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Analysis of yield performance and genotype × environment effects on selected maize (*Zea mays*) landrace accessions of India

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ABSTRACT

The study pertains to multi-location phenotypic evaluation of a set of 48 landrace accessions of maize (*Zea mays* L.) in India. The geographical coordinates of the collection sites of these accessions were first mapped, followed by evaluation of yield performance and flowering behaviour at three locations (Almora, Bajaura and Hyderabad) during 2006–07. The study revealed considerable phenotypic diversity among the accessions for grain yield and its components, besides genotype x environment (G × E) interactions. Statistical analyses, including biplot analysis and cluster analysis, demonstrated significant genetic variability among the accessions. Biplot analysis also revealed the potential of some of the landraces to display both location-specific as well as broader adaptability across locations. The study was successful in identifying some highly promising accessions on the basis of their performance for various yield components and flowering behaviour. These include accessions collected from Himachal Pradesh, Madhya Pradesh, Jharkhand, Uttarakhand, Karnataka, Andhra Pradesh, Haryana, Gujarat, Bihar, Orissa and West Bengal. Such accessions could be potentially utilized in developing broad-based gene pools for improving diverse agronomically important traits in maize.

Key words: Biplot, Diversity, G × E, Landrace, Yield components, *Zea mays*

Maize (*Zea mays* L.) is grown in varied environmental conditions both in the tropical and temperate regions. Diverse arrays of maize landraces exist worldwide owing to natural and artificial selections. Landraces in maize are genetically heterogeneous populations that are typically selected by farmers for their adaptation to specific local environments and are understood to differ in agronomic and nutritional characteristics, including prolificacy, biotic and abiotic stress resistance, maturity, nutritive value, etc. They have evolved under subsistence agriculture and are still cultivated by farmers in different regions worldwide, including India. A maize landrace is mostly defined by the farmer in terms of ear characteristics; ear type is usually maintained by the farmers through conservative selection in spite of considerable gene flow (Louette *et al.* 1997, Louette and Smale 2000). Yet, it is relevant to note that only a tiny fraction of this valuable diversity is used in maize breeding programmes around the world (Dowswell *et al*. 1996), indicating that much of this diversity remains to be characterized, evaluated and utilized. For better conservation and utilization of such germplasm, it is important to generate proper agronomic and genetic knowledge (Nass *et al*. 1993).

In India, maize landraces are prevalent in diverse agro-ecologies, extending from the extreme semi-arid to sub-humid and humid regions (Singh 1977, Prasanna and Sharma 2005, Prasanna 2010). These genetic resources occupy significant area in Madhya Pradesh (82%), Uttar Pradesh (42%), and Bihar (45%) during the rainy (*kharif*) season (Joshi *et al*. 2005). Many of these landrace accessions have specific characteristic features, but only a few of them have been utilized in maize improvement programmes (Prasanna and Sharma 2005). Extensive variability in plant, tassel and ear characteristics of local varieties grown by the farmers in the North Eastern Himalayan (NEH) and Northwestern

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Table 1 List of selected maize landrace accessions with passport data and kernel characteristics

Gene Bank No.	Code*	Village	District	State	Elevation (m.a.s.l.)	Kernel Type#
IC 77418	IML 118	Jagadhari	Ambala	Haryana	277	Y/W F
IC 77433	IML 119	Jai Singhpura	Ambala	Haryana	277	Y F
IC 77469	IML 123	Shamli Mundate	Muzaffarnagar	Uttar Pradesh	239	O F
IC 77477	IML 124	Bakshi Khola	Almora	Uttarakhand	1468	W/Y F
IC 77604	IML 133	Akhadra Tonk	Tonk	Rajasthan	303	Y F
IC 77611	IML 134	Jambuda	Junagarh	Gujarat	21	Y/O F
IC 82097	IML 143	Chidiyawsa	Banswara	Rajasthan	243	O F
IC 97997	IML 172	Dharamshala	Hamirpur	Himachal Pradesh	850	O/Y F
IC 108151	IML 185	Nora	Mandi	Himachal Pradesh	1524	O F
IC 199114	IML 288	Ramchandrapur	Bhagalpur	Bihar	48	O F
IC 199124	IML 294	Parham	Munger	Bihar	46	O F
IC 199157	IML 296	Sonka	Darbhanga	Bihar	55	Y/W
IC 251267	IML 297	Paheli Shepti	Bankura	West Bengal	91	O F
IC 283422	IML 321	Bharirwar	Begusarai	Bihar	44	Y F
IC 319791	IML 324	Jharwar	Mandi	Himachal Pradesh	1524	O F
IC 325937	IML 325	Dondachia	Nandurbar	Maharashtra	250	Y/O D
IC 331544	IML 330	Khedarpura	Vaishali	Bihar	54	Y/W F
IC 331594	IML 331	Sanhoula	Gopalganj	Bihar	71	O/Y F
IC 332300	IML 332	Gandhinagar	Khargaon	Madhya Pradesh	240	O F
IC 395739	IML 339	Ramgarh	Panchmahal	Gujarat	128	O D/F
	IML 340	Jaunpur local	Jaunpur	Uttar Pradesh	81	O F
	IML 341	Jhabua local	Jhabua	Madhya Pradesh	397	O F
	IML 342	Dausa local	Dausa	Rajasthan	335	O F
	IML 346	Arabhavi local	Arabhavi	Karnataka	641	Y/W F
IC 262988	IML 404	Behera	Sonbhadra	Uttar Pradesh	280	Y F
IC 263215	IML 405	Gazar	Almora	Uttarakhand	1468	O F
IC 267464	IML 409	Bhusuria	Daltonganj	Jharkhand	426	W/Y F
IC 273246	IML 413	Sundrel	Khargaon	Madhya Pradesh	240	Y F
IC 273281	IML 416	Mohan Katia	Dhar	Madhya Pradesh	505	Y/O F
IC 274642	IML 422	Gada Dongri Kadta	Sagar	Madhya Pradesh	515	O F
IC 279809	IML 426	Naganichhoti	Uttarkashi	Uttarakhand	2621	O/Y F
IC 282536	IML 431	Karimnagar	Palamau	Jharkhand	426	O F
IC 298558	IML 434	Sompur	Sabarkantha	Gujarat	38	O F
IC 309931	IML 436	Lyoagwada	Alwar	Rajasthan	281	O F
IC 332276	IML 452	Baralyakhurd	Indore	Madhya Pradesh	531	Y/W F
IC 333247	IML 454	Jamli	Barawani	Madhya Pradesh	415	O F
IC 337439	IML 459	Ratan pura	Vadodara	Gujarat	43	Y D
IC 342653	IML 462	Jamukhandi	Kodarma	Jharkhand	325	O F
IC 353812	IML 467	Orgoundanurpudur	Thiruvannamalai	Tamil Nadu	481	Y/O F
IC 370494	IML 474	Jhadoli	Sirohi	Rajasthan	471	Y/W F
IC 373213	IML 475	Jatabal	Nabarangpur	Orissa	922	O/Y F
IC 374676	IML 476	Gund	Srinagar	Jammu & Kashmir	1837	O D
IC 385875	IML 480	Sahargaon	Pakaur	Jharkhand	274	O F
IC 397864	IML 485	Kanfara	Una	Himachal Pradesh	561	O F
IC 430635	IML 496	Bhandarugudem	Khammam	Andhra Pradesh	114	O F
IC 436850	IML 498	Pittaguda	Adilabad	Andhra Pradesh	283	O F
	IML 499	Kadanuru	Bangalore Rural	Karnataka	824	Y Pc
	IML 505	Kosipur	Nainital	Uttarakhand	1050	Y F

*Code given by Maize Genetics Unit, IARI, for convenience in analysis and presentation; #Y – Yellow; O – Orange; W – White; F – Flint; D – Dent; Pc – Pop corn; Longitude and latitude data available from the corresponding author on request.

highlands in India was reported (Singh 1977). However, very few systematic studies have been conducted to characterize and evaluate these landraces.

The present study was, therefore, undertaken (i) to evaluate the agronomic performances of selected landrace accessions of India with specific focus on those accessions collected from regions other than North East Himalayan (NEH) regions, and analyze the genotype × environment (G × E) interactions; (ii) to classify the accessions based on their agronomic performance, and identify promising accessions for potential use in breeding programmes.

MATERIALS AND METHODS

A selected set of 48 landrace accessions representing diverse agro-ecologies of the non-NEH region in India, including the tribal hill regions as well as the plains, were selected as experimental material for this study, based on preliminary analyses of available passport data for a large set of non-NEH accessions, under an ICAR National Fellow Project. The accessions were obtained from two sources: (i) National Gene Bank, NBPGR, New Delhi, India; and (ii) some collections made by the Maize Genetics Unit, IARI, New Delhi. Collection sites of the selected landraces used in this study are presented in Table 1.

Phenotypic evaluation of the selected landrace accessions was undertaken at three locations in India: (i) VPKAS Experimental Farm at Hawalbagh, Almora, Uttarakhand [29°36'09.36"N; 79°39'10.00"E; 1234 masl]; (ii) CSKHPKV Regional Research Station, Bajaura, Himachal Pradesh [31°51'00.00"N; 77°09'00.00"E ; 1580 masl]; and (iii) DMR Winter Maize Nursery, Hyderabad, Andhra Pradesh [17°23'23.19"N; 78°31'21.81"E; 427 masl]. The trials at Bajaura and Almora were undertaken during *kharif* (monsoon) season 2006, and at Hyderabad during *rabi* (winter) season 2006-07.

At Bajaura, the trial was conducted in a randomized complete block design with two replicates, including two composite varieties, Pusa Composite 3 (PC3) and Pusa Composite 4 (PC4), as checks. At Almora, the trial was undertaken in an augmented design having eight blocks with the same checks (PC3 and PC4). The trial at Hyderabad was conducted in an augmented design with five checks comprising four composite varieties (PC2, PC3, PC4 and Navjot), and one private-sector hybrid (CP818). The accessions were planted in 4m single-row plots with row-to-row spacing of 0.75m and plant-to-plant spacing of 0.20m. Standard agronomic management practices relevant for specific location were followed. Besides days to 50% anthesis and 50% silking, ear length, ear diameter, number of kernel rows per ear, kernel number per ear row, kernel number per ear and 100-kernel weight were recorded using five randomly selected ears from each plot, excluding border plants. Grain yield was recorded on a per plot basis, after drying the ears to 14% moisture content.

The datasets collected from individual location for various quantitative traits were subjected to statistical analysis. Analysis of variance (ANOVA) was performed for individual location-wise data using PROC GLM and PROC MIXED in SAS (SAS Institute, Version 9.1). Analysis of means for each trait was done using the least square means method. Combined analysis of the data across environments was performed using PROC MIXED in SAS. For analysis of G × E interactions, biplots of the two principal components were computed and analyzed using Site Regression (SREG) model (Parsad *et al.* 2006, Crossa and Cornelius 1997). The biplot analysis was performed to identify the genotypes that showed stable performance across environments as well as to identify genotypes suitable for environment or a subset of environments. The best linear unbiased predictors (BLUP) were obtained for G × E interaction, and the matrix of BLUP was used for site regression analysis. Cluster analysis of the accessions was done using the data obtained for all quantitative traits recorded in the study, using PROC CLUSTER of SAS. Euclidean distances were estimated and the matrix was further analyzed using Ward's method of minimum variance for clustering the accessions.

RESULTS AND DISCUSSION

Understanding the extent and geographic patterns of genetic diversity within germplasm accessions, particularly landraces, is important for effective future collection, development of conservation strategies, and efficient use of these genetic resources (Frankel *et al*. 1995). The significance of phenotypic evaluation of maize landraces was highlighted by studies undertaken in various countries, including Canada (Azar *et al*. 1997), Turkey (Ilarslan *et al*. 2002) and Mexico (Pressoir and Berthaud 2004). Harlan *et al*. (1973) suggested that agronomic and ecological characteristics could influence the genotypic constitution of landraces during domestication, and hence a relation exists between the agro-ecology of the collection region and the morpho-physiological make-up of the landrace.

Analysis of the phenotypic performance of the selected Indian maize landrace accessions at three different locations in India (Almora, Bajaura and Hyderabad) for various yield attributes in the present study revealed the presence of significant genetic variability among the accessions. The summary statistics of the traits recorded on the accessions through multi-location trials are presented in Table 2. In general, the improved (check) varieties outperformed the landraces under all the three environments, but there were notable exceptions; some of the landrace accessions recorded promising performance for specific yield components at some locations or across locations.

Based on the individual location data, grain yield, ear diameter and 100-kernel weight showed significant differences among accessions at all three tested locations (Table 2). At Almora, considerable genetic variability was

Table 2 Summary and statistical significance of traits measured in selected maize accessions at different locations during 2006–07

Trait	Alm		Baj		Hyd		Mean across entries			Standard Deviation			Significance		
	Min	Max	Min	Max	Min	Max	Alm	Baj	Hyd	Alm	Baj	Hyd	Alm	Baj	Hyd
GY	0.16	4.93	0.35	5.72	0.66	9.88	1.63	2.62	4.22	1.15	1.02	2.49	**	**	**
EL	6.3	17.3	7.9	17.6	5.5	19.3	13.23	12.67	12.94	3.08	1.38	2.88	ns	ns	**
ED	8.25	15.9	9.8	14.18	8.5	15.91	11.58	12.15	12.30	0.59	0.32	0.60	**	**	**
KR	9	15.6	9.6	16	8	15.2	12.18	12.62	12.36	1.37	1.26	1.87	ns	**	**
KPR	16	37	15.3	37.6	11.5	39.5	27.95	27.39	28.63	6.73	3.46	6.13	**	ns	**
KN	166.4	515.52	176	527.2	116	531.6	342.87	344.95	374.29	96.89	63.33	98.69	ns	**	**
100 KW	9.46	35.12	11	36.4	7.55	32.32	18.58	19.12	19.15	5.81	4.30	6.52	**	**	**
DA	49	68	54	69	67	74	59.58	60.49	68.31	4.74	3.04	1.66	**	ns	ns
DS	50	71	56	72	67	78	62.01	62.88	70.24	4.97	3.34	3.06	**	ns	ns

Alm: Almora; Baj: Bajaura; Hyd: Hyderabad; **Significant at P = 0.01; ns: non-significant

GY: Grain yield (t/ha); EL: Ear length (cm); ED: Ear diameter (cm); KR: No. of kernel rows per ear; KPR: No. of kernels per ear row; KN: No. of kernels per ear; 100 KW: 100- kernel weight (g); DA: Days to 50% anthesis; DS: Days to 50% silking.

also observed among the accessions for days to 50% anthesis and silking, grain yield, ear diameter, number of kernels per ear row and 100-kernel weight. At Bajaura, grain yield, ear diameter, number of kernel rows/ear, kernel number/ear, 100-kernel weight showed significant differences while at Hyderabad, ear length, ear diameter, number of kernel rows/ear, number of kernels/ear row, kernel number/ear and 100 kernel weight showed high genetic variability among accessions.

Comparison of the days to flowering in the tested accessions at different locations showed that the accessions came to flowering earlier at Almora than at other two locations. Some accessions recorded less than 58 days for flowering at Almora, while none of the accessions came to flowering in less than 67-68 days at Hyderabad. Days to flowering is highly influenced by genetic as well as environmental factors, including photoperiod and temperature. Taking into account the flowering data from both Almora and Bajaura, IML 123, IML 324, IML 404, IML 409, IML 413, IML 462 and IML 467 showed early flowering as compared to the rest of the entries. IML 409 and IML 462 can be considered as extra early flowering accessions.

Analysis of variance (ANOVA) of combined data revealed highly significant effects of locations, genotypes as well as genotype × environment (G × E) interactions for different yield components. Grain yield showed significant location effect, genotypic effect and G × E interaction. Ear length and ear diameter showed non-significant variations over locations, and significant effects of genotypes as well as G × E interaction. The 100-kernel weight showed non-significant effects over locations and significant genotypic variation and G × E interaction. Kernel rows, kernel number/ear row and kernel number/ear showed significant genotypic effect while showing non-significant location and G × E interaction effects.

For further analysis of G × E interactions, biplot analysis was carried out, using the Sites Regression (SREG) model, to discriminate accessions on the basis of performances at specific locations as well as for analyzing the stability of performance across locations for a specific yield component. In this analysis, the accessions are represented as points (labeled with entry number for each accession/entry) and locations are represented by vectors (S_3: Bajaura, S_4: Almora and S_5: Hyderabad). The angle between the point of location of individual accession (treatment vector) and the line for a specific location (location or environment vector) indicates the performance of a specific accession at the respective location. An angle less than 90° or larger than 270° between a treatment vector and an environment vector indicates that the accession had a positive response at that environment. A negative treatment response is indicated if the angle is between 90° and 270°. If an accession falls close to the center of the biplot, it indicates stable performance across all locations (Parsad *et al.* 2006).

The biplot for grain yield (Fig 1) showed that some of the accessions significantly interacted with the individual locations/environments, while some showed stability in performance across the locations. The accessions which interacted with each location were highlighted (circled) in the biplot figures. Based on this analysis, IML 33, IML 480, IML 346 and IML 436 were found to have positive interactions with location Bajaura (S_3), while IML 452, IML 475, IML 185, IML 409, IML 462, IML 325, IML 467 and IML 340 showed an interaction effect with Almora (S_4). Several accessions recorded positive interaction with Hyderabad (S_5). Based on the results of biplot analysis as well as the mean values of various yield attributes, IML 459, IML 505, IML 496, IML 143 and IML 498 could be identified as the most stable and promising accessions for grain yield. The biplots for 100-kernel weight, ear length and ear diameter also showed highly significant G × E interaction. Some of the accessions recorded high G × E interaction, while some

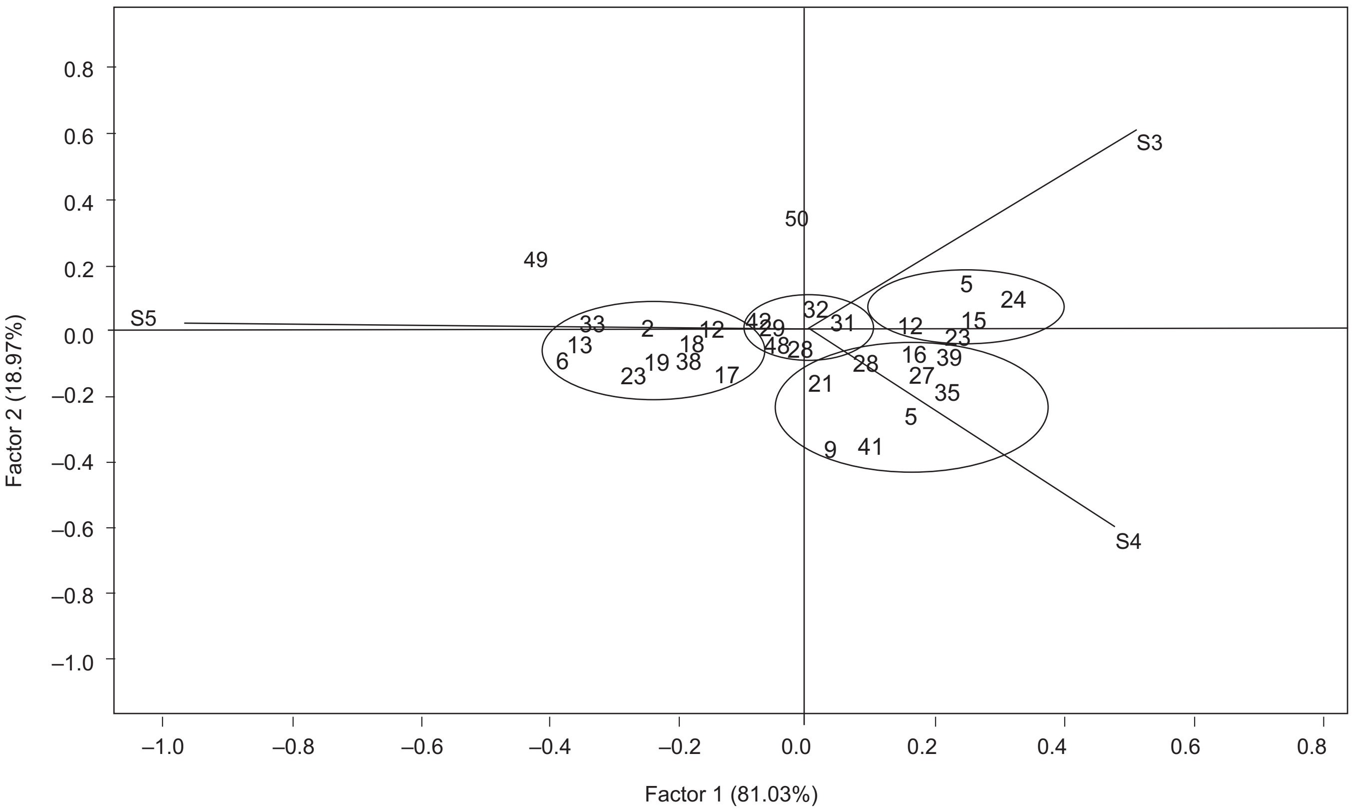

Fig 1 Biplots of grain yield based on analysis of combined data of maize accessions evaluated at three locations in India (S_3: Bajaura; S_4: Almora; S_5: Hyderabad).
1: IML118, 2: IML119, 4: IML124, 5: IML133, 6: IML134, 7: IML143, 9: IML185, 10: IML288, 12: IML296, 13: IML297, 14: IML321, 15: IML324, 16: IML325, 17: IML330, 18: IML331, 19: IML332, 21: IML340, 23: IML342, 24: IML346, 25: IML404, 26: IML405, 27: IML409, 28: IML413, 29: IML416, 31: IML426, 33: IML434, 34: IML436, 35: IML452, 36: IML454, 37: IML459, 38: IML462, 39: IML467, 40: IML474, 41: IML475, 42: IML476, 43: IML480, 44: IML485, 45: IML496, 46: IML498, 47: IML499, 48: IML505, 49: PC3, 50: PC4.

performed well across diverse locations. For instance, IML 133, IML 346, IML 485, IML 413 and IML 467 revealed showed high G × E interactions with location Bajaura for various yield components, whereas IML 452, IML 325, IML 332, IML 340, IML 409 and IML 475 showed interaction with the location Almora, and IML 499, IML 342, IML 331 and IML 498 with the location Hyderabad. In contrast, IML 505 (Uttarakhand), IML 496 (Andhra Pradesh), IML 499 (Karnataka), IML 332 (Madhya Pradesh), IML 459 (Gujarat), IML 452 (Madhya Pradesh) and IML 498 (Andhra Pradesh) showed stable and high performance for the yield components across the locations (Table 3).

The overall performance of the non-NEH landrace accessions was relatively better at Hyderabad as compared to other two phenotyping locations. Apart from grain yield, performances with respect to ear length, ear diameter, number of kernel rows, kernels/ear row, kernel number/ear, and 100-kernel weight revealed not only high diversity among the accessions, but also that some of these accessions could perform either on par or superior to the improved composite (check) varieties. For instance, IML 332 (Madhya Pradesh), IML 324 (Himachal Pradesh) and IML 459 (Gujarat) recorded high grain yields comparable to the check varieties (PC3 and PC4), at all the three test locations. Although the relative contributions of the yield components varied in the accessions analysed, ear length, ear diameter, kernel number/ear, and 100-kernel weight were found to be the main traits involved in determining the grain yield.

The accessions selected for this study represented different agro-ecological zones identified by the All India Coordinated Research Project (Maize). It is interesting to note that some accessions from a specific zone performed well in phenotyping locations that belonged to different zones. For example, at Almora (Zone 1), out of seven accessions which recorded grain yields higher than 3 tonnes/ha, three accessions originated from Zone 5 (Gujarat and Madhya Pradesh), two accessions from Zone 3 (Odisha and Bihar), and two accessions from Zone 1. Similar observations could be drawn with regard to yield performance of specific accessions at other phenotyping locations. These observations

Table 3 Promising accessions identified based on simultaneous consideration of performance for different yield components.

Accession	State of collection	Specific traits*
IML119	Haryana	EL; ED; GY
IML134	Gujarat	EL; KN; GY
IML185	Himachal Pradesh	ED; KN; GY
IML297	West Bengal	KPR; KN; GY
IML324	Himachal Pradesh	EL; GY
IML331	Bihar	100KW
IML332	Madhya Pradesh	KR; GY
IML409	Jharkhand	Extra early flowering
IML431	Jharkhand	100KW; GY
IML452	Madhya Pradesh	KR; KN; GY
IML459	Gujarat	ED; GY
IML462	Jharkhand	Extra early flowering
IML475	Orissa	ED; GY
IML496	Andhra Pradesh	KR; KN
IML498	Andhra Pradesh	EL; ED; KR; KPR; KN
IML499	Karnataka	KPR; KN
IML505	Uttarakhand	KR; KN

*GY, Grain yield, EL, ear length; ED, ear diameter; KR, no. of kernel rows/ear; KPR: no. of kernels/ear row; KN: no. of kernels/ear; 100KW, 100- kernel weight

were reinforced by the results of the biplot analysis which clearly demonstrated that some maize landraces could exhibit both location-specific as well as broader adaptability as regards important yield attributes. Such accessions identified in this study include IML 331 (Bihar), IML 332 (Madhya Pradesh), IML 452 (Madhya Pradesh), IML 459 (Gujarat), IML 475 (Odisha), IML 496 (Andhra Pradesh), IML498 (Andhra Pradesh), IML499 (Karnataka) and IML505 (Uttarakhand). IML 119 (Haryana) and IML 297 (West Bengal) recorded better performance in the plains (Hyderabad), while IML 185 and IML 324 (both from Himachal Pradesh) showed zone-specific performance.

Cluster analysis based on Ward's method of minimum variance led to grouping of the accessions into four clusters (Fig 2). Different members within a cluster were assumed to be more closely related in terms of the traits under consideration. Cluster I comprised majority of accessions (26 out of 41; 63.4%). The mean performance of this cluster was moderate as compared to the other three clusters. Cluster II had 10 accessions (24.4% of the total), characterized mainly by high yield, long ears and high kernel number/ear, and with promising performance across locations for all the tested traits (except days to flowering). Cluster III comprised

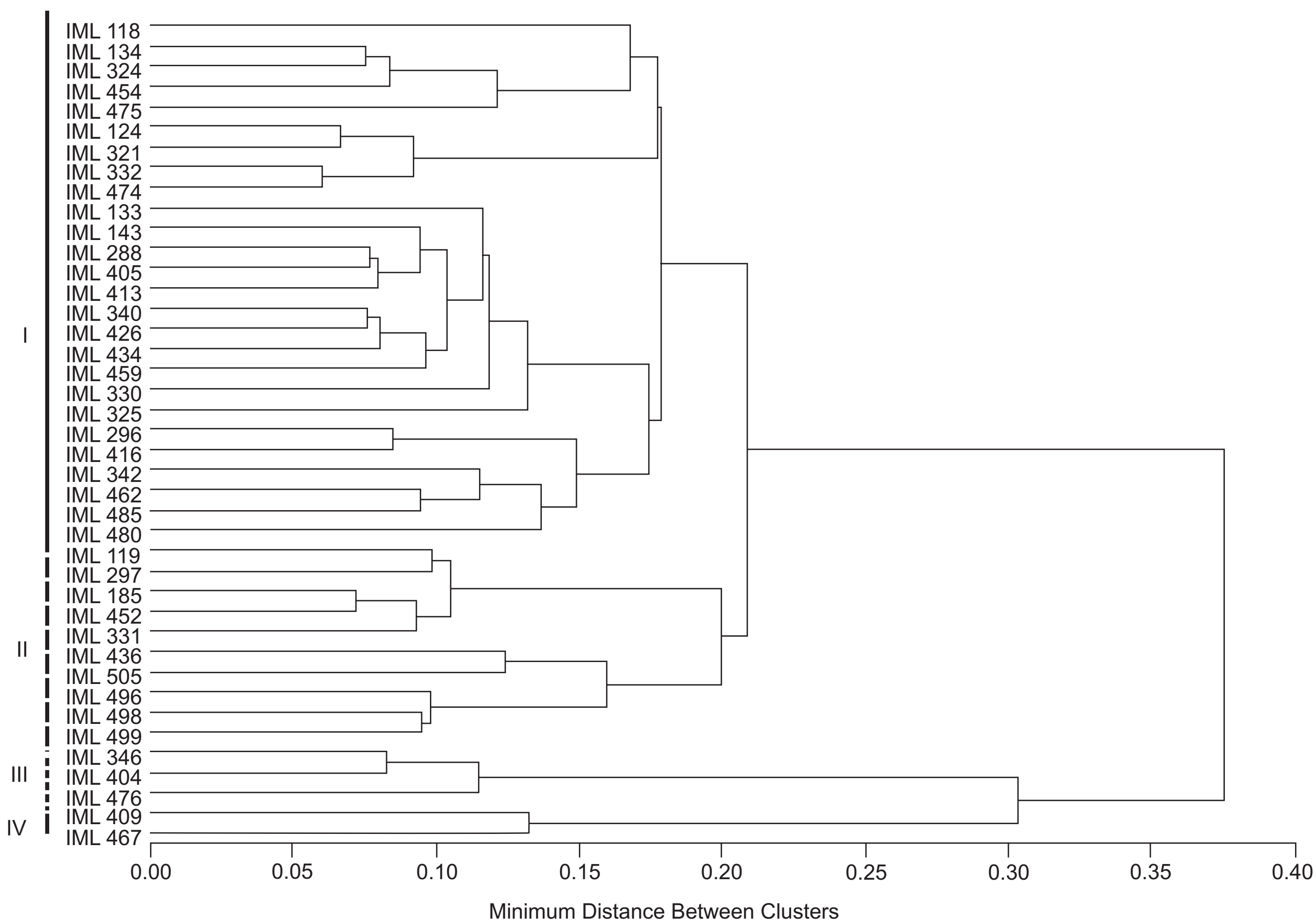

Fig 2 Cluster analysis of maize accessions based on agronomic performance data, using Euclidean distance and Ward's clustering algorithm.

only three accessions (7.3% of the total), characterized by small ear size. Cluster IV comprised only two accessions (IML 409 and IML 476), which were distinctly different from the other clusters, and characterized by low grain yield and extra early flowering, particularly at Almora and Bajaura. The cluster groups did not, however, show any specific correspondence with the geographical sites of collection of the accessions.

In summary, intensive phenotypic evaluation of the selected landrace accessions at three different test locations, followed by statistical analyses (including biplot analysis and cluster analysis), led to identification of some highly promising accessions with location-specific, agro-ecological zone-specific as well as broader performance. Such accessions could be potentially utilized in developing broad-based gene pools for improving diverse agronomically important traits. From the breeding viewpoint, the results obtained in this study could also be potentially used to design a strategy for efficient characterization, evaluation and utilization of a broader set of maize landrace accessions for important target traits in maize breeding programmes in India.

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