, and insect-pests like stem borers. To breed for resistance, germplasm and breeding materials need to be continuously evaluated for their reaction to pests. To accomplish it, many hotspot locations among the available coordinated research centers were identified and used. These include Pantnagar for stalk rots and brown stripe downy mildew, Ludhiana for maydis leaf blight and post-flowering stalk rots, Gurdaspur for brown stripe downy mildew and banded leaf and sheath blight, Delhi for maydis leaf blight and banded leaf and sheath blight, Udaipur for sorghum downy mildew. In addition certain centers were specifically created in hot spots to work on disease resistance, namely Dhaula Kuan for stalk rots and brown stripe downy mildew, Mandya for sorghum downy mildew and Nagenhalli for turcicum leaf blight. The Project developed excellent stem borer (*Chilo partellus*) rearing laboratories at Delhi and Ludhiana, and a large germplasm are evaluated every year under artificial infestation conditions.

Population Improvement

Population improvement involves recurrent selection, that is, selection generation after generation with recombination of the selects. It aims at gradually increasing the frequency of favorable alleles in the population and at the same time maintaining genetic variability. It may be carried out for intra-population or inter-population improvement. Intra-population improvement is carried out in a population to accumulate genes in a manner that the mean of improved population is maximized. Inter-population improvement involves two populations and accumulates genes to maximize the mean of inter-population cross between their improved versions and the inbred lines derived from them.

Intra-population Improvement and Cultivar Development

An extensive intra-population improvement programme was initiated at the national level during 1974 to enhance the performance of a number of elite populations representing different maturity groups and adaptation to agro-ecologies. These populations include Vijay, Makki Safed 1, Ageti 76, Navjot, Kiran, Partap, Parbhat, J663, D1, D743, BVI, Manjri, Diara, Hunius, L4, H3, Safaida, J1 Arr2, B21, B23, Pool 7, Tarun, Naveen, Surya, Kisan, Super 1 & 2. In the project, five broad based gene pools (both in yellow and white grain colour), AB yellow, AB white, BC yellow, CD yellow and CD white representing a wide array of maturity levels germplasm were constituted and subjected to population improvement. In almost all cases, modified full-sib (FS) family selection method was followed in which recombination of selected families and generation of new families were carried out simultaneously and one cycle of selection was completed in a year (Lonnquist, 1964, Compton and Lonnquist, 1982). These studies generally resulted in 2-3% gain in grain yield per cycle of selection. However, the experiences at P AU showed that intra-population improvement accompanied by introgression of new germplasm was more rewarding than the elite populations without germplasm introgression as generally conducted by various centres of AICMIP, when the objective is to improve the populations for direct use as commercial cultivars. Intra-population improvement in released composites resulted in the development of only a limited number commercial cultivars, namely Partap 1, Diara 3 and MCU 508.

Inter-population Improvement and Development of Heterotic Pools

Initially inter-population improvement did not get much attention because of its complexity and large resource requirement, and above all, emphasis on composite breeding. Yet a reciprocal recurrent selection programme was undertaken in J1 (Vijay) and Cuba 11J. In view of the international experience in hybrid maize breeding, a number pairs of heterotic pools were later developed. The PAU developed three pairs of heterotic pools to cater to the needs of different agro-climates (Dhillon *et al*., 1986). These are Makki Safed and Tuxpeno pools and Indigenous and Semi-exotic pools adapted to the monsoon season, and Ludhiana Lancaster and Ludhiana Stiff Stalk adapted to the winter season. Makki Safed and Tuxpeno pools have high yield potential and long duration. These were developed using Makki Safed 1-DR (an improved local) and Tuxpeno PBL (an adapted version of Tuxpeno Planta Baja C7) as testers. Indigenous and Semi-exotic pools have short duration and stress tolerance. The testers used to develop these pools were JS2 (composite constituted from elite locals collected from rainfed areas in Punjab) and CM124 x CM125 (male parent of double cross hybrid Sartaj). Semi-exotic pool has two sub pools, namely Semi-exotic pool A and Semi-exotic pool B, on the basis of type of germplasm used. For the development of Ludhiana Lancaster and Ludhiana Stiff Stalk, CM202 x Mo17-# and B73 x B79-# were used as testers. To facilitate the germplasm from one pool to another, efforts were made to assign Lancaster related materials to Makki Safed pool, Semi-exotic pool A and Ludhiana Lancaster pool; and Stiff Stalk related materials to Tuxpeno pool, Semi-exotic pool B and Ludhiana Stiff Stalk pool.

Modified reciprocal recurrent selection, discussed later, was carried out to enhance heterosis between the opposite pools, while at the same time paying due attention to performance of pools per se and variability within them (Dhillon *et al*., 1997). New germplasm was introgressed keeping in view the above objectives and to rectify specific defects. The overall objective was to develop heterotic pools which are genetically diverse, highly heterotic, have good performance per se and acceptable inbreeding tolerance; so as to promote the derivation of vigorous and heterotic inbred lines and high performance hybrids.

The important germplasm which have been used to develop various pools or has been introgressed into the pools are: Makki Safed pool - indigenous germplasm (Makki Safed 1-DR, J617, J6663), indigenously developed materials using exotic germplasm (Vijay, Ageti 76, Partap, Navjot, Tarun, Arun, CM202) and US Corn Belt lines (Mo17, FR13A, FR619, FR670, FR Va26, H96, H101); Tuxpeno pool - Tuxpeno Planta Baja, CM123, CM206, Suwan 1 and B73; Indigenous pool - locals and related germplasm; Semi-exotic pool A - Makki Safed pool, Ageti 76, Tarun, Mo17 and FR13A; Semi-exotic pool B - B73, B79, Tuxpeno pool, CIMMYT

Populations 24, 26, 31 and 36; Ludhiana Lancaster pool - Partap and Lancaster germplasm (CM 111, CM202, CM205, Mo17, FR13A, B57, H98, H99, H101, A670, FRVa26); and Ludhiana Stiff Stalk pool - Suwan 1 and Stiff Stalk germplasm (B73, B79, B84, FR632, H100, BS13, MSP!). In case of populations, inbred lines derived from them were tested in combination with the tester, and selected ones used for the synthesis of pools or introgression into them. Commercial hybrids like Paras, Parkash, JH3459, Sheetal and Buland have been developed using the inbred lines derived from these heterotic pools.

The AICMIP developed eight pairs of complementary heterotic pools in various maturity groups (Singh, 1995). These include XI(Y), X2(Y); XI(W), X2(W), in each maturity group. In full season maturity the testers used were CM111 and CM202 for yellow (Y) and CM300 and CM400 for white (W) grained pools. Two early maturing pools [Pool 1 (tester: Pop. 31), Pool 2 (tester: Tarun)] have recently been developed by GB Pant University of Agriculture and Technology, Pantnagar, and VPKAS. Two pairs were developed by Indian Agricultural Research Institute, New Delhi (A62 x AD609, A61 x MDR1).

Collaboration with CIMMYT

Indian maize breeding programme has a very strong linkage with CIMMYT since the latter was established in 1960s. The CIMMYT liberally supplied germplasm which has been extensively used in the Indian breeding programme. Further, there has been a free flow of scientific ideas and strong support in human resource development and capacity building. The AICMIP has been a very active partner in CIMMYT's international progeny, experimental variety and elite experimental variety testing programme. In addition to these, AICMIP is operating some specific projects in collaboration with CIMMYT on breeding for resistance/tolerance to Asian maize stem borers and resistance to downy mildews and post- flowering stalk rots. Indian maize programme has not only been greatly benefited by the materials generated at CIMMYT, but its breeding strategies and objectives (composite breeding and population improvement in 1970s and hybrid breeding in 1980s) have also been influenced by the CIMMYT.

Advances in Breeding Methodology

New scheme of population improvement programme having higher genetic gain per unit time as compared to those already available, and an approach to efficiently sample foundation plant for inbreeding have been proposed. Further genetic stocks for haploidy induction have been developed. These are briefly discussed below:

Selfed Plant Mass Selection

Selfed plant mass (SPM) selection, proposed by Dhillon (1991a), involves selfing of plants in a random mating population and subjecting the resultant S1 population to modified mass selection of Gardener (1961). One cycle of SPM requires one (off) season for selfing the plants and another (test) season for evaluation and recombination and it can be completed in a year if an off-season nursery is available. The relative efficiency of SPM selections vs. mass selection has been examined by Dhillon (1991a). The SPM selection generally has higher expected genetic gain per cycle, when mean degree of dominance varied between no dominance to complete dominance and gene frequency from 0.1 to 0.7, than mass selection. Three cycles of SPM selection were carried out in an experimental composite, J1413, and 2.4% gain per cycle was obtained for grain yield (Table 4).

Table 4. Selfed plant mass selection in J1413

Population	Grain yield (Kg/ha)	Days to silk	Plant height (cm)
J1413C3	3963 (7.3%)*	56.6	173
J1413C0	3695	56.3	171

*Gain due to selection

Modified S1 Selection

There are three types of families, namely half-sib (HS), FS sib (FS) and selfed (S); and among these, S families have the largest variability. But a cycle of selection based on S families generally requires more seasons than those based on HS and FS families. One cycle of S1 (one generation selfed) family selection requires three seasons for (i) development of families, (ii) evaluation of families, and (iii) recombination of selected families. In modified S1 (MS1) selection, the evaluation and recombination phases are accomplished together (Dhillon and Khehra, 1989). The evaluation experiment in one environment is grown in an isolated evaluation-cum-recombination block (Lonnquist, 1964) in which S1 families are inter-planted with balanced male (BM) composite developed by mixing an equal number of seeds of all S1 families under evaluation. The S1 families are detasseled and are, thus, allowed to pollinate with the pollen of BM composite. Selection is conducted among and within S1 families.

One cycle of MS1 selection is completed in two seasons, one (off) season to develop S1 families and another (test) season to evaluate and recombine S1s; and in one year if an off-season nursery is available. The expected genetic advance of MS1 selection vs. other methods of intra-population improvement (for assumed heritability estimates relevant to breeding programmes) showed the superiority of MS1 selection over others. Sekhon *et al.* (1999) conducted two cycles of MS1 selection in Composite Kesri and obtained 3.2% grain in grain yield.

Two-stage Recurrent Selection

Dhillon (1991b) proposed alternate evaluation of S1 and HS families to take advantage of the fact that recombination of selected families generates HS families. One cycle of the proposed selection method requires four seasons. It was shown that alternate evaluation of HS and S1 families has higher expected genetic gain than other methods of intra-population improvement. Various other options involving different types of families (S1, S2, HS, FS) and individuals were also considered. Dhillon *et al.* (1993) discussed two-stage recurrent selection to breed for resistance to insect-pests. Kaur (1996) carried out two-stage recurrent selection in Composite Parbhat. She conducted two cycles in 2 years and each cycle included HS selection and MS1 selection. She reported 12.9% gain per cycle of HS/MS1 selection.

Modified Half-sib Reciprocal Recurrent Selection

Comstock *et al.* (1949) proposed reciprocal recurrent (RR) selection for inter-population improvement of two heterotic populations. The method involves development of inter-population top-crosses (HS families, tester – opposite population) and S1s, evaluation of top-crosses, and within population recombination of S1s selected on the basis of top-cross performance. In modified HSRR (MHSRR) selection (Dhillon *et al.*, 1997), the evaluation of intra-population HS and S1 families is incorporated into RR selection. It involves: (i) development of S1s in each population (test season), (ii) development of inter-population top-crosses (S1s x opposite population) and possible mild selection in S1s (off-season), (iii) evaluation of top-crosses (test season), and (iv) within population recombination of S1s selected on the basis of top-cross performance aided by performance per se, that generates HS families within each population (off-season). The HS families are evaluated in the next (test) season, and in selected HSs, S1s are developed for second cycle of selection. Thus, intra-population improvement is incorporated in inter-population improvement in MHSRR selection. It aims at the concentration of genes for enhanced heterosis and performance per se; and is an appropriate method to develop source populations for the derivation of heterotic and vigorous inbred lines. The method was proposed for Hico breeding (Hico being an inter-population cross having high heterosis in F1 and least inbreeding depression in subsequent generations raised through random mating) to partially exploit heterosis in the absence of well developed seed industry, and is still relevant in less developed regions/countries. Two cycles of MHSRR selection (without germplasm introgression) were practiced in MS1-DR and Tux PBL and (MS1-DR x Tux PBL) C2 Syn2 and Syn3 were evaluated. In Syn 3 grain yield declined 8.7% but Syn 3 was on a par with the composite check. It indicated the possibility of hico breeding.

Comprehensive Recurrent Selection

Recurrent selection may have one or more of the following objectives: (i) improvement of random mating generation of the population for the development of germplasm and OP cultivars, (ii) improvement of selfed generation of the population enabling development of productive inbred lines, and (iii) improvement of the combining ability to develop high performance hybrids. Comprehensive recurrent selection offers opportunities to select for all three objectives (Dhillon, 1998). The various steps are: (i) development of HS families in the first (off) season, (ii) evaluation of HS families and development of S1 families in HS families in the second (test) season, (iii) development of test-crosses (TCs) in an isolated crossing block in third (off) season and also mild selection among S1 families, (iv) evaluation of TCs and their S1 parents in separate trials and selection among TCs and S1s in the fourth (test) season, and (v) recombination of S1 families selected on the basis of TC and S1 performance, thereby, generating HS families for evaluation in the next cycle of selection. The selfs in selected S1 families may be used for inbred lines development. Comprehensive recurrent selection is a multi-stage recurrent selection based on the evaluation of inbred (S1) and outbred (HS) families within a population and crosses (TCs) with an appropriate tester (for example – related or unrelated), and represents a synthesis of intra-population and inter-population improvement. Dhillon (1998) compared comprehensive recurrent selection with other methods and showed it to generally have higher expected genetic gain.

Unit Selection

Singh and Singh (1968) and Singh *et al.* (1982) proposed unit selection and its modifications. They considered a sub-population derived from six plants as a unit. In unit selection three female plants are pollinated with bulk pollen of three selected male plants. The resulting units are evaluated as experimental varieties and also used to develop second cycle units. This method has been used in a number of populations, which led to the development of some composite cultivars including MCU 326 and MCU 508.

Other Modifications in Population Improvement Methods

Two dual purpose designs that permit the conduct of selection as well estimation of additive and dominance components of genetic variance, have been proposed. These are combined HS-FS selection (Dhillon *et al.*, 1984), partial diallel matings in modified FS selection (Dhillon *et al.*, 1987). Many suggestions have also been given to enhance the genetic gain due to recurrent selection methods based on evaluation-cum-recombination block (Vasal *et al.*, 1997).

Selection of Foundation Plants for Inbreeding

Dhillon *et al.* (1994) proposed to sample the foundation plants for inbreeding, as half-sibs rather than S1s, and then initiate inbreeding. This helps in better sampling and identification of foundation plants.

Production of Homozygous Lines through Haploidy

The production of homozygous diploid lines through doubling the chromosome number of haploids is a quicker approach than the conventional approach of selfing and selection for 5-6 generations or more. This requires efficient method to produce and identify haploids and then chromosome doubling through colchicine treatment. Sarkar *et al.* (1994) developed haploidy inducer lines (using Coe Stock 6) yielding haploid frequency as high as 5%. They also incorporated suitable genetic markers (seed marker) in the inducer stocks to identify haploids.

Relative Expected Genetic Response for Intra-population Improvement

Expected Response to Selection

Hallauer (1992) worked out expected response to different methods of population recurrent selection for intrapopulation improvement in Iowa Stiff Stalk Synthetic of maize. His results alongwith additional computations are presented in Table 5. SPM selection showed higher expected response than modified mass selection when a year had two seasons, but modified mass selection seemed to be better when there is only one season per year. Among family-based methods, S_1 selection showed markedly higher expected gain per cycle than other methods. The MS_1 selection closely followed by MFS selection had higher expected response per year than other methods when the year was assumed to have two seasons. On the other hand, expected response due to MER selection was higher when only one season per year was available. The AR selection showed higher expected response than other methods under both situations: HS-S_1 and MER-S_1 selection methods being better when a year had two seasons and HS-MS_1 selection being better when a year had only one season.

Impact of Improved Cultivars on Productivity

The impact of a crop improvement programme depends upon the adoption of improved varieties and is expressed as productivity enhancement. The data on average yield, area under high yielding varieties (HYV), and area under irrigation (from TE 1961-62 to TE 2001-02, decade wise) are presented in Table 6. The productivity around the time

Table 5. Expected response to different methods of intrapopulation recurrent selection for grain yield in Iowa Stiff Stalk Synthetic of maize

Selection Methods	Expected response (g/plant)*		
	Per cycle	Per year**	
		Two seasons	One season
Modified mass	3.5	3.5	3.5
Selfed plant mass	5.1	5.1	2.6
Mod. Ear-to-row (MER)	7.8	7.8	7.8
Standard Half-sib (HS)	8.2	8.2	4.1
FS	10.8	5.4	3.6
Mod. FS	10.8	10.8	5.4
S1	17.5	8.8	5.8
Mod. S1 (MS1)	11.2	11.2	5.6
AR: HS - S1	25.7	12.9	6.4
AR: MER - S1	25.3	12.7	6.3
AR: HS - MS1	19.4	9.7	9.7

* Estimates of components of variance used to predict response were reported by Silva and Hallauer (1975): $V_A = 169$, $V_D = 193$, $V_{AE} = 92$, $V_{DE} = 75$, $V_E = 185$, $V_E = 1301$. Selection intensity was assumed to be 10% (k=1.75). Three environments each with two replications were assumed for family evaluation and selection. Equal allele frequency ($p = q = 0.5$) was assumed for the methods based n the evaluation of selfed populations and selfed progenies.

** A year is considered to have two crop seasons (one for evaluation and another for raising off-season breeding nursery) and a year has only one season.

Table 6. Mean yield, area under high yielding varieties (HYV) and area under irrigation in India

Year	Yield (kg/ha)	Area under HYV (%)	Area under irrigation (%)
TE 1961-62	940	–	10.7
TE 1971-72	1049	8.6	16.2
TE 1981-82	1100	30.1	19.3
TE 1991-92	1509	46.2	22.2
TE 2001-02	1896	58.0	21.7

of release of first set of the hybrids was 940 kg/ha (TE 1960-61) which doubled to 1896 kg/ha during TE 2001-02. The impact of improved varieties is evident as the area under HYV during the same period increased from 8.6 to 58.0%. Of course, other inputs also contributed to the productivity increase. For example, the area under irrigation rose from 10.7 to 21.7%.

In comparison to maize, the impact of HYV of wheat and rice on productivity and production has been far greater. The progress in maize is still very significant when analyzed in the following context:

1. In both wheat and rice, new plant types which have dwarf stature, lodging resistance and input responsiveness were developed. But in maize no such advancement could be made (deployment of dwarfing gene did not favorably affect grain yield). Even in the absence of such a path-breaking research in plant type of maize, there has been steady improvement in grain yield.
2. Wheat and rice improvement programmes in India in comparison to that of maize, got distinctly greater support from the international agricultural research system. There are many direct releases in India, of wheat and rice materials developed at CIMMYT and International Rice Research Institute, Manila, respectively. In maize, however, the only direct releases of CIMMYT's maize materials are Laxmi, Hemant, Dhawal, NLD, Kanchan, Panch Ganga and Devaki, and these also did not occupy large area.
3. Seed supply in maize is critical factor and it continues to be a limiting one even at present. In hybrid maize it has to be continuous, as fresh seed is needed for every planting. Even in case of composite cultivars of maize, more frequent seed replacement is needed than that in pure line cultivars of wheat and rice. In composites, there may be outcrossing disturbing the genetic structure and adversely affecting the performance and phenotypic appeal.
4. Most importantly, the national food security needs and policy favoured wheat and rice. Subsidy on inputs (fertilizer, water, electricity) has benefited rice more than maize (Table 7). Both rice and wheat have minimum support price, assured procurement and are included in public distribution of foodgrains. In 1980, there was price parity of maize and paddy but presently maize price is about 80% of rice (Table 8).

Table 7. Maize and rice area under irrigation and High Yielding Varieties (HYV)

Year	Rice	Maize
Irrigated Area 1995-99	51.0	22.0
Area under HYV (%) 1995-98	74.9	58.6

Table 8. Minimum support price of maize and rice since 1976-77

	MSP (Rs/q)	
Year	Rice	Maize
1976-77	74	74
1982-88	122	118
1991-92	230	210
1996-97	380 (414)*	320 (332)
1998-99	440 (495)	390 (427)
1999-2000	490 (562)	415 (461)

* Increase in MSP (over 1976-77)

In spite of all these factors the productivity increase in maize has been at least as good as that in rice (Table 9).

Maize Improvement Programme – An Analysis

The AICMIP, a multi-centre and multi-disciplinary project, was the first of its kind in India. Besides the development of improved varieties that have played a significant role in increasing maize production and productivity, the project gave a short-term approach of developing non-conventional (double top-crosses), concept of composite breeding, new methods of intra- and inter-population improvement with higher expected response to selection. The AICMIP was also instrumental in laying the foundation of seed industry with the establishment of National Seeds Corporation. Above all the project has served as a model of coordinated efforts leading to the establishment of a large number of similar projects in crop improvement research as well as in other areas like long-term fertilizer application, rodent control and pesticide residue. But an analysis of the achievements, objective and approaches, indicates that the programme may have suffered on following accounts.

Table 9. Increase in productivity of maize and rice since 1951

Year	Rice			Maize		
	Mean yield (kg/ha)	% increase in productivity over		Mean yield (kg/ha)	% increase in productivity over	
		1951-56	1976-81		1951-56	1976-81
1951-56	815	–	–	741	–	–
1956-61	914	12	–	856	15	–
1961-66	986	21	–	992	33	–
1966-71	1033	27	–	1066	44	–
1971-76	1128	38	–	1022	38	–
1976-81	1227	51	–	1065	43	–
1981-86	1393	71	14	1252	68	17
1986-91	1622	99	32	1371	85	29
1991-96	1829	123	48	1539	107	44
1996-01	1920	136	56	1772	139	66
2001-02	2066	153	68	1918	159	80

Consistency in Breeding Programme

There have been very sharp turns in the breeding approach. The hybrid breeding was taken up with the establishment of the AICMIP in 1957. Eight hybrids were developed and released since 1961 to 1964. Considering that lower than expected progress in the area under hybrid maize is due to seed production problems, composite breeding got prioritized. Six composites were released in 1967, but again the acceptance of HYV was not as much as expected. Up to 1972, 21 cultivars were released and all these were of at least 95-day maturity with some exceptions (national releases like Ganga 1, Ganga 3, Vikram in comparison to about 80 to 85 days maturity of most of the locals under cultivation. Expecting the longer duration of HYV to be the main factor limiting their popularity, the breeding programme was reoriented during 1970s towards early maturity. Further, intra-population improvement was undertaken on a vast scale. There is no disagreement on the importance of early maturing composite cultivars and their population improvement but whole emphasis shifted to these. Consequently, hybrid breeding was discontinued except at some centers where it was practised on a small scale. Again a similar shift took place in late 1980s when emphasis was shifted to hybrid breeding particularly single crosses at the cost of other options.

It was, however, not appreciated that outstanding cultivars, namely Hybrid Ganga Safed 2, Hybrid Hi-Starch, Hybrid Ganga 5 and Composite Vijay, were developed during 1960s. These performed very well in farmers' fields and continued to be under cultivation over a long period. The success of four of 16 cultivars (three of 10 hybrids and one of six composites) released during 1960s was not a poor performance. Evidently, an in-depth analysis was not carried out that resulted in sudden turns in the breeding programmes rather than a balanced approach. An emphasis on the development of hybrids and composites having full season maturity to create an initial impact in favourable agro-ecologies was a sound approach. But neither ignoring the development of early maturing cultivars over a long period (1960s) nor diverting almost all resources to composite breeding and population improvement (1970s) are understandable. The same is true of the present overwhelming emphasis on single cross hybrid breeding.

Population Improvement and Germplasm Introgression

As discussed earlier an extensive intrapopulation improvement was undertaken in elite composites without any germplasm introgression, whereas the experiences at PAU indicated intrapopulation improvement accompanied by germplasm introgression has been more successful in cultivar development.

Emphasis on Wide Adaptation

Maize is cultivated in India under very diverse conditions including many stresses. Probably there has been greater than required emphasis on breeding for wide adaptation under favourable conditions

Utilization of Indigenous Germplasm

Variability in the indigenous germplasm, though, limited in comparison to that in the center of diversity, is of special significance as this germplasm has evolved in balance with the prevalent agro-climatic/factors including biotic and abiotic stresses, cropping patterns and needs of the farmers. This is highlighted by the fact that locals continued to be cultivated over a large area indicating that they possess certain traits that enable them perform well on the farmers' fields. Further, Ganga Safed 2 had Rudrapur Local as male parent. But the importance of local germplasm was not appreciated and its utilization, practically ignored.

Breeding Programmes of Different Centres

All the centres of the AICMIP did not work seriously and efficiently. Some centres simply conducted the evaluation trials. These did not have any worthwhile breeding programme and did not develop any commercial cultivar. An analysis is presented in Table 10.

Utilization of Non-inbred Parents of Hybrids

Hybrids Ganga Safed 2, Hi-Starch and Ganga 5 were all double topcrosses, their male parents being Rudrapur Local (CM600), Jellicourse (CM601) and Antigua Gr.1 (CM500), respectively. The natural course should have been to derive inbred parents or at least develop non-inbred parents (populations/synthetics or HS/FS families) with narrow-genetic base or early generation inbred lines. Some work was carried out on the development of inbred lines but it was not successful. Perhaps, more intensive efforts were needed. In case of severe inbreeding depression (as in case of locals because of their narrow genetic base), options of recycling of early generation inbred lines or the development narrow-genetic base non-inbred parents might have been examined. It may be added that inbreeding in Suwan 1 (CM501), the male parent of double top-cross, Ganga 11, has been carried out successfully.

Table 10. Number of cultivars released at national and/or state level that have been developed by different centres

Centre	Hybrids	Composites	National+State=Total[1]
a) Centre that developed cultivar released at national and state level			
Delhi - DMR	9	11(10)	19+1 = 20
1. Delhi - IARI	3	3	6+0 = 6
2. Ludhiana	7(4)	14(8)	12+9 = 21
3. Hyderabad	8	5(2)	11+2 = 13
4. Almora	7	3	7+3 = 10
5. Pantnagar	2(1)	7(3)	4+5 = 9
6. Dholi[2]	4(2)	4	2+6 = 8
7. Udaipur	0	4(1)	3+1 = 4
8. Kohlapur	0	3(1)	2+1 = 3
b) Centre that developed cultivar released at state level only			
1. Srinagar	0	9	0+9
2. Godhra	0	6	0+6
3. Chhindwara	0	5	0+5
4. Dharwad	2	2	0+4
5. Coimbatore[3]	2	1	0+3
6. Kullu	0	3	0+3
7. Karnal[3]	2	0	0+2
8. Kanpur	0	2	0+2
9. Nagenhalli	0	1	0+1
10.Ranchi	0	1	0+1

[1] Releases at national/zonal level or over states + state level = total

[2] Two hybrids and two composites are direct introductions

[3] Are/were not centres of AICMIP

Recording and Utilization of Data

There are certain limitations in data recording and utilization which need to be corrected. Grain yield is computed assuming 80% shelling and is adjusted for grain moisture (15%). But there is wide variation in shelling percentage (Dhillon *et al.*, 1994) which is ignored. Further, the method used to estimate grain moisture is prone to sampling and technical fluctuations.

The data are sometimes interpreted very strictly, such as the differences in days to silk of the experimental entry vs. check cultivar, even though, it is well appreciated that this trait is appreciably influenced by environment; and there is variability for post-silking days to maturity and days to silk is not a fool proof indicator of days to mature (Mittal *et al.*, 1997).

Pollination Technique

Silks are cut to carry out control pollination. But pollinating without silk cutting has certain advantages (Dhillon, 1998) and this needs to be adopted.

Hybrid vs. Composite Breeding

Hybrid and composite breeding and cultivars have certain advantages and limitations as discussed earlier. Hybrid cultivars have higher performance potential and better phenotypic appeal. However, composite cultivars are expected to be more widely adapted and stable. These also have an advantage in simpler seed production and their maintenance by the farmers; whereas, farmer cannot maintain hybrid cultivars and fresh F1 hybrid seed is required for every planting. In composite breeding, the breeder selects the promising materials and recombines them, thereby, generating a number of new genotypes. Thus, breeder does not have a full control over the materials that he is handling. This affects breeder's skill, interest and criticality (he can not identify all the genotypes in the population). In comparison to composite breeding, hybrid breeding is complex, resource and technology intensive, and has long gestation period. But the breeder has the control and knowledge over the process. On the whole both types of cultivars have a place in the agriculture in developing countries.

Maize Improvement Programme – Objectives and Approaches

Maize is a C4 plant, has wide adaptation (monsoon, winter and spring/summer seasons) and has diverse breeding options. The demand for maize is bound to increase due to consumption for human food, livestock and poultry feed and as industrial raw material. Maize has an added importance as it is an important candidate to replace rice in rice-wheat cropping system. This system is the most popular one and it, specifically rice, has adversely affected soil heath and quality and quantity of water particularly in North-West India; and there is an urgent need for diversification. Maize requires less water than rice and has less adverse effects on soil and water resources.

Objectives

To exploit the emerging opportunities, maize breeding needs to be more focused on the following objectives:

Breeding for Specific Adaptation: Earlier there has been emphasis on wide adaptation. Though, there has been good success, but it is easier to breed for high yield in combination with specific adaptation rather than wide adaptation. Further, this will enhance on-farm diversity. The breeding programmes need to emphasize the development of cultivars as follows:

Input Responsive, High Yielding Hybrids: To get a quantum jump, it is imperative to develop input responsive hybrids for cultivation under optimum growing conditions. Irrigated areas in monsoon season and winter season provide such maize production conditions. While breeding cultivars for these areas, the emphasis should be on the development of high yielding, input responsive hybrids, preferably single crosses, of as long duration as much permitted by the prevalent cropping systems. For intensive cropping system under irrigated conditions, the duration of the hybrids has to be shorter as per requirement of the crop rotations. Efforts should be made to exploit the positive correlation between grain yield and crop duration. In winter maize breeding programme, there seem to be greater chances of exploiting temperate germplasm. Further, tolerance to low temperature is an important trait.

Stress Tolerant, Short Duration Cultivars: Maize is cultivated under different stresses; and cultivars (composites and hybrids) with stress tolerance, good and stable yield and generally short duration are needed for cultivation under the stressed conditions.

Drought and Low N Stresses: During monsoon season, about 80 per cent of maize area is under rainfed cultivation where the crop faces many stresses; drought and low N being the main stresses. In addition to stress tolerance and short duration, other important traits while breeding for drought tolerance, include short anthesis-silking interval, prolificacy, stay green, increased number of kernels, reduced tassel size and plant height. The evaluation and selection under high plant density has been effective in reducing anthesis-silking interval and barrenness, and increasing harvest index.

Water Logging: It is another important stress encountered during monsoon season. Genetic variability has been observed for various agronomic traits under water-logged conditions. Brace root development and root porosity are the important traits for avoiding damage due to water logging. 'Saracura' a population developed in Brazil having tolerance to water logging need to be studied for adaptation to Indian conditions and use in the breeding programmes.

High Temperature Stress: Maize is cultivated during spring/summer season on a limited scale. This season is characterized by high temperature (>40°C) that results in tassel blast, pollen desiccation and ovule abortion. *Sathi* germplasm (about 70 days to mature) possesses heat tolerance and that need to be exploited in breeding cultivars for this season.

Breeding Fodder Maize: Maize is an important fodder crop, but this has not received due attention. Only two composites of fodder maize, African Tall and J1006, have been released. Of these, African Tall has higher fodder yield but is low grain yielder. A strengthening of the programme on fodder maize breeding with due importance to fodder yield, nutritional quality and seed yield is called for. There are greater chances of utilizing tropical germplasm in fodder maize breeding. Further, closer and effective collaboration is required between the scientists working on maize and fodder crop projects to develop fodder maize cultivars, preferably composites.

Breeding Speciality Maize: Quality protein maize has special significance for us in view of maize being staple food of a large population including tribal and poor; and it has recently been focused again. It may be more rewarding if the development of single crosses for cultivation during winter season is prioritized. Other specialty maize namely baby corn, popcorn, sweet corn, waxy and amylo-maize possess high market value. Uniformity of their produce is preferred for processing. Therefore, the emphasis has to be on hybrid breeding. However, not much effort has been made to breed cultivars, hybrids or even composites, of these special maize types.

Breeding for Intercropping Systems: Maize is cultivated in some intercropping systems. The experiments conducted in other crops do not indicate any need for separate breeding programmes for mono- and intercropping systems. But there is a need to generate such information in maize. Some important traits while breeding cultivars for intercropping are short plant height, narrow and erect leaves and small tassel.

Breeding for Multiple Resistance to Biotic Stresses: To realize yield potential, incorporation of resistance to the diseases and insect pests prevalent in the given season and region, is very important. With the intensification of agriculture, stalk rots, downy mildews, leaf blights and stem borers, which cause considerable economic losses, are becoming more serious. It is important to pay more attention to develop genetic stocks possessing multiple resistance and combine resistance with other desirable traits in improved varieties.

Development of Seed Production Technology: Seed production technology did not get much attention in the past. In fact seed production of hybrids was taken for granted. The importance of research on seed production technology has increased with single cross hybrid breeding. Inbred lines need to be evaluated under different agronomic treatments so as to develop a complete seed production-protection technology package.

Approaches: To achieve these objectives, the approaches that need to be strengthened/followed are:

Development and Improvement of Heterotic Pools: The synthesis and improvement of heterotic pools greatly facilitate hybrid cultivar development. The pools should be diverse, heterotic and have high mean performance, inbreeding tolerance and within-population genetic variability. To accomplish this, diverse germplasm need to be evaluated for these parameters and put together in two or more pools keeping in view pedigree and geographic diversity; and subjected to population improvement accompanied by germplasm introgression.

Integration of the Population Improvement with Hybrid Breeding: This integration is very important but has been lacking. Population improvement methods that involve the evaluation of crossbred and selfed families should be preferred so that inbred lines and hybrids are continuously obtained as a spin off (Dhillon *et al.*, 1997; Dhillon, 1998).

In the development and improvement of pools and integration of population improvement and hybrid breeding, choice of base populations, selection method and selection criteria are all important.

Development of Vigorous Inbred Lines: The importance of vigorous lines has increased with single cross hybrid breeding. To accomplish it, greater emphasis has to be laid on the improvement of performance per se and inbreeding tolerance of base germplasm and selection for performance per se of inbred progenies during inbreeding.

Development of Seed and Pollen Parents of Hybrids: With the development of the breeding programme, it would be desirable to concentrate the alleles controlling the traits associated with seed parent (high number of kernels, bold kernel, small tassel) on one side, and those with pollen parent (profuse pollen production) on the other side in the heterotic pools or sub-pools and during second cycle inbred line development.

Breeding Non-inbred Parents of Parents: Some very successful hybrids have non-inbred parent. Such parents may particularly be relevant in the development of short duration, stress tolerant hybrids. The experiences indicate that it is difficult to develop early maturing inbred lines that are vigorous and stress tolerant. The use of non-inbred parent as a female parent may be a stopgap arrangement till vigorous early maturing inbred lines become available.

Exploitation of Temperate Germplasm: Tropical maize yields lower than temperate maize in spite of producing higher biomass. Important traits of temperate germplasm include high harvest index (about 50% in comparison to 30-35% in tropical maize), relatively light canopy and erect leaves, input responsiveness, and adaptation to high plant density. Temperate maize germplasm, however, generally performs poorly under tropical conditions due to early maturity and susceptibility to diseases and insect-pests. Though, some efforts have been made to use temperate maize germplasm (Khehra *et al.*, 1986a; 1986b) but these efforts need great strengthening. More germplasm should be introduced and evaluated; and the promising ones hybridized with tropical inbred and non-inbred germplasm for introgression and second cycle breeding.

Application of Multiple Selection Criteria: Though much progress has been made in computer technology, its application in our breeding programme is below desired level. Experimental entries (hybrids or composites) are many times promoted/rejected on the basis of a single trait like grain yield or days to silk, even following arbitrary cut offs. Multi-trait selection criteria need to developed and applied to promote/reject experimental entries. Further, there should be flexibility for the promotion of experimental varieties. An outstanding experimental entry may be directly promoted from Initial Varietal Trial to Advance Varietal Trial-II Year.

Due Importance to Target Environment: The important states for maize cultivation are Rajasthan, Uttar Pradesh, Madhya Pradesh, Karnataka, Gujarat, Bihar, Andhra Pradesh, Jammu & Kashmir and Himachal Pradesh. All these states jointly account for 79% area and 86% of the national maize production during 1997-02 and the first four states are particularly important. The allocation of resources, besides administrative considerations, should be in accordance with the maize area, uniqueness of agro-ecology and output; so that materials are developed and evaluated in target environments.

Breeder-farmer Interaction and Farmers' Field Evaluation: There has been intensive discussion on farmer participatory plant breeding/participatory varietal selection in recent years. Suggestions have been made to the extent of involving farmers in the selection of parents for hybridization and in the evaluation and selection in segregating generations. While these suggestions seem quite exaggerated, there is always a scope for improvement of the system.

There is no gainsaying that the breeder, to be successful, must know the farmers' field conditions and their needs. The breeder must interact with farmers and frequently visit the farmers' field and arrange farmers' visits to the experiment station. Further, materials must be evaluated under the conditions prevalent at the farmers' fields. For the release of cultivars at state level, elite experimental entry (ies) (generally one), identified in research station trials, is evaluated in farmers' field trials for 1-2 years by. To collect more data on the performance of experimental entries in the target environment and enhance the farmers participation, these trials should be conducted as early as possible (may be after 2-year evaluation at experiment station) and with as many experimental entries as possible; and farmers view should get due importance. For varietal releases at the national and zonal levels, pre-release farmers' field trials (then known as minikit trials) used to be conducted. But the experiences were not encouraging. The data were received very late and that were not very reliable either; and these trials had to be discontinued. Thus, the national/zonal releases should be followed by aggressive demonstrations.

Germplasm Evaluation under Stresses: Generally the experimentation is carried out under uniform and favourable conditions to maximize genetic expression and minimize non-genetic effects so as to enhance heritability and genetic advance through selection. This has led to criticism of the Indian crop improvement programme that the evaluation is done under favourable conditions. But it is mostly unfounded. Germplasm/ breeding materials/ experimental entries are being evaluated under stresses. Of course stresses are prioritized on the basis of resources and technologies available and expected genetic returns. Maize breeding materials have been continuously evaluated for reaction to leaf blights, stalk rots and downy mildew under artificial inoculation or in hot spots and for *Chilo* under artificial infestation. These efforts need to be expanded and the required facilities developed. Further, evaluation under high plant density has proved very successful, and this needs to be incorporated in the evaluation protocol.

Liberal Varietal Release: There is an unrealistic expectation that each and every released variety should be successful. It is very difficult, if not impossible, in case of all field-based technologies as cannot be thoroughly evaluated under all field conditions including stresses. There should be reasonable testing and liberal release of cultivars so as to give wider choice to the farmers.

Integrating Biotechnology with Maize Improvement: Very rapid advances are being made in biotechnology and its application in plant breeding. Biotechnology has quickened the pace of plant breeding and made it precise. Some of the important areas of research are the development of transgenics for resistance/tolerance to insect-pests, diseases and abiotic stresses, marker assisted selection and prediction of hybrid performance based on molecular diversity among parents. We, on the whole, are not keeping pace with the advances in biotechnology. To take advantage of these developments and to work in a synergistic manner, plant biotechnologists need to initially work in close collaboration with maize improvement teams, and they should ultimately be absorbed in the team. This needs immediate attention.

In addition to recording and consideration of data on some important traits and use of appropriate pollination technique is important.

Streamlining the Working of Coordinated-Project Centres

The project has delivered well and has served as a model of coordinated efforts not only in crops but also in other areas. But some lethargy and complacency has crept at certain centres which carry out only routine varietal testing and do not produce any significant breeding materials. The Directorate of Maize Research and eight centers have developed cultivars and 10 others have developed cultivars for their state only (Table 10). The remaining centers have not developed even one cultivar.

The research in various disciplines needs to be toned up and facilities strengthened particularly with reference to basic research, breeding for resistance/tolerance to abiotic and biotic stresses and upgradation of nutritional quality. Also there is an urgent need to promote collaborative efforts of maize breeding units, probably by putting various scientists (maize breeder, agronomist, plant pathologist, entomologist) under one administrative control as is the case at some centres. These teams need to interact closely with plant biotechnologists (as discussed above) and plant physiologists.

The project should have a dynamic system of location of centers depending on the area under maize cultivation and uniqueness of the agro-ecology, so as to facilitate due importance to target environments. There is also a need to strengthen zonal/regional testing. Some of the zones have only 3-4 centres which are not enough to generate adequate data. Above all, the need is for dedicated, consistent and persistent efforts.

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