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Research Article

Studies on genetic parameters and combining ability in maize for the production of hybrids with low phytic acid

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Abstract
Phytic acid is a major constraint in affecting the nutritional concerns of the people feeding on maize. Being a strong negatively charged chelator, this compound binds all the positively charged minerals like iron and zinc. It also acts as a major storage compound of phosphorous. Thus monogastric animals lacking phytase, fails to absorb these minerals and is considered as a antinutritional factor. This experiment was conducted to identify the potential donors for low phytic acid to produce hybrids with moderate phytic acid content. With this objective a reference set for phytate (2-16 mg/g) formed from a base population was screened. A D^2 analysis in the reference set was done and this classified the genotypes into eight clusters. The genotypes with low phytate were grouped in cluster 4. Highest significant variability was observed for all the traits including phytic acid. Cob weight followed by phytic acid had a highest heritability with high genetic advance as percent of mean indicating the effectiveness of selection for these traits due to the presence of additive gene action. Among the six low phytate lines observed, UMI-113 had lowest phytate content of 2.77 mg/g. These six low phytate genotypes classified in cluster 4 were then selected as testers and were crossed to four elite lines. Among the 24 hybrids produced, three hybrids., UMI 1200 x UMI 1099, UMI 1201 x UMI 1099 and UMI 1210 x UMI 1099 yielded higher than the standard check with medium levels of phytic acid ranging from 10.23-10.46 mg/g. The line UMI-1099 was found be a good general combiner for yield related traits with a negative combining ability for phytic acid. Hence this line could be successfully used in low phytate breeding programs and these identified hybrids could be further used in poultry testing trials for analyzing the bioavailability of nutrients.

Keywords
Diversity, combining ability, phytic acid and variability

Introduction

Maize is widely cultivated throughout the world and has the highest production among all the cereals.With changing global food demands and consumer choices, maize is now becoming the wonder crop for many countries especially in developing countries like India. Maize is also a rich source of nutrients such as carbohydrate, protein, iron, vitamin B, and minerals such as phosphorous, magnesium, manganese, zinc,copper, iron, selenium as well as potassium and calcium. Although maize being a highest yielder bound with nutrients, the phytic acid present in it is a major antinutritional factor (Raboy *et al*.,2000). Phytic acid (myoinositol-1,2,3,4,5,6-hexakisphosphate,InsP6) is a ubiquitous compound present in the embryo and scutellum of maize seeds (O'Dell *et al*.,1972). It is the major storage compound of phosphorous and is synthesized in plants during the seed development. During germination the phytate is degraded by the phytase enzymes to remobilise the phosphorous. As it is negatively charged the phytate precipitates the mineral cations such as zinc, potassium, calcium and magnesium. Maize as a source of food, when fed to the monogastric animals like humans and chickens excretes the phytate along with the mineral bound cations due to lack of phytase enzymes in their digestive tracts. This excretion also leads to eutrophication in the environment (Raboy *et al*.,2000).Also the availability and management of phosphorous in agriculture is challenging as reserves of phosphorous rock are non-renewable. This enforces the efficient utilization of phosphorous. Hence identification of lines with reduced phytate content would help combat the nutritional insecurities in the world. The identification of germplasm lines with low phytate content, followed by crossing low phytate lines to elite lines would help in production of hybrids with reduced phytate content. Most of the low phytate lines are known to have negative pleiotropic effects such as reduced seed set ratio, seedling growth and vigour (Lorenz *et al*.,2007) and thus this study was carried out to identify lines having better combining ability for producing low phytate elite hybrids.

Materials and Methods

A Reference set with 58 genotypes for phytic acid in maize was developed from a base population of 338 inbreds in such a way that it follows normal distribution for phytate content ranging from 2-16 mg/g (Srinivas 2016).Further the formulated reference set was raised, characterised and diversity analysis by MahalanobisD^2 (1936) was carried out to identify the clusters with low phytate content. The identified cluster with low phytate lines were selected anda crossing block was raised with four lines and six testers. The lines comprised of the elite inbreds from Department of Millets,TNAU and the testers were the low phytate accessions selected from the low phytate cluster in the reference set. The F_1's were raised in the year 2016 along with their parental lines, check (CO 6) and sixteen traits viz., days to 50% tasselling and silking, anthesis silking interval, cob placement height, plant height, tassel length, cob length, cob breadth, number of leaves,cob weight, number of rows per cob, number of kernels per row, shelling %, hundred seed weight and seedling vigour index (Abdul Baki and Anderson, 1973)including two biochemical analyses for phytic acid and high inorganic phosphorous were recorded. The statistical analysis for combining ability and standard Heterosis (Falconer,1967) were carried out by Sprague and Tautum (1942). The phytate estimation was carried out with Davies and Reid (1979) and high inorganic phosphorous by Raboy *et al., (*2000). (Table 1.)

Results and Discussion

The hierarchicalcluster analysis classified the genotypes in the reference set based on their similarity and genetic diversity. The 58 genotypes were classified into eight clusters with cluster 2 being the largest with 25 genotypes (Table 2). Out of the eight clusters, the low phytate lines were grouped to the fourth cluster (Table 3). The cluster 4 had the lowest mean value for the phytic acid content. The identified six low phytate genotypes in the cluster 4(Table3) were then selected for hybridization with four elite lines to analyze their combining abilityand to produce hybrids with moderate phytic acid content. The phytic acid content of the selected elite lines were high and ranged from 12.60-13.78 mg/g (Table 4).

The combining ability of the lines and testers for yield including low phytic acid led to the identification of the elite inbreds for these two traits. Among four lines, UMI 1200 and UMI 1210had good general combining ability for yield and yield attributing traits such as cob weight, number of rows per cob and number of kernels per row (Table 5& 6). Within the lines UMI 1210 reported a minimum high level of phytic acid (12.90) with a higher hundred seed weight, seedling vigor index (3359.45) and cob weight (122.20 g). The plant height of this line was 164.45 cm and is found to be the tallest among the inbreds (Table 5 and 6). It had a significant *gca* effect for the traits, single plant yield, cob weight, number of rows per cob, and number of kernels per row.It also had a low anthesis-silking interval of 2.75 days indicating the ability of this genotype to cope up with drought stress (Table 5 & 6).Therefore, utilizing UMI 1210 as one of the female parent in hybridization programs will help in obtaining good hybrids with medium phytic acid content.

Among the six testers, UMI 1099 was found to be superior for most of the traits with significant *gca* effects. It also recorded higher mean values for plant height, seed weight, number of rows per cob, cob weight, seedling vigour index and higher inorganic phosphorous. This tester also had a medium phytate content of 7.10 mg/g(Table 4). Although six testers were taken for the crossing program, UMI 1099 showed a good general combining ability for moderate phytate and seed yield (Table5& 6). *Per se* performance was also found to be higher for tassel length, cob length, number of leaves and cob weight.Other testers though, were low in phytic acid content had undesirable effects on yield and height with higher anthesis silking interval (Lorenz *et al*.,2007,Badone *et al.,* 2010; Maupin *et al.,* 2011).Hence, UMI-1099 could be used as a donor in low phytic acid breeding without compromising seed yield traits in producing moderate phytic hybrids.

There was a significant variability for most of the traitsamong the parents, including plant height, cob traits and seed yield (Table 7). Narrow difference between phenotypic and genotypic co-efficient of variation indicates minimum environmental influence and effectiveness of selection for these traits (Najeeb *et al.*2009).The highest GCV with high heritability and genetic advance were observed for traits such as grain yield, cob weight and Phytic acid (Table 8)indicating effective selection of these traits due to additive gene action (Johnson *et al*., 1955, Rafique *et al.,*2004).

The superiority of SCA effects over GCA in hybridsrevealed the preponderance of non-additive gene action for phytic acid and yield which arises due to dominance and epistasis effects (Table 9). This indicates the heterotic potential of the quantitative traits studied (Aminu *et al*. 2014).Among the twenty-four hybrids from six lines and four testers, three hybrids; UMI 1210 x UMI 1099, UMI 1201 x UMI 1099 and UMI 1200 x UMI 1099 had superior agronomic performance than the check CO 6. They alsohad moderate levels of phytic acid content ranging from 10.23-10.46 mg/g (Table 4, 10 & 11).

The hybrid UMI 1210 x UMI 1099 was found to be the tallest hybrid with a yield increase of seven percent over the standard check (Panwar *et al*.,2013). This phenotype attributed to compactness and higher yield (Stellar *et al.*,2016). It was also sturdy and lodging resistant. It had the highest *sca* effects for plant height and cob placement height (Mahmood *et al*.,2004). This hybrid also recorded a phytate content of 10.46 mg/g (Table10,11&12).

The Second hybrid UMI 1201 x UMI 1099 had an increase in yield of more than eight percent over the standard check with a medium level of phytic acid among all hybrids (10.23 mg/g). It also showed a higher significant *sca* effect for yield with highest seedling vigour index of more than 4000 indicating its higher potential for seedling establishment in field (Pollock and Roos,1972) (Table 11).This hybrid had significant specific combining ability with higher per se performance for cob placement, number of rows per cob, number of leaves, cob weight, single plant yield with moderately lower levels of phytic acid and could be used in poultry feed to increase the bioavailability of micronutrients (Table 10,11& 12).

Out of the three hybrids, the hybrid UMI 1200 x UMI 1099 was found to be the highest yielder with an increase of ten percent over the standard check and had a phytate content of 10.69 mg/g. It also exhibited higher *sca* values for the traits like number of rows per cob, number of leaves, cob weight, hundred seed weight, single plant yield and lower phytic acid indicating the degree of non-additive gene action which is very well expected in better performing hybrids (Table 10,11&12).Along with highest per se performance (Table 11) for eleven characters,this hybrid also reported highest standard heterosis for yield and could be better promoted to the poultry industry (Woyengo and Nyachoti, 2012).

These three observed hybrids recorded the highest *Per se* performance, *sca* effects and higher standard heterosis for yield attributing traits such as cob weight and number of Kernels per row with negative heterosis for the phytate content (Table 12). Among all the hybrids considering the yield being a primary concern to feed the population, production of hybrids with lower phytic acid is being a concern. The testers although reported lower level of phytic acid had a very poor agronomic performance and this necessitates the importance of screening lines across locations to identify the suitable donors for producing low phytate hybrids. The poor performance of the low phytate lines also indicates the role of phytic acid in seed health (Raboy *et al*.,2000) and considering these views, testing of moderate phytate lines in poultry would give us a better scope to forward the low phytate breeding programs and hence these identified hybrids; UMI 1210 x UMI1099, UMI 1201 x UMI 1099 & UMI 1200 x UMI 1099, could be tested in poultry sector to study the efficiency of the bioavailability of micronutrients.

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Table 1. Details of the lines used in the Line X Tester analysis

S. No.	Code No.	Name of the lines	Single Plant yield (g)	Phytate content (mg/g)
1.	L_1	UMI- 1200	59.30	13.78
2.	L_2	UMI- 1201	83.42	12.60
3.	L_3	UMI- 1205	71.25	13.64
4.	L_4	UMI- 1210	95.20	12.90
S .No	**Code No.**	**Name of the Testers**	**Single plant yield(g)**	**Phytate content (mg/g)**
1.	T_1	UMI- 113	50.60	2.77
2.	T_2	UMI- 158	47.55	5.36
3.	T_3	UMI- 300-1	56.70	5.75
4.	T_4	UMI- 447	52.75	2.36
5.	T_5	UMI- 467	40.50	2.73
6.	T_6	UMI- 1099	61.80	7.10

Table 2. Details of genotypes present in each cluster

Name of clusters	No of genotypes in clusters	Genotypes
Cluster No. 1	13	UMI-137-6, UMI 1004, UMI 300-1, UMI 1030, UMI 262, UMI 1027, UMI 113, UMI 58, UMI 334-1, UMI 504, UMI 507, UMI 857-1 and UMI 960-1.
Cluster No. 2	25	UMI 135, UMI 1054, UMI 1017, UMI 304, UMI 955-2, UMI 351, UMI 1005-1, UMI 1009-2, UMI 51WS, UMI 823, UMI 919-1, UMI 1113, UMI 1156, UMI 375, UMI 260, UMI 1124, UMI 473-1, UMI 1105, UMI 550, UMI 607, UMI 612, UMI 510-1-2, UMI 614A, UMI 779, UMI 1126-1.
Cluster No. 3	1	UMI 258
Cluster No. 4	6	UMI 447, UMI-467, UMI-113, UMI-158,UMI-1099& UMI-300-1
Cluster No. 5	3	UMI 679, UMI 1112, UMI 1036
Cluster No. 6	4	IN-3, IN-6, UMI 170-4, UMI 1100
Cluster No. 7	4	UMI 163-3, UMI 265, UMI 1101, UMI 363
Cluster No. 8	2	IN-12, UMI 1031

Table 3. Mean values for phytate contents in the clusters

Clusters	Phytate content (mg/g)
Cluster 1	11.46
Cluster 2	9.84
Cluster 3	6.78
Cluster 4	7.13
Cluster 5	10.11
Cluster 6	10.51
Cluster 7	10.94
Cluster 8	7.47

Table 4. Classification of genotypes based on phytate ranges

S.No	Phytate content range(mg/g)	Level of Phytic acid
1.	<5	Low
2.	5-10	Medium
3.	>11	High

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Table 5.Mean performance of parents (4 lines and 6 testers)

	50TAS	50 SILK	ASI	PH	CP	TL	CL	CB	NRPC	NKPR	NL	CW	SP	100 SW	PA	IP	SVI	SPY
Lines																		
UMI-1200	58.5	**61.25**	2.75	**154.25**	**68.62**	26.72	12.84	11.81	**11.85**	**16.50**	14.42	**74.60**	79.48	30.69	**13.78**	0.34	**3222.05**	**59.30**
UMI-1201	**57.75**	61.25	**3.50**	161.00	73.93	27.02	13.85	12.23	13.00	**22.25**	**14.45**	103.22	**80.80**	**30.80**	**12.60**	0.37	3307.50	83.42
UMI-1205	**60.25**	**63.25**	3.00	164.30	75.65	**25.37**	**11.95**	**10.82**	12.75	19.25	14.18	92.40	**77.10**	30.00	13.64	**0.38**	3316.50	71.25
UMI-1210	59.5	62.25	**2.75**	**164.45**	76.18	**29.93**	**14.80**	**12.92**	**15.30**	20.25	**12.98**	**122.02**	78.05	29.86	12.90	**0.29**	**3359.45**	**95.20**
Grand Mean	59	62.00	3.00	161.00	73.60	27.26	13.36	11.95	13.23	19.56	14.00	98.06	78.86	30.34	13.23	0.34	3301.38	77.29
Minimum	57.75	61.25	2.75	154.25	68.62	25.37	11.95	10.82	11.85	16.50	12.98	74.60	77.10	29.86	12.60	0.29	3222.05	59.30
Maximum	60.25	63.25	3.5	164.45	**76.18**	29.93	14.80	12.92	15.30	22.25	14.45	122.02	80.80	30.80	13.78	0.38	3359.45	95.20
SE	0.52	0.63	0.31	3.84	0.26	0.40	0.43	0.52	0.72	0.75	0.03	2.88	0.42	0.24	0.25	0.01	18.46	1.81
CD (5%)	2.34	2.83	1.41	17.25	1.18	1.80	1.93	2.35	3.26	3.36	0.13	12.96	1.90	1.09	1.11	0.07	83.01	8.14
Testers																		
UMI- 113	52.75	**55.50**	**2.75**	123.50	57.80	28.75	12.92	11.78	12.70	20.50	10.00	**81.85**	75.51	23.75	**2.77**	**0.98**	**3228.05**	50.60
UMI- 158	53.50	56.75	3.25	99.50	46.25	**22.25**	12.31	11.44	14.50	20.75	12.60	60.75	78.34	**15.88**	5.36	0.52	2953.13	47.55
UMI- 300-1	**52.75**	57.50	**4.75**	91.35	55.55	27.21	11.50	11.77	**14.75**	21.00	10.35	74.00	76.61	18.35	5.75	0.54	3166.00	56.70
UMI- 447	53.50	57.25	3.75	81.25	37.08	**30.63**	**14.40**	10.40	12.00	**23.00**	8.98	71.00	**74.32**	19.00	2.36	**0.41**	3082.25	52.75
UMI- 467	54.40	59.00	4.60	**77.20**	**35.23**	22.71	**9.50**	**9.50**	12.10	19.25	10.65	**50.75**	**79.78**	17.70	2.73	0.50	**2827.50**	40.50
UMI- 1099	**55.50**	**59.50**	4.00	**140.60**	**79.21**	27.10	12.38	**12.07**	**11.25**	**17.75**	13.13	67.80	74.65	**25.60**	**7.10**	0.93	3016.25	**61.80**
Grand Mean	53.73	57.58	3.85	102.23	51.85	26.44	12.17	11.16	12.88	20.38	10.95	67.69	76.53	20.05	8.58	0.64	3045.53	51.65
Minimum	52.75	55.50	2.75	77.20	35.23	22.25	9.50	9.50	11.25	17.75	**8.98**	50.75	74.32	15.88	8.17	0.41	2827.50	**40.50**
Maximum	55.50	59.50	4.75	140.60	79.21	30.63	14.40	12.07	14.75	23.00	**13.13**	81.85	79.78	25.60	9.06	0.98	3228.05	61.80
SE	0.45	0.32	0.52	1.55	1.81	0.41	0.12	0.26	0.19	0.53	0.07	1.42	0.72	0.80	0.05	0.01	25.01	1.04
CD (5%)	1.65	1.15	1.88	5.63	6.57	1.48	0.43	0.94	0.71	1.94	0.25	5.15	2.63	2.90	0.17	0.05	90.91	3.78

PH – Plant height (cm); CP – Cob placement (cm); TL – Tassel length (cm); CL- Cob length (cm); CB – Cob breadth (cm); NRPC – Number of rows per cob; NKPR - Number of kernels per row; NL – Number of leaves; 50TAS – Days to 50 % tasseling; 50SILK- Days to 50 % silking; ASI – Anthesissilking interval; CW – Cob weight (g); SP – Shelling percentage; 100SW – One hundred seed weight (g); PA – Phytic Acid (mg/g); IP – Inorganic phosphorous (mg/g); SVI – Seedling vigour index, SPY – Single plant yield (g).

Table 6. General combining ability (*gca*) effects of parents (4 lines and 6 testers)

Lines	50 TAS	50 SILK	ASI	PH	CP	TL	CL	CB	NRPC	NKPR	NL	CW	SP	100SW	PA	IP	SVI	SPY
UMI-1200	-0.17	- 0.37*	- 0.54**	-4.79**	-1.83**	-1.73**	-0.7**	0.01	-0.11	-1.69**	-0.1**	-7.62**	-0.3	0.28	0.5**	-0.02	-16.69	-6.87**
UMI-1201	0.27	0.00	-0.28	-2.72**	-1.86**	0.3	-0.12	-0.24	0.17*	1.19**	-0.57**	4.37**	0.26	-0.53	-0.22**	0.01	27.42	3.82*
UMI-1205	-0.06	-0.49*	-0.43**	7.57**	6.87**	-1.6*	-0.67*	0.49	0.01	-0.58*	0.79**	-6.89**	0.64	0ns	0.18**	0.01	-7.21	-4.33*
UMI-1210	-0.04	0.12	0.16	-0.06	-3.17**	3.04**	1.49**	-0.25	-0.07	1.08**	-0.12**	10.14**	-0.6	0.25	-0.46**	0ns	-3.53	7.38**
CD (5 %)	**0.6035**	**0.5559**	**0.4399**	**2.6455**	**1.8635**	**1.7053**	**0.7046**	**0.7484**	**0.1912**	**0.7812**	**0.0665**	**3.6211**	**2.3609**	**1.1283**	**0.1680**	**0.0301**	**48.2428**	**4.6585**
Testers																		
UMI- 113	-0.69*	-1.05**	-0.36	-1.78	-1.7*	-1.04	-1.1**	0.31	0.23**	-2.14**	-0.21**	-12.25**	-1.02	-1.11*	0.24**	0.04**	-50.52*	-11.7**
UMI- 158	-0.06	-0.83**	-0.77**	2.53*	-2.08*	-1.39	0.42	-0.21	-0.33**	-0.12	0.05	-18.87**	-0.12	-1.67**	0.55**	0.06**	-105.57**	-15.78**
UMI- 300-1	-1.13**	-1.3**	-0.17	-9.06**	-1.73*	2.25**	0.29	0.23	0.11	-0.09	-0.25**	-6.78**	-1.51	-1.59**	0.29**	0.00	-36.8	-8.17**
UMI- 447	-0.47	-0.98**	-0.51*	-14.21**	-9.57**	2.18**	0.17	-0.69*	0.14	-0.49	-1.41**	-15.68**	2.25*	-1.76**	0.27**	-0.03*	-82.44**	-8.93**
UMI- 467	0.88**	1.89**	1.02**	-0.03	1.37	-1.24	-0.12	-0.71*	-0.4**	1.33**	-0.57**	-6.64**	-0.58	-0.97	0.29**	-0.07**	-60.52**	-6.59**
UMI- 1099	1.47**	2.27**	0.8**	22.55**	13.71**	-0.77	0.34	1.07**	0.25**	1.51**	2.39**	60.22**	0.98	7.1**	-1.64**	-0.01ns	335.85**	51.17**
CD (5 %)	**0.7391**	**0.6808**	**0.5387**	**3.2401**	**2.2823**	**2.0886**	**0.8630**	**0.9166**	**0.2342**	**0.9567**	**0.0814**	**4.4349**	**2.8915**	**1.3819**	**0.2058**	**0.0368**	**59.0851**	**5.7055**

PH – Plant height (cm); CP – Cob placement (cm); TL – Tassel length (cm); CL- Cob length (cm); CB – Cob breadth (cm); NRPC – Number of rows per cob; NKPR - Number of kernels per row; NL – Number of leaves; 50TAS – Days to 50 % tasseling; 50SILK- Days to 50 % silking; ASI – Anthesissilking interval; CW – Cob weight (g); SP – Shelling percentage; 100SW – One hundred seed weight (g); PA – Phytic Acid (mg/g); IP – Inorganic phosphorous (mg/g); SVI – Seedling vigour index, SPY – Single plant yield (g).

Table 7. Analysis of Variance for Combining Ability

Source of variation	Degrees of freedom	Mean sum of Squares
Lines	3	539.980**
Testers	5	5111.287**
Line x testers	15	269.099**
Error	27	30.388

Table 8. Variability parameters

Characters	Mean	PCV	GCV	h^2	GA	GAM
Days to 50 per cent tasseling	53.56	2.09	1.61	59.45	1.37	2.56
Days to 50 per cent silking	56.67	2.92	2.68	84.17	2.87	5.06
Anthesissilking interval	3.11	32.22	27.53	72.99	1.51	48.46
Plant height	161.89	8.93	8.72	95.31	28.40	17.54
Cob placement	79.11	13.05	12.75	95.44	20.30	25.66
Tassel length	34.25	10.04	8.13	65.55	4.64	13.56
Cob length	18.58	7.75	6.31	66.42	1.97	10.60
Cob breadth	13.96	7.34	3.69	25.32	0.53	3.83
No. of rows per cob	13.35	3.86	3.47	80.77	0.86	6.43
No. of kernels per row	35.05	6.23	5.64	82.05	3.69	10.52
No. of leaves	13.86	10.51	10.50	99.06	2.99	21.60
Cob weight	190.57	16.23	16.07	98.08	62.48	32.79
Shelling percentage	81.49	4.18	2.39	32.77	2.30	2.82
100 seed weight	33.37	10.92	10.16	86.58	6.50	19.47
Phytic acid	12.32	7.65	7.47	95.54	1.85	15.05
Free phosphorous	0.3029	20.71	17.06	67.85	0.09	28.94
Seedling vigour index	3722.94	4.64	4.37	89.06	3.16	8.50

PV – phenotypic variance GV – Genotypic variance ,PCV – Phenotypic coefficient of variation,
GCV – Genotypic coefficient of variation h^2 – Heritability percentage GA – Genetic advance
GAM – Genetic advance as percentage of mean

Table 9. Magnitude of GCA and SCA variance for eighteen traits

S. No.	Characters	GCA: SCA Ratio
1.	Days to 50% tasseling	-0.9761
2.	Days to 50% silking	-9.5380
3.	Anthesissilking interval	0.1460
4.	Plant height	0.1780
5.	Cob placement	0.0670
6.	Tassel length	0.1182
7.	Cob length	0.1035
8.	Cob breadth	-0.2133
9.	No. of rows per cob	0.0000
10.	No. of kernels per row	0.1173
11.	No. of leaves	0.1571
12.	Cob weight	0.3663
13.	Shelling percentage	-0.0177
14.	100 seed weight	0.4520
15.	Phytic acid	0.2290
16.	Inorganic phosphorous	0.0833
17.	Seedling vigour index	0.4000
18.	Grain yield	0.3448

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Table 10. Specific combining ability (*sca*) effects of 24 hybrids

Hybrids	50 TAS	50 SILK	ASI	PH	CP	TL	CL	CB	NRPC	NKPR	NL	CW	SP	100SW	PA	IP	SVI	SPY
$L_1 \times T_1$	-0.21	0.50	0.71	-0.43	0.88	**-2.93**	**-2.00****	-0.48	-0.06	**-2.22****	0.18**	**-21.89****	-0.61	-1.79	0.41**	0	**-79.73**	**-18.37****
$L_1 \times T_2$	-0.33	0.04	0.37	0.39	6.25**	-2.10	0.65	-0.15	0.64**	0.57	0.74**	8.42*	0.96	-0.53	-0.08	0.04	-11.73	8.8*
$L_1 \times T_3$	-0.27	0.25	0.52	6.36**	6.06**	1.28	-0.66	-0.19	-0.1	-0.52	-0.01	-7.41*	0.47	-0.71	0.22	0.03	-42.70	-5.06
$L_1 \times T_4$	0.45	-0.06	-0.51	9.36**	-3.51*	**4.38****	0.77	0.24	-0.38*	0.83	-0.87**	2.64	-2.87	-0.60	0.22	0.04	31.19	-2.65
$L_1 \times T_5$	0.23	**-0.68**	**-0.91***	-4.87*	-2.77	-1.11	**0.90**	-0.15	-0.44*	0.92	0.43**	-1.30	3.87	1.17	-0.03	**-0.1****	66.77	5.87
$L_1 \times T_6$	0.14	-0.06	-0.19	**-10.81****	-6.91**	0.48	0.34	**0.74**	0.34*	0.41	0.4**	19.54**	-1.82	2.46*	**-0.75****	-0.01	36.20	11.4**
$L_2 \times T_1$	-0.15	0.13	0.28	-5.81*	-0.64	0.44	-0.40	0.58	-0.45*	-1.11	-0.08	-3.79	0.19	0.72	0.44**	-0.02	-48.84	-2.70
$L_2 \times T_2$	-0.27	-0.08	0.19	-7.13**	-7.07**	-0.63	0.29	0.04	-0.1	-0.37	**-1.3****	-2.08	-0.28	0.33	0.08	0.00	12.96	-1.88
$L_2 \times T_3$	-0.21	-0.62	-0.41	-1.45	**-13.76****	-0.45	-0.11	0.24	-0.33*	-0.36	-1.07**	-6.66*	-3.21	-0.16	0.29	-0.01	-57.01	-11.24**
$L_2 \times T_4$	0.14	-0.18	-0.32	5.58*	5.43**	-2.08	0.27	0.44	0.34*	0.44	0.88**	-2.76	**5.89****	0.32	-0.22	0.01	50.83	8.52*
$L_2 \times T_5$	0.54	0.19	-0.35	7.86**	**10.27****	0.29	0.34	-0.07	0.18	1.23	**1.04****	4.80	-0.88	-0.57	-0.36*	0.04	-0.84	2.43
$L_2 \times T_6$	-0.05	**0.57**	0.62	0.95	5.77**	2.42	-0.39	**-1.23**	0.35*	0.15	0.34**	**26.38****	2.06	1.73	-1.02**	0	**151.8****	**25.19****
$L_3 \times T_1$	-0.06	-0.64	-0.57	**9.47****	0.68	2.27	0.87	-0.30	0.62**	1.57*	0.53**	10.49**	-1.71	-0.65	-0.23	-0.02	42.89	4.87
$L_3 \times T_2$	**0.81**	0.50	-0.31	4.03	0.12	1.90	-1.13	-0.06	0.07	-1.94**	0.85**	-6.31*	1.42	1.09	0.21	-0.05	28.85	-2.98
$L_3 \times T_3$	0.13	0.11	-0.01	-4.81*	6.37**	-1.48	0.41	-0.02	0.53**	0.62	0.43**	4.60	-1.34	-1.79	-0.25	-0.01	-34.43	1.16
$L_3 \times T_4$	-0.53	0.30	**0.83***	-7.10**	-10.34**	0.42	-0.51	-0.20	-0.3	0.37	-0.74**	-2.35	-0.29	-0.90	0.00	0.01	-37.54	-2.83
$L_3 \times T_5$	**-0.63**	0.17	0.80*	2.67	0.21	-1.11	-0.18	0.24	-0.41*	-0.44	-0.08	-5.03	**-3.22**	-0.76	0.56**	**0.05**	-95.6*	-9.67*
$L_3 \times T_6$	0.28	-0.45	-0.73	-4.27	2.96	-2.00	0.55	0.34	-0.51**	-0.17	-0.79**	-17.3**	1.37	0.62	0.5**	0.00	-13.08	-10.87*
$L_4 \times T_1$	0.42	0	-0.41	-3.23	-0.91	0.22	1.53*	0.20	-0.11	**1.75***	-0.43**	-0.70	-1.64	-0.66	0.17	0.02	-23.24	-4.12
$L_4 \times T_2$	-0.21	-0.46	-0.25	2.71	0.69	0.83	0.18	0.18	-0.61**	1.74*	-0.29**	-0.04	-2.1	-0.9	-0.21	0.01	-30.09	-3.95
$L_4 \times T_3$	0.35	0.25	-0.1	-0.43	1.33	0.65	0.37	-0.02	-0.10	0.25	0.66**	9.47**	4.08	**2.66****	-0.27	-0.01	134.14**	15.14**
$L_4 \times T_4$	-0.05	-0.06	-0.01	0.39	8.42**	-2.73	-0.54	-0.49	0.33	-1.65*	0.73**	2.47	-2.73	1.18	0.00	-0.06*	-44.47	-3.05
$L_4 \times T_5$	-0.15	0.32	0.46	6.36**	-7.70**	1.93	-1.05	-0.02	0.67**	-1.71*	-0.53**	1.53	0.23	0.15	-0.17	0.01	29.66	1.37
$L_4 \times T_6$	-0.36	-0.06	0.31	9.36**	-1.83	-0.91	-0.49	0.15	-0.18ns	-0.39	-0.14*	-12.73**	2.16	**-2.43***	**-0.48****	0.04	-66.01	-5.40
CD (5 %)	**1.4782**	**1.3617**	**1.0775**	**6.4802**	**4.5647**	**4.1772**	**1.7260**	**1.8332**	**0.4683**	**1.9135**								

**Significant at 1% level
* Significant at 5 % level

PH – Plant height (cm); CP – Cob placement (cm); TL – Tassel length (cm); CL- Cob length (cm); CB – Cob breadth (cm); NRPC – Number of rows per cob; NKPR - Number of kernels per row; NL – Number of leaves; 50TAS – Days to 50 % tasseling; 50SILK- Days to 50 % silking; ASI – Anthesis silking interval; CW – Cob weight (g); SP – Shelling percentage; 100SW – One hundred seed weight (g); PA – Phytic Acid (mg/g); IP – Inorganic phosphorous (mg/g); SVI – Seedling vigour index, SPY – Single plant yield (g).

Table 11. Mean performance of 24 hybrids

Hybrids	50 TAS	50 SILK	ASI	PH	CP	TL	CL	CB	NRPC	NKPR	NL	CW	SP	100 SW	PA	IP	SVI	SPY
$L_1 \times T_1$	52.50	56.50	4.00	154.89	76.45	**28.54**	**14.77**	13.79	13.40	**29.00**	13.73	**148.80**	79.57	30.75	**13.48**	0.33	3576.00	**118.40**
$L_1 \times T_2$	53.00	56.25	3.25	160.02	81.45	29.02	18.95	13.60	13.55	33.80	14.55	172.50	82.03	31.45	13.29	**0.39**	3588.95	141.50
$L_1 \times T_3$	**52.00**	56.00	4.00	154.40	81.61	36.05	17.50	14.00	13.25	32.75	13.50	168.75	80.16	31.35	13.33	0.33	3626.75	135.25
$L_1 \times T_4$	53.38	56.00	2.63	152.25	64.20	39.08	18.82	13.52	13.00	33.70	**11.48**	169.90	80.57	31.29	13.31	0.30	3655.00	136.90
$L_1 \times T_5$	54.50	58.25	3.75	152.20	75.87	30.17	18.65	13.10	12.40	35.60	12.77	175.00	84.48	33.85	13.08	**0.12**	3712.50	147.75
$L_1 \times T_6$	55.00	59.25	4.25	168.83	84.08	32.23	18.55	15.78	13.83	35.28	**16.55**	262.70	80.35	**43.22**	10.43	0.27	4078.30	**226.65**
$L_2 \times T_1$	53.00	55.75	2.75	151.57	74.90	33.95	16.95	14.60	13.30	33.00	13.00	178.90	80.92	32.45	12.78	0.34	3651.00	144.75
$L_2 \times T_2$	53.50	55.75	2.25	154.56	68.10	32.53	19.17	13.54	13.10	35.75	12.05	174.00	81.35	31.50	12.73	0.38	3657.75	141.50
$L_2 \times T_3$	52.50	54.75	2.25	148.65	**61.76**	36.35	18.63	14.18	13.30	35.80	11.98	181.50	**77.03**	31.10	12.68	0.31	3656.55	139.75
$L_2 \times T_4$	53.50	55.50	2.00	150.53	73.11	34.65	18.90	13.47	14.00	36.20	12.77	176.50	**84.88**	31.40	12.15	0.30	3718.75	158.75
$L_2 \times T_5$	55.25	58.75	3.50	167.00	88.88	33.60	18.67	12.93	13.30	**38.80**	13.77	193.10	80.28	31.30	12.03	0.29	3689.00	155.00
$L_2 \times T_6$	55.25	**59.50**	4.25	182.66	96.73	36.20	18.40	13.55	14.13	37.90	16.23	**265.65**	81.01	39.30	**10.23**	0.29	**4129.10**	223.15
$L_3 \times T_1$	52.75	**54.50**	1.75	177.15	84.95	33.87	17.67	14.45	**14.20**	33.90	14.78	197.80	83.17	34.00	11.73	0.36	3817.00	164.50
$L_3 \times T_2$	54.25	55.85	**1.60**	176.01	84.02	33.15	17.20	14.17	13.10	32.40	15.55	158.50	83.43	32.80	13.27	0.32	3639.00	132.25
$L_3 \times T_3$	52.50	55.00	2.50	155.58	90.62	33.41	18.60	14.65	14.00	35.00	14.83	181.50	79.28	**30.00**	12.55	0.31	3644.50	144.00
$L_3 \times T_4$	52.50	55.50	3.00	148.15	66.07	35.25	17.57	13.56	13.20	34.35	12.50	165.65	84.08	30.73	12.78	0.30	3595.75	139.25
$L_3 \times T_5$	53.75	58.25	4.50	172.10	87.55	30.30	17.60	13.97	12.55	35.35	14.00	172.00	78.33	31.65	13.35	0.29	**3559.60**	134.75
$L_3 \times T_6$	**55.25**	58.00	2.75	187.73	**102.65**	29.88	18.79	**15.86**	13.10	35.80	16.25	226.60	84.48	41.10	11.36	0.30	4038.50	191.31
$L_4 \times T_1$	53.25	55.75	2.50	156.82	73.33	36.47	20.50	14.21	13.40	35.75	13.10	187.75	78.23	31.85	12.27	0.36	3645.65	146.90
$L_4 \times T_2$	53.25	55.50	2.25	167.06	74.55	36.73	20.67	13.67	**12.35**	37.75	13.50	181.80	78.66	31.05	12.20	0.37	3583.75	143.00
$L_4 \times T_3$	52.75	55.75	3.00	152.66	75.54	**40.18**	**20.73**	13.91	13.30	36.30	14.15	203.40	83.46	34.70	11.88	0.29	3816.75	169.70
$L_4 \times T_4$	53.00	55.75	2.75	**139.78**	74.79	36.74	19.70	**12.53**	13.75	34.00	13.06	187.50	80.41	33.05	12.13	0.22	3592.50	150.75
$L_4 \times T_5$	54.25	59.00	**4.75**	156.14	69.60	37.98	18.90	12.97	13.55	35.75	12.65	195.60	80.54	32.80	11.98	0.24	3688.55	157.50
$L_4 \times T_6$	54.63	59.00	4.38	**198.50**	87.82	35.61	19.92	14.92	13.35	37.25	16.00	248.20	84.02	38.30	10.69	0.33	3989.25	220.63
CO 6	54.25	56.50	2.25	169.06	79.03	33.13	20.23	14.90	14.13	35.75	14.88	260.00	79.01	39.35	12.35	0.30	3668.25	205.40

PH – Plant height (cm); CP – Cob placement (cm); TL – Tassel length (cm); CL- Cob length (cm); CB – Cob breadth (cm); NRPC – Number of rows per cob; NKPR - Number of kernels per row; NL – Number of leaves; 50TAS – Days to 50 % tasseling; 50SILK- Days to 50 % silking; ASI – Anthesissilking interval; CW – Cob weight (g); SP – Shelling percentage; 100SW – One hundred seed weight (g); PA – Phytic Acid (mg/g); IP – Inorganic phosphorous (mg/g); SVI – Seedling vigour index, SPY – Single plant yield (g).

Table 12. Standard Heterosis for yield & Phytic acid of 24 hybrids

Hybrids	Single Plant yield	Phytic Acid
$L_1 \times T_1$	-42.36**	9.11**
$L_1 \times T_2$	-31.11**	7.61**
$L_1 \times T_3$	-34.15**	7.94**
$L_1 \times T_4$	-33.35**	7.77**
$L_1 \times T_5$	-28.07**	5.87**
$L_1 \times T_6$	**10.35****	**-15.59****
$L_2 \times T_1$	-29.53**	3.44
$L_2 \times T_2$	-31.11**	3.04
$L_2 \times T_3$	-31.96**	2.63
$L_2 \times T_4$	-22.71**	-1.62
$L_2 \times T_5$	-24.54**	-2.63
$L_2 \times T_6$	**8.64****	**-17.21****
$L_3 \times T_1$	-19.91**	-5.06**
$L_3 \times T_2$	-35.61**	7.41**
$L_3 \times T_3$	-29.89**	1.58
$L_3 \times T_4$	-32.21**	3.44
$L_3 \times T_5$	-34.4**	8.06**
$L_3 \times T_6$	-6.86*	-8.02**
$L_4 \times T_1$	-28.48**	-0.65
$L_4 \times T_2$	-30.38**	-1.21
$L_4 \times T_3$	-17.38**	-3.85*
$L_4 \times T_4$	-26.61**	-1.82
$L_4 \times T_5$	-23.32**	-3.04
$L_4 \times T_6$	**7.41****	**-13.44****

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