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An Overview of Registration of Maize Genetic Resources in India

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A B S T R A C T

Plant genetic resources are the bed rock of any crop improvement programme. Applied breeding programme emphasizes selection within elite germplasm sources to enhance the opportunities of developing genotypes superior to those currently available. Indigenous as well as exotic germplasm constitute important resources for addressing serious breeding issues, viz. increasing genetic variability, improving the derived populations for specific traits especially biotic and abiotic stresses or even yield, enhancing quality and eventually broadening the genetic base of present-day cultivars. Maize inbreds are used extensively in hybrid production as seed parents and pollinators and represent a fundamental resource for studies in genetics, breeding and molecular biology. The improvement programmes target breeding of several lines with desirable traits some of which show potential in varietal development. But many lines which otherwise possess several desirable traits remain either as the backup stock with the breeders or are recycled and may even be lost since only the top performing material is promoted for cultivation. In order to motivate the breeders so that cultivar development goes on unhampered, a system has been developed and implemented, in India, whereby a breeder can opt for soft protection of the breeding material, viz. inbred lines, populations, pools, genetic stocks, etc possessing unique combination of traits- agro-morphological, phenological, protein and / or grain quality; resistance / tolerance to biotic/abiotic stresses, etc. Availability of information and material in public domain play a key role in strengthening the efforts in utilizing genetic resources effectively in shaping the crop breeding programmes. Hence, keeping the above in backdrop, an overview of registered plant genetic resources in maize in India has been presented with an objective to identify potential germplasm especially inbred lines with its unique traits available in public domain for exchange and research purposes. An attempt has also been made to identify the future germplasm requirements in Indian public breeding programmes.

Introduction

Maize, (*Zea mays* ssp *mays* L.) is a versatile crop that adapts easily to a wide range of production environments. It grows at latitudes ranging from the equator to slightly above 50^{o} North and South, from sea level to over 3,000 meters above sea level (masl), under heavy rainfall and in semi-arid conditions. The crop growing cycle can range from three months to more than a year (Dowswell *et al.,* 1996). Maize is a widely grown C4 crop with a high rate of photosynthetic activity leading to higher grain and biomass yield potential. It is predominantly a cross-pollinating species, a feature that has contributed to its broad morphological variability and wider geographical adaptability. Depending on the latitude and the climate in which it is grown, maize is classified into three distinct types, tropical, temperate and subtropical. There are four major maize mega-environments that include the lowland tropics (or tropical lowlands), tropical highlands, subtropics/ mid-altitude zones and temperate zones (CIMMYT Maize Program 1988; Dowswell *et al.,* 1996; Hartkamp *et al.,* 2000). Across all developing countries including Asia, maize is grown mainly in tropical lowland and temperate environments. However, while tropical lowland production environments are found in all the world's regions and in all Asian countries, temperate production environments are found mostly in East Asia (87%), particularly in northern China. There are three major production environments for maize in Asia: rainfed –lowland-commercial, rainfed-semi-commercial and commercial environments.

India is a land of diverse agro-ecologies. It is located between 8° - 38°N and 68° - 97°.5' E and exhibits extreme variation in altitude as well as climate. Maize is among the most important cereal crops of all these regions in the country. It ranks third after rice and wheat but has the highest genetic yield potential among the food grain crops. In India, the crop is grown in all the seasons i.e., Kharif, Rabi and summer. Of these three seasons, nearly 90% of the production is from Kharif alone, 7-8% during Rabi season and remaining 1-2% during summer season, respectively (Indian maize summit, 2016).

In India, broadly two production environments exist: (1) traditional maize growing areas including Bihar, Madhya Pradesh, Rajasthan, and Uttar Pradesh, and (2) non-traditional maize areas including Andhra Pradesh, Telangana State, Karnataka, Maharashtra and Tamil Nadu. Former is low productive as the crop is often grown in marginal lands, primarily as a subsistence crop to meet food needs.

In contrast, maize in the non-traditional areas is grown mainly for commercial purposes–i.e., to meet the feed requirements of the booming poultry sector and starch requirement of the industries. In recent years, maize has turned out to be a commodity with impressive growth rate and has contributed immensely to the national economy.

The maize growing environments are characterized, among other things, by a complex array of biotic and abiotic stresses which limit its production. Owing to that, the crop productivity fluctuates widely from region to region (non-traditional versus traditional areas of maize cultivation) and season to season (Kharif versus Rabi). The most commonly reported biotic constraints are downy mildews, Asian corn borers, stem borers, stalk rots, weevils, and weeds besides ear, cob and kernel rots, etc.

Abiotic constraints include declining soil fertility, soil erosion, temperature and more importantly drought. Despite major chunk of maize farming concentrating in marginal environments, it contributes more than 9% in the national food basket and is considered to be the crop of opportunities (Indian Maize Summit. 2016). Hence, maize is an economically important crop for feed, fiber, fuel, and food. It is also used as an ingredient in an endless list of manufactured products that affect the nutrition of the under-privileged populations as well as high-end consumers.

Major characteristics of Indian maize

In India, in view of changing resource base under the current farming scenario, maize and maize- based cropping systems are becoming important for food and nutritional security (Yadav *et al.*, 2015; 2016). As a consequence, high yielding hybrids of different maturities suitable to various cropping systems are increasingly sought for all the production conditions across ecologies/ cropping seasons. Globally, three major maturity durations in maize are identified – short, medium or intermediate and long (Hartkamp *et al.*, 2000). In Indian context, short duration types are extra-early or early, taking on an average ≤75 or 76-85 days in plains in Kharif to mature; intermediate types mature in 86-95 days and long duration types are late in maturity and take ≥96 days in plains in Kharif. Generally, full season cultivars i.e. long duration types are preferred to be grown in favourable production conditions with high inputs and assured water supply i.e. Rabi and high input-Kharif. The short duration cultivars tend to be cultivated under rain fed conditions (Kharif) with minimal interventions.

Maize genetic resources

Plant genetic resources are the bed rock of any breeding programme. Genetic resources in maize comprise land races, synthetics and OPVs, old and obsolete cultivars, hybrids including experimental hybrids, elite inbred lines, F_1s, F_2s and other segregating populations, etc. The relative use of the different categories of germplasm depends on the primary objectives of the research programmes. Applied breeding programmes emphasize selection within elite germplasm sources to enhance the opportunities of developing genotypes superior to those currently available. Indigenous as well as exotic germplasm constitute important resources for addressing serious breeding issues, viz. increasing genetic variability, improving the derived populations for specific traits especially biotic and abiotic stresses or even yield, enhancing quality and eventually broadening the genetic base of present-day cultivars.

Being highly cross pollinated, maize offers the possibility of exploiting heterosis through the development of hybrids. Among the various types, viz. double cross hybrids, top crosses, double top crosses and three-way crosses, single cross hybrids (SCHs) are the most uniform and have the potential to give maximum grain yield. Hybrids in general and SCHs in particular have thus captured the interests of breeders and policy makers world-wide including India. The country has embarked upon the path of developing and popularizing hybrid technology on farmers' fields. Consequently, the breeding programmes have been implemented which cater to the needs of evolving genetically superior inbred lines, their testing in 2-parent combinations and identifying best yielders. A strong germplasm base is therefore, a pre-requisite for developing high yielding hybrids with in-built mechanisms to ward off diseases and insect-pests.

Maize inbred lines represent a fundamental resource for studies in genetics and breeding. While maize inbreds are used extensively in hybrid production, they have also been a critical resource for diverse genetic studies including the development of linkage maps, QTL mapping, molecular evolution, developmental genetics, physiological genetics, phenotype-genotype association analyses, estimation of Linkage Disequilibrium, etc (Liu *et al.*, 2003). As mentioned, inbred lines are the key components of inbred-hybrid technology and it's *per se* performance is the most important factor governing the adoptability of the hybrids (Dass *et al.*, 2012; Kumar *et al.*, 2012). Hence, of a large number of lines that are developed in any breeding programme and evaluated over the environments (years and seasons) only the top performing ones end up as parentals in hybrid technology. Many lines which otherwise possess several desirable traits remain either as the backup stock with the breeders or are recycled further and may even be lost (Kaul *et al.*, 2012; Rakshit *et al.*, 2008).

Development of germplasm is a cost-intensive, time- consuming and long process which may take years before a final product may be identified for cultivation. In certain situations the variety may not be identified at all. In order to motivate the breeders so that cultivar development goes on unhampered, a system has been developed and implemented, in India, whereby a breeder can opt for soft protection of the breeding material possessing unique combination of traits. The breeding material may be inbreds which may or may not be the parental lines of the released hybrids; genetic stocks as source/s of tolerance to desirable traits in breeding programmes; breeding/mapping populations, etc. A committee of experts called Plant Germplasm Registration Committee (PGRC) at ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR), New Delhi scrutinizes each proposal minutely drawing comparisons between the performances of new proposed material/line/s with already known material/lines in public domain. The approved proposals are granted protection for a period of 15 years. Each registered material is allotted two sets of numbers, a) Indian National Germplasm Registration (INGR) number and b) Indigenous Collection (IC) number. Through this process, since 2003, an effort has been made in maize to conserve the precious, useful germplasm, enable its sharing and exchange and also give due credit to its developers (Tyagi and Kak, 2012).It has been seen that the utility of conserved germplasm depends upon the availability of information about its usefulness in breeding programmes. In this manuscript, an overview of registered plant genetic resources in maize has been presented with an objective to identify potential germplasm with its unique traits available in public domain for exchange and research purposes. An attempt has also been made to identify the future germplasm requirements in Indian public breeding programmes.

Biochemistry of maize kernels

The typical mature kernel as a whole is composed of 70-75% starch, 8-10% protein and 4-5% oil. However, there are large differences in the relative concentrations of these components between different parts of the kernel. The two major structures of the kernel are the endosperm and the germ (embryo), constituting about 80% and 10% of the mature kernel dry weight, respectively. The endosperm is largely starch while the germ contains high levels of oil and protein. These differences become a significant consideration when maize is processed for consumption. On an average, maize, contains 14.9 % moisture, 3.6 % fat, 2.7 % fibre, 66.2 % other carbohydrates and 1.5% minerals (Gupta *et al.*, 2009).The kernel protein is made up of five different fractions, viz. albumin 7 %, globulin 5 %, non-protein nitrogen 6 %, prolamine 60 % and glutelin 25% and the left-over 5 % is residual nitrogen. Because zeins or prolamines are devoid of lysine and tryptophan, hence conventional maize is deficient in these two essential amino acids and also has imbalanced leucine to isoleucine ratio which affects niacin biosynthesis.

Quality protein and biofortified maize

The breeding of Quality Protein Maize (QPM) with enhanced nutritional profile (doubled concentration of lysine and tryptophan in mature kernels) is one of the most significant developments to strengthen agriculture-nutrition linkage (Vasal, 2000). Quality Protein Maize (QPM) is an improved version of maize which contains higher amount of lysine and tryptophan with lower amount of leucine and isoleucine in the endosperm than those contained in conventional i.e. normal maize (Prasana *et al.,* 2001). Such balanced combination of amino acids in the endosperm results into its higher biological value ensuring more availability of protein to human and animals than normal maize. In addition to its nutritional importance, maize also represents one of the most important sources of carotenoids as well – the feature that enables the crop for biofortification (Kuhnen *et al.,* 2011; Vallabhaneni *et al.,* 2009).

Maize types

Maize can be classified based on: (1) endosperm and kernel constitution; (2) kernel colour; (3) maturity; (4) use. Economically, the most important types of maize are grown for grain or fodder and silage production. However, in the tropical countries of Latin America (LA), sub-Saharan Africa (SSA) and South Asia (SA), grain is primarily grown for human consumption. The physical appearance of kernel type is determined by its pattern of endosperm composition as well as quantity and quality of endosperm. Hence, maize is classified into following types:

Dent corn (*Zea mays var indentata)*:- This is the most common type grown in USA. The depression or dent in the corn of the seed is the result of rapid drying and shrinkage of the soft starch.

Flint corn (*Zea mays var indurata)*:- The endosperm of kernel is soft and starchy in the centre and completely enclosed by a very hard outer layer. The kernel is rounded on the top. Flints are widely grown in Europe, Central/ South America and Asia including India. Popcorn (*Zea mays var everta)*:- The size of kernels is small but the endosperm is very hard. When the kernels are heated, the pressure built- up within it suddenly results in an explosion and the cotyledon pops out.

Flour corn (*Zea mays var amylacea)*:- Mainly grown in USA and parts of Africa, it possesses a soft endosperm. Kernels are soft and though all coloured types are grown but white and blue are the most common. They are like fruit kernels in shape.

Sweet corn *(Zea mays var Saccharata)*:- The sugar makes the major component of the endosperm that results in sweet taste of the kernels before they attain the maturity and subsequently, the kernels become wrinkled. The cobs are picked up green for canning and table purposes.

Waxy corn *(Zea mays var ceratina):-* The endosperm of the kernel when cut or broken gives a waxy appearance. It produces the starch similar to tapioca starch for making adhesive for articles.

Pod corn *(Zea mays var tunicata)*:- Each kernel is enclosed in a pod. It is a primitive type of corn.

In India, the crop improvement programmes target the development of yellow flints as well as dents. Of late, latter has been targeted much more because of its amenability in industrial processing. Besides kernel texture, the breeding programmes exploit the variability that exists for kernel colour (brown, red, purple and blue, yellow, orange, orange-yellow and white). However, the cultivars with yellow / yellow-orange/ orange kernels are generally preferred as poultry feed whereas white is the preferred kernel colour for food uses.

Trends in registration

In general, no clear-cut trend is visible in registration of maize genetic resources at NBPGR, New Delhi. Though the process of granting protection began in 1997, but the lack of awareness among the breeders remained a major hurdle in proposing germplasm for registration (Tyagi and Kak, 2012). Initially a couple of All India Coordinated Research Project on Maize [AICRP (M)] centres came forward with the proposals and later many other centres also began to evince keen interest in getting the precious germplasm registered at NBPGR. Eventually since then, 103 unique genetic resources that emanated from public breeding programmes have been registered over the last 15 years. The year-wise information on number of registrations in maize is given in Figure 1. As is evident from the graph,78.6% i.e. 81 unique germplasms were registered during the five years, viz. 2004, 2008, 2009, 2010 and 2011, while no germplasm was registered during 2005, 2013, 2015 and 2016,respectively. The erratic trend indicates that emphasis needs to be given on creating more and more awareness on beneficial sides of germplasm registration especially keeping in mind the lengthy process of genetic enhancement in maize.

The information about the contribution of different AICRP (M) centres including IIMR (formerly DMR) and NBPGR in getting potential germplasm registered at ICAR-NBPGR, New Delhi is given in Table 1 (Figure 2). Of the total germplasm registered, nearly 64% belong equally to the AICRP (M) centre located at CCSHAU Uchani Karnal and ICAR-IIMR (and formerly DMR), respectively. The registered germplasm comprised the useful inbred lines bred at these locations. The pools / populations emanating from the breeding programmes at the AICRP (M) centres of formerly ANGRAU (now PJSTAU), Hyderabad and PAU Ludhiana, too, have been registered. In maize, one genetic stock (with multi-cob trait) developed by Regional Station, NBPGR, has been registered in 2014.

Based on the study of an assessment of availability of registered genetic resources in different categories of maize, it could be seen that 93.2% have been the inbred lines 63.2% of which comprise normal maize (NM) types with rest being QPM followed by specialty corns (SCs) and others (Table 2). The NM types are represented by 51.5% Normal Yellow (NY) and 9.7% Normal white (NW) lines based on kernel colour. The 10 lines, namely HKI 1347-4LT, HKI 1332, HKI 1352-5-8-9, HKI 1354, HKI 322, HKI 139-2, HKI 1348-2, HKI 1341, HKI 1344 and HKI 1342 possess white kernel colour and were developed by AICRPM centre located at CCSHAU Uchani Karnal. The data further displays that 18 QPM lines enriched with lysine and tryptophan and 15 SCs comprising eight sweet corn (Sc), three pop corn (Pc) and four high oil (Ho), respectively, have been registered. These lines originated from CCSHAU Uchani Karnal and DMR New Delhi (now IIMR Ludhiana).The other genetic resources of maize viz. pools/populations (six) have been registered during the initial phase of maize registration. These resources have been utilized in hybrid breeding programme for the extraction of inbred lines at select centres namely PJTSAU Hyderabad and PAU Ludhiana. The information on various categories of maize germplasm registered at NBPGR, New Delhi has been given in Figure 3 A and B.

Unique traits of registered genetic resources

The importance of registered germplasm in supplementing the efforts of breeders lies in their unique combination of traits. Many lines may be used as donors for resistance to diseases and insect-pests while some may augment the efforts of quality breeding in maize and eventually lead to its enhanced industrial applications. Hence, it became pertinent to carefully assess the traits of the registered germplasm. The analysis revealed the following details:

Most of the inbred lines emanating from breeding programmes at different AICRP (M) centres possessed a combination of quantitative traits, tolerance to biotic / abiotic stresses and biochemical quality. A perusal of the traits indicated that mostly inbred lines that possess unique characteristics viz. agro-morphology, phenology and yield-components; pigmentation, protein quality / quantity, %TSS, poppiness and oil, etc have been considered for the purpose of granting registration. The other traits included resistance to biotic (diseases and insect-pests) and tolerance to abiotic (drought, water logging, cold, etc) stresses. In a few cases, breeding value of the lines, too, has been considered for registration.

The various combinations of the traits for which several inbred lines were registered included plant morphology like height, tassel shape/ size, ear shape/ size, leaf width, time of anthesis/ silking and crop maturity, foliage pigmentation and kernel characteristics (colour, texture and test weight), etc. On the basis of the analysis, it was found that 28 lines have been registered for their maturity attributes.

Of these, nine are early, 11 medium and eight late, respectively. Only one line HKI 209 developed by AICRP (M) centre Uchani Karnal has the unique feature of protogyny a condition under which female flowers emerge earlier than male. Based on plant height, one dwarf (BML-5) and two tall (HKI-327T and BML-8) lines were granted protection. The registered germplasm also included lines with long ears, viz. BML-3, HKI-1354 and HKI-326; prolific rabbit ears (BML-2) ; conical ears (BML-8); sorghum panicle shaped tassel (BML-11); large tassel (BML-22); erect plant type (HKI-1105, HKI 1332); etc. Likewise, potential lines with bold seed (high test weight) yellow or white in colour were also included e.g. V373, HKI 1342, HKI-1341, HKI 1126, HKI-1105, etc. Several lines were registered based on presence / absence of pigmentation e.g. BML-14 was granted registration because of its completely green tassel; BML-20 showed extra-green stem whereas HKI-287L, HKI-139, HKI-586, HKI-1341, etc possessed dark green leaves besides other traits. Such lines may be used in mapping programmes to trace / identify desirable segregants based on pigmentation.

An attribute of great significance in hybrid development is long pollen shedding duration. Such lines are used as pollinators in hybrid seed production in maize. Many lines namely HKI-47, HKI1040-4, HKI-1040-7, HKI-1348-2, HKI-1352-5-8-9, BML-14, etc displayed extended pollen shedding duration and are considered good sources of tassel traits for the development of single cross hybrids. As far as seed productivity is concerned, many promising lines with superior *per se* performance e.g. BML-3, HKI-288-2, HKI-1126, HKI -1347-4LT (1+2+3), DMR -7, DMR-15, DMR-16, DMR-17, etc have been developed and registered.

As many as 27 lines possessed good general combining ability (GCA).Most of these belonged to AICRP(M) centres at CCSHAU Uchani Karnal and PJTSAU, Hyderabad, with a few from VPKAS Almora and IIMR Ludhiana (DMR New Delhi), respectively. Some of the promising lines of NM as well as QPM are as follows: V-373, BML-2, BML-3, BML-5, BML-7, BML -15, BML-20, HKI 139, HKI 1105, HKI 1348-2, HKI 1354, HKI 170(1+2), HKI 164-7-6, HKI1040-5, etc.

Fig.1 Trends in registration of maize genetic resources in India (2003-2017)

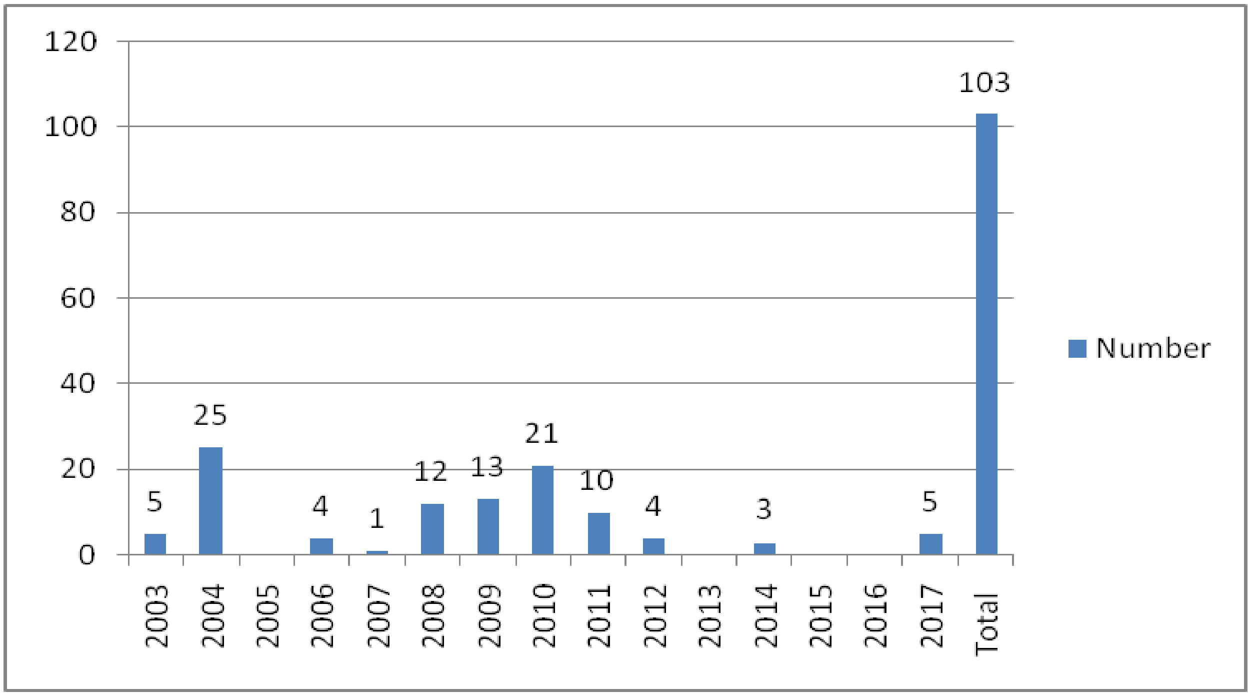

Fig.2 Contribution of different AICRP (M) Centres including IIMR and NBPGR in registration of promising germplasm in maize

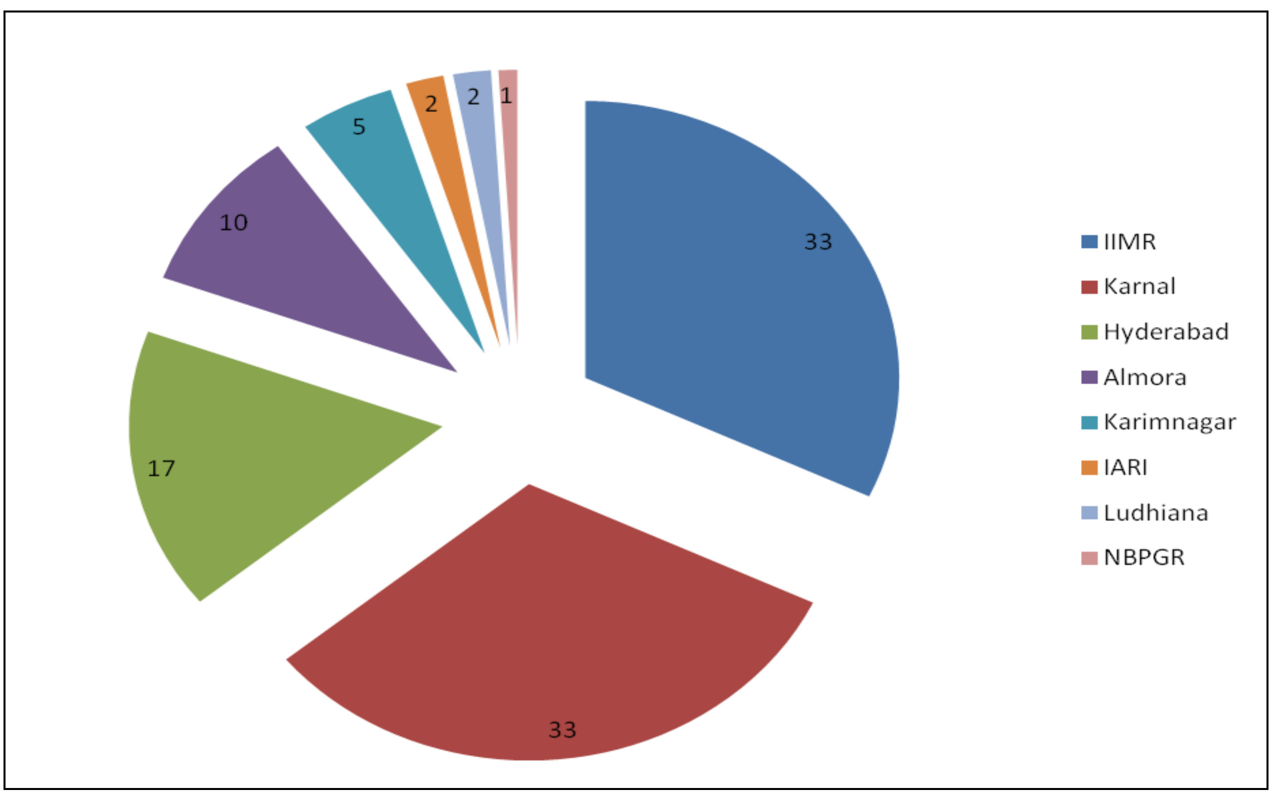

Fig.3 Category-wise information about A) lines and B) other material comprising pools / populations/ GS registered at NBPGR

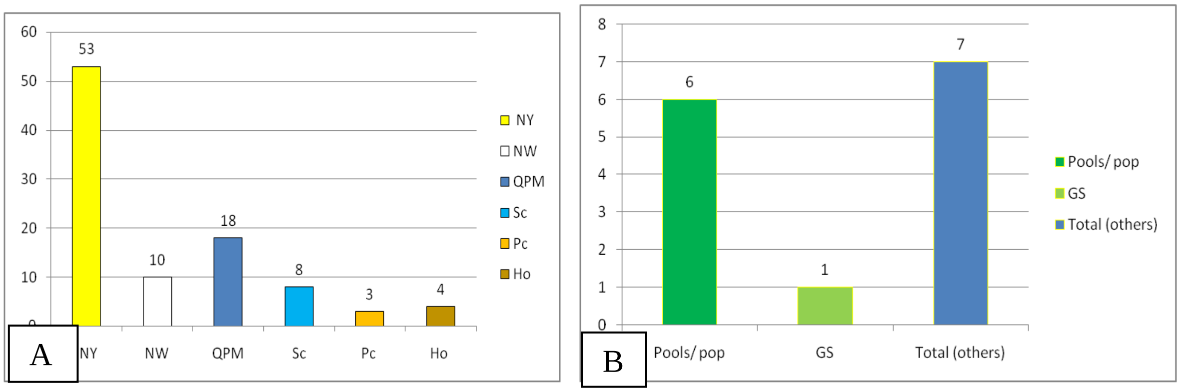

Table.1 AICRP (M) centre-wise unique germplasm resources registered at ICAR-NBPGR, New Delhi

AICRP(M) centre	Inbred lines	Pools/populations	GS	Total	% contribution
CCS HAU, Uchani Karnal	33	-	-	33	32.0
ANGRAU, Hyderabad	13	4	-	17	16.6
VPKAS, Almora	10	-	-	10	9.8
ANGRAU, Karim nagar	5	-	-	5	4.9
IARI, New Delhi	2	-	-	2	1.9
PAU,Ludhiana	-	2	-	2	1.9
NBPGR, New Delhi	-	-	1	1	0.9
IIMR, Ludhiana	33	-	-	33	32.0
Total	96	6	1	103	100.0

Table.2 Information on different categories of registered maize genetic resources in India

Category	Number	Per cent (%)
Inbred lines	**96**	**93.2**
Normal maize (NM)	63	61.2
Normal Yellow (NY)	53	51.5
Normal White (NW)	10	9.7
QPM	18	17.5
Specialty corns (SCs)	15	14.6
Sweet corn (Sc)	8	7.8
Pop corn (Pc)	3	2.9
High oil corn (Ho)	4	3.9
Others	**7**	**6.8**
Pools/populations	6	5.8
Genetic stocks	1	0.9
Total registered germplasm	**103**	

Source: Kaul *et al.*, 2012; Kaul *et al.*, 2017; Rakshit *et al.*, 2008

Table.3 List of potential inbred lines bred at DMR, New Delhi (now IIMR Ludhiana) and their unique traits besides other information

S.No.	Inbred line	INGR#	IC #	Source germplasm	Unique traits	Period of protection
NM						
1	**DML-339**	17022	0612721	NZBOPH (12)-1-2-1-2-2-1	Source of resistance to Charcoal Rot (CR) in normal maize genetic background	2017-32
2	**IML-PFSR-R3**	17024	0593934	JCY3-7	Resistance to PFSR, TLB, MLB, Stiff and stay green, high oil content > 5.0 (5.53%)	2017-32
3	**DMRE-63**	14014	0594373	WNZPBTL	Source of tolerance to pink borer	2014-2029
4	**DMRE-9**	11094	0589141	WNZPBTL-3	Source of resistance to pink borer	2011-2026
5	**DMRE-57**	11095	0589142	WNZPBTL-6	Source of resistance to pink borer	2011-2026
6	**DMR-PFSR-1**	11041	0590094	SW 93D-313-23-Pop-49-S4	Resistance to PFSR	2011-2026
7	**DMR-PFSR-9**	11042	0590095	JCY3-7-1-2-1	Resistance to PFSR with stiff, strong stalk, stay green	2011-2026
8	**DMR-7**	10077	0584583	WNZPBTL-2	Flint, productive, resistant to pink borer	2010-2025
9	**DMR-15**	10078	0584584	NC 262 B-1	Flint, productive, good combiner, attractive grain colour, temperate origin	2010-2025
10	**DMR-16**	10079	0584585	NC 390	Flint, productive, good combiner, long cob, attractive grain colour, temperate origin	2010-2025
11	**DMR-17**	10080	0584586	NC 418	Flint, productive, good combiner, attractive grain colour, temperate origin	2010-2025
QPM						
12	**DQL 2105-1**	17013	0621103	HQPM-7	Source of resistance to Maydis Leaf Blight (MLB) and Turcicum Leaf Blight (TLB)	2017-32
13	**DQL 2048**	17014	0621104	HQPM-1	Source of resistance to Maydis Leaf Blight (MLB) and Turcicum Leaf Blight (TLB)	2017-32

14	**DQL 1019**	17023	IC0612704	HQPM-1	Source of resistance to Charcoal Rot (CR)	2017-32
15	**DMRQPM- 58**	14012	0594368	Shakti-1	Early maturity, tryptophan 0.66% in protein	2014-2029
16	**DMRQPM(03)-124**	14013	0594271	Shakti-1	Medium maturity, tryptophan 0.67% in protein	2014-2029
17	**DMRQPM-103**	13034	0594370	CLQRCY41	QPM line, high tryptophan, early	2013-2028
18	**DMRQPM-102**	13075	0594369	CLQRCY30	QPM line, high tryptophan, medium	2013-2028
19	**DMRQPM-107**	10084	0584590	CLQRCY47 B-B-	QPM line, high tryptophan (0.77%), medium, yellow, flint, good combining ability and thin cob	2010-2025
Sc						
20	**DMS-201**	10088	0584594	CP Golden Sweet 3	Sweet corn line, yellow, shrunken, high sugar	2010-2025
21	**DMSC-1**	10086	0584592	Mus Madhu	Sweet corn line, yellow, shrunken, high sugar	2010-2025
22	**DMSC-6**	10087	0584593	Mus Madhu	Sweet corn line, yellow, shrunken, high sugar	2010-2025
23	**DMS-203**	10089	0584595	NSS2W9301A (*sh2sh2*) x Sweet corn	Sweet corn line, yellow, shrunken, high sugar	2010-2025
24	**WSC-1**	10091	0584591	Win orange sweet corn	Sweet corn line, yellow, shrunken, high sugar	2010-2025
25	**DMS- 206**	10090	0584596	WSCI x Mus Madhu	Sweet corn line, yellow, shrunken, high sugar	2010-2025
26	**DMS-207**	10091	0584597	Cuba 378	Sweet corn line, yellow, shrunken, high sugar	2010-2025
27	**DMS-208**	10092	0584598	Cuba 379	Sweet corn line, yellow, shrunken, high sugar	2010-2025
Pc						
28	**DPcl-10**	11096	0589143	Winpop-8	Pop corn line, high popping (100%), and high protein (11%)	2011-2026
Ho						
29	**DMRHO-57**	11090	0589137	Tempx Trop(H0)QPM-B-B-B-57-B-B	Late maturity, oil 6.34%	2011-2026

Note: Any query on seed-related issue may be addressed to the Director, ICAR-NBPGR, New Delhi-110 012

Table.4 DUS descriptors in maize and crop stages of recording with notes and scores

Sr. No	Characters	Stage Code	State	Note	Recording at
1.	Leaf: angle between blade and Stem (on leaf just above upper ear)	61	Small (<45^0) Wide (>45^0)	3 7	Beginning of anthesis
2.	Leaf attitude of blade (on leaf just above upper ear)	61	Straight Drooping	1 9	Beginning of anthesis
3.	Stem: anthocyanin colouration of brace roots	65-75	Absent Present	1 9	Anthesis halfway-Medium milk
4.	Tassel: time of anthesis (on middle third of main axis, 50% of plants)	65	Very early (<45 days) Early (45-50 days) Medium (50-55 days) Late (>55 days)	1 3 5 7	Anthesis halfway
5.	Tassel: anthocyanin colouration at base of glumes (in middle third of main axis)	65	Absent Present	1 9	Anthesis halfway
6.	Tassel: anthocyanin colouration of glumes excluding base (in middle third of main axis)	65	Absent Present	1 9	Anthesis halfway
7.	Tassel: anthocyanin colouration of Anthers (in middle third of main axis on fresh anthers)	65	Absent Present	1 9	Anthesis halfway
8.	Tassel: density of spikelets (in middle third of main axis on fresh anthers)	65	Sparse Dense	3 7	Anthesis halfway
9.	Tassel: angle between main axis and lateral branches (in lower third of tassel)	65	Narrow (<45^0) wide (>45^0)	3 7	Anthesis halfway
10.	Tassel: attitude of lateral branches (in lower third of tassel)	65	Straight Curved Strongly curved	1 5 9	Anthesis halfway
11.	Ear: time of silk emergence (50% plants)	65	Very early (<48 days) Early (48-53 days) Medium (53-58 days) Late (>58 days)	1 3 5 7	Anthesis halfway
12.	Ear: anthocyanin colouration of silks (on day of emergence)	65	Absent Present	1 9	Anthesis halfway
13.	Leaf: anthocyanin colouration of sheath (below the ear)	71	Absent Present	1 9	Caryopsis watery ripe
14.	Tassel: length of main axis above lowest side branch	71	Short (<20 cm) Medium(20-30) Long (>30cm)	3 5 7	Caryopsis watery ripe
15.	Inbred lines only plant length (up to flag leaf)	75	Short (<120cm) Medium (120-150cm) Long (>150cm)	3 5 7	Medium milk
16.	Plant: ear placement	75	Low Medium High	3 5 7	Medium milk
17.	Leaf: width of blade (leaf of upper ear)	75	Narrow (<10cm) Medium (10-15cm) Broad (>15cm)	3 5	Medium milk

				7	
18.	Ear: length (without husk)	92	Short (<10cm) Medium(10-15cm) Long (>15cm)	3 5 7	Caryopsis hard (can no longer be dented by thumbnail)
19.	Ear: diameter (in middle)	92	Small (<4cm) Medium(4-5cm) Large (>5cm)	3 5 7	Caryopsis hard (can no longer be dented by thumbnail)
20.	Ear: shape	92	Conical Conico-cylindrical cylindrical	1 2 3	Caryopsis hard (can no longer be dented by thumbnail)
21.	Ear: number of rows of grains	92	Few (<8) Medium (10-12) Many (14)	3 5 7	Caryopsis hard (can no longer be dented by thumbnail)
22.	Ear: type of grain (in middle third of ear)	92	Flint Semi -dent / semi- flint Dent	1 2 3	Caryopsis hard (can no longer be dented by thumbnail)
23.	Ear: colour of top of grain	92	White White with cap Yellow yellow with cap orange red others	1 2 3 4 5 6 7	Caryopsis hard (can no longer be dented by thumbnail)
24.	Ear: colouration of glumes of cob	93	White Light purple Dark purple	1 2 3	Caryopsis loosening daytime
25.	Kernel row arrangement	93	Straight Spiral Irregular	1 2 3	Caryopsis loosening daytime
26.	Kernel: Poppinesss*		Absent Present	1 9	
27.	Kernel: Sweetness*		Absent Present	1 9	
28.	Kernel: Waxiness*		Absent Present	1 9	
29.	Kernel: Opaqueness*		Absent Present	1 9	
30.	Grain shape	93	Shrunken Round Indented Toothed Pointed	1 2 3 4 5	Caryopsis loosening daytime
31.	1000 Kernel weight	93	Very small (<100g) Small (100-200g) Medium (200-300g) Large (>300g)	1 3 5 **7**	Caryopsis loosening daytime

Source: Kaul *et al.*, 2012

*presently no guidelines available to record these descriptors as per PPVFRAct, 2001; the breeders are free to use the standard procedures

Biotic /abiotic stress tolerance

There are the lines of NM as well as QPM which possess several traits of importance in maize breeding and genetics. Most of the lines like HKI 139, HKI 1025, HKI1348-2, HKI1344, HKI 1126, DQL 1019, DML 339, DQL 2105-1, DQL 2048, DMR E9, DMR E57, DMR7, BML 3, BML 5 BML7, etc are good source/s of resistance to biotic stresses, e.g. Maydis leaf blight (MLB), Turcicum leaf blight (TLB), common rust, post-flowering stalk rots (PFSR), charcoal rot (CR), pink borer, etc.

Many of these lines have productive ears, attractive grain colour and enhanced nutritional attributes as well. The breeding programme at DMR/IIMR resulted in the development of lines with resistance to pink borer which affects Rabi maize. Based on the mean Leaf injury rating (LIR) of $\leq$ 2.0, several lines were identified as resistant/ tolerant out of which lines, viz. DMRE 57, DMR-7, DMRE-9, and DMRE-27 were proposed and approved for registration.

In India, maize productivity is severely affected by certain abiotic constraints faced during the main Kharif cropping season. Hence, the breeding programmes have been effected under which tolerant germplasm is being evolved and shared amongst the breeders. Drought and excess soil moisture (ESM) or water logging remain serious impediments which hamper the full exploitation of hybrid / inbred potential. The drought tolerant lines bred by AICRP (M) centres at PJTSAU Karim nagar, viz. KDTML-82, KDTML- 19 and KDTML-66 have been registered. The pattern of monsoon rains is erratic with long spells of dryness followed by incessant rains. So far, only two lines namely BML-2 and BML-15 have been granted registration based on their performance under water logging stress. However, one line, KML-29 has been registered as it possesses both drought as well as ESM stress tolerance.

There are many secondary traits that can lead to a more robust crop under moisture limited conditions, but synchrony between male and female flowering time is particularly important. This synchrony is called the Anthesis Silking Interval (ASI). Some lines possess a small Anthesis–silking interval (ASI) –a parameter which enables lines to withstand moisture stress –a feature of importance in hybrid breeding programme. These are DMRQPM102, DMRQPM103 and DML 339, respectively. Likewise, stay green is a post flowering dehydration tolerance mechanism. A well sustained source capacity is a key factor to maximize yield potential during both vegetative and reproductive phases, particularly under source-limiting conditions that commonly characterize drought-stressed crops. Delaying leaf senescence maintains transpiration and increases cumulative photosynthesis over the crop life cycle (Vadez *et al.,* 2011a b). The traits monitored most frequently to obtain indirect estimates of photosynthetic potential are chlorophyll concentration, stay-green and delayed senescence, which are interconnected (Shukla *et al.*, 2004). Post-flowering drought causes leaf senescence and reduced seed weight. Leaf senescence reflects a loss of chlorophyll which reduces photosynthesis rate. The inbred lines / varieties possessing the stay green trait therefore, tend to remain green for longer period. At cell level they maintain the integrity of chloroplast proteins as well (Borell *et al.*, 2001). Only two lines namely HKI335 and IMLPFSR (R3) with stay green as one of the potential traits have been registered.

As far as germplasm other than inbred lines is concerned, during the initial phases of hybrid breeding in India, efforts at PAU Ludhiana culminated in the breeding of heterotic pools (MS Pool C4 and Tux Pool C4) which were utilized later in extracting inbred lines. During this period several populations, too were bred (at ANGRAU, Hyderabad) mainly as source/s of resistance to PFSR (BPPTI 32, BPPTI34, BPPTI 35, BPPTI 37). With the popularization of inbred-hybrid technology in India, the utilization of genetically improved germplasm, viz. commercial hybrids, trait-specific populations, CIMMYT Maize Lines (CMLs/ CLs/CLQs), etc gained ascendance (Dass *et al.,* 2012). Many exotic lines like CML 9, CML164, CML 170, CML327, CLQRCY-30, CLQRCY41; exotic hybrids viz. cargill665-1, CG633, BC-318, ET38146x38147; indigenously bred hybrids like HQPM1, HQPM 7,etc; trait specific populations namely NZBOPH -12, WNZPBTL-9, WNZPBT-6,WNZPBTL-3, JCY 3-7, SW93D-313-23 Pop49S4, Talar, ShdER-6, Temp x tropical HO QPMB-B-B-57-B, etc have been effectively utilized as sources in line development initiatives at certain AICRP(M) centres including DMR/IIMR.

QPM

In India, a strong breeding programme at select centres (CCSHAU, Uchani Karnal, VPKAS Almora, RPCAU Dholi, IIMR/ DMR Ludhiana/ New Delhi) has been taken up to address the issues of malnutrition among the poor masses. Scores of nutritionally enriched lines have been developed at these centres which have been used in hybrid breeding. Some of the promising QPM lines with higher levels of tryptophan (≥0.6%) in combination with good agronomic base multiple disease resistance and kernel characteristics are as follows: VQL-1, VQL-2, VQL-3, VQL-5, VQL-30, HKI -164-7-6, DMRQPM58, DMRQPM102, DMRQPM103, DMRQPM107, DMRQPM03-124, DQL2105-1, DQL2048, DQL1019,etc.

Specialty corns (SCs)

Maize breeding activities and priorities have changed and diversified with the development of India’s economy over the last few decades. Maize suitable for industrial application entails looking for special traits e.g. sugar, poppiness oil, starch, etc and utilizing relevant germplasm in targeted breeding. The cultivation of such products have the potential for crop diversification, livelihood security and raising maize - based farm incomes especially in peri-urban context. The breeding programmes resulted in the development of many lines of sweet corn, popcorn and high oil. Such lines have special traits like high sugar (>6.0% in mature kernels; ≥15% TSS which is recorded in immature kernels by 18-21 days after pollination) in Sc, poppiness and high popping volume/ popping expansion in Pc and high oil (>6.0% in mature kernels) in Ho, respectively. Some of the potential sweet corn lines with high %TSS are WSCI, DMSC-1, DMSC-6, DMS-201, DMS-203, DMS-206, DMS-207 and DMS-208; popcorn lines are HKI PC-4B, HKI PCBT-3 and DPcl10; high oil lines are IML-PFSR-R3, DMRHO57, HKI-6 and HKI-1(T), respectively. The vital information about the unique traits, IC number, INGR number, source germplasm and period of protection in respect of inbred lines bred at DMR New Delhi (now IIMR Ludhiana) and registered at NBPGR has been compiled in Table 3.

DUS descriptors in maize

The introduction of IPRs in agriculture is an aspect that has serious implications for development of new varieties, germplasm conservation and its documentation, crop management, etc. In 2001, India responded to the changed international scenario by adopting a *sui generic* system through the enactment of a unique piece of legislation called “The Protection of Plant Varieties and

Farmers' Rights (PPV&FR) Act, 2001". The Act provides for registration of new and extant varieties including inbred lines for a period of 15 years (for agricultural crops like maize) besides documentation and conservation of genetic resources. Under its new category, the varieties need to undergo a two-year testing for Distinctivity, Uniformity and Stability called DUS (at two specific locations) as per notified guidelines. The variety is granted protection if found distinct, uniform and stable, and, possesses at least one novel trait that distinguishes it from the varieties in public domain. The DUS testing in maize is based on recording of 31 DUS-related descriptors (Table 4). Since 2001, recording of DUS descriptors has been made an important activity and the elite germplasm including inbred lines are characterized as per DUS parameters. The process of granting registration depends on the presentation of information on DUS descriptors of proposed material which may facilitate its registration at NBPGR.

Access to germplasm

Crop improvement plays a significant role in sustainable agriculture, food and nutrition security, and helps mitigate adverse effects of climate changes on agricultural production. Hence, exchange of genetic resources is essential for all crop improvement programmes. Germplasm is critical for continued maize breeding activities especially in the wake of climate changes; lack of appropriate germplasm resources is considered as a major bottle neck of hybrid breeding programmes. As can be seen evolving improved cultivars relies on access to suitable parental germplasm. However, gaining access to such germplasm is becoming increasingly politicized and legally controlled, subject to developing international agreements as well as to national legislation. Under Convention on Biological Diversity (CBD), each nation has a sovereign right over its own biodiversity. The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was negotiated as a direct response to the CBD, to facilitate access to crop genetic resources in harmony with the CBD through an efficient mutually agreed multilateral system of access and benefit sharing.

Germplasm requirement for future maize breeding in India

The future of single cross hybrid development mainly depends on the strong inbred base with diverse genetic background. Therefore, genetically improved germplasm will play a significant role in further enhancing the yield potential of SCHs. Hence, in addition to their maintenance and distribution activities, a strong parallel programme should be further strengthened for evaluation of germplasm and pre-breeding activities. In this regard, the breeding centres need to acquire temperate germplasm with dent / semi-dent kernels from Corn Belt of USA as these are considered to have gene/s for high yielding potential. However, temperate germplasm may not grow under sub-tropical Indian conditions and therefore temperate x tropical hybridization i.e. tropicalization of temperate germplasm is the need of the day. Only then, Indian germplasm base may be broadened with useful gene/s. Secondly, productive inbred lines (ex PVP) may be imported from diverse geographic origin (China, USA, EU, etc) as source/s of resistance to various diseases and insect-pests (for which no or little documented sources exist in India) like Banded leaf and sheath blight (BLSB), Downy mildews (DMs), Chaeffer beetle, etc. In order to augment peri-urban agriculture, genetically diverse sweet corn germplasm with super sweets (*sh2*) and sugar enhancer genes (Thailand, Hawai, etc); baby corn suitable germplasm with prolific ears

(Thailand) and popcorn germplasm (USA) may be focused in breeding programmes.

Registered genetic resources in maize offer an opportunity of using trait-specific germplasm in genetic enhancement programmes in the country. Currently, all AICRP (M) centres including IIMR are involved in the development and popularization of inbred-hybrid technology for which access to such precious germplasm and its utilization in appropriate projects play pivotal roles. The report is an attempt in generating the much needed awareness about the registration system in place as well as availability of such unique material in public domain.

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