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ESTIMATES OF HERITABILITY, HETEROSIS AND INBREEDING DEPRESSION FOR YIELD AND QUALITY TRAITS IN MAIZE

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SUMMARY

The experiment was conducted to evaluate the six single cross hybrids and their F_2 populations developed from crossing and selfing between five inbred lines of maize at experimental area of CCS Haryana Agricultural University Regional Research Station, Uchani, Karnal during 2013-14 to estimate heritability, genetic advance, heterosis and inbreeding depression for 15 quantitative traits. Highly significant heterosis over better parents was found for all the characters, correlated that with inbreeding depression for all traits. The highly significant positive heterosis to better parent was observed for most studied traits, indicating that dominance direction was towards the best parent except for days to 50 per cent tasselling, days to 50 per cent silking and days to maturity in all the six crosses which showed highly significant negative heterosis over better parent indicating that dominance direction was towards the lower/inferior parent. Selfing caused a significant decrease in the measurements of all the characters taken in all selfed (F_2) populations, except for days to tasselling, days to silking and days to maturity which showed an increase in magnitude. Narrow sense heritability and genetic advance were low in most of the cases due to the prevalence of non-additive gene action in controlling the genetic variation of the most of the studied traits. The inbred lines and hybrids revealed good potential for yield and quality traits and can be used as parents for crosses between improved populations or inbred lines developed from them.

Key words : Heterosis, hybrids, QPM, inbred, gene action, heritability

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop, belongs to the tribe Maydeae, of the grass family, Poaceae and is widely cultivated crop throughout the world and its suitability to diverse environments is unmatched by any other crop. Maize can also serve as human food as well as feed and fodder for domestic animals. It is one of the major food crops in India where it is used as human food and animal feed. About 50 to 60 per cent of maize production in India is consumed as food for humans and feed for cattle, 30 to 35 per cent goes to poultry, piggery and fish meal, 10 to 12 per cent in wet milling industry e. g. in starch and oil and about 3 per cent in dry milling for traditional requirements like Dalia, Sattu and other food products such as corn bread corn chips. It is commonly used in animal feed as an energy source for its high starch content. As maize has become an all season crop in India so it can be grown in spring, **kharif** and **rabi**. Normal maize has poor nutritional value because of lower contents of essential amino acids such as lysine and tryptophan.

As maize has been the source of nutrient for human as cereal crop and animals as fodder, the improvement of maize in terms of its protein quality mainly lysine and tryptophan is very important. For the development of hybrids, the foremost step is the development and evaluation of the inbreds and to know the nature and magnitude of heterosis for grain yield and its component traits. The study of heritability and genetic advance, heterosis and inbreeding depression in the germplasm will help to ascertain the real potential value of the genotype. Realizing the importance of vigorous inbred lines for developing high yielding single cross hybrids in maize, studies were undertaken to identify inbreeding tolerant source populations and lines.

[1]The present research work is the part of Ph. D. thesis of the 1st author.

MATERIALS AND METHODS

The field experiment was conducted in experimental area of CCS Haryana Agricultural University Regional Research Station, Uchani, Karnal during the growing seasons of 2013 and 2014. Karnal is located at 29.43º N latitude and 76.58º E longitude and is about 250 metres above mean sea level. The average annual rainfall was about 354.5 mm, in which around -29 per cent of the total rainfall was received during the months from July to September which was distributed evenly during the cropping period and the soil type was clay loam. The monthly maximum and minimum temperatures during hot months ranged from 39.5 ºC to 19 ºC and during cold months ranged from 4ºC to 32ºC.The six experimental single cross hybrids (F_1) were generated by mating between three inbred lines viz., HKI 209, HKI 1332 and HKI 325-17AN used as females and two inbred lines viz., HKI 1128 and HKI 163 (QPM) used as male during **kharif** 2013. In the second season, **rabi** 2013-14, F_1 plants of each cross were selfed and backcrossed to the two parents to obtain F_2, BC_1 and BC_2 generations. The six populations i.e. P_1, P_2, F_1, F_2, BC_1 and BC_2 of the six maize crosses were grown in a single row of 5 m length and the distance between rows and plants was kept at 75 and 20 cm, respectively. The data were recorded on following traits viz., days to 50 per cent tasselling, days to 50 per cent silking, days to maturity, plant height (cm), ear height (cm), cob length (cm), cob diameter (cm), number of grains per cob, 100-grain weight (g), grain yield per plant (g), shelling percentage, protein content (%), tryptophan content (%), oil content (%) and starch content (%) were obtained for the analysis of the data. Quality traits were determined at quality laboratory using Near Infrared Spectrophotometer (NIRS). The magnitude of heterosis for all the characters was estimated in relation to better parent and was calculated as :

Heterobeltiosis = F_1-BP/ BP, where, BP = Better parent value in the particular F_1 cross (P_1 or P_2).

The estimate of inbreeding depression was calculated as : F_1-F_2/ F_1, where F_1 = Mean of F_1 and F_2 = mean of F_2.

Heritability in broad sense = h^2 (bs)= $$\frac{VF_2-(VP_1+VP_2+VF_1)/3}{VF_2}$$

Heritability in narrow sense = h^2 (ns)= $$\frac{2VF_2-(VBC_1+VBC_2)}{VF_2}$$

Where,
VF_2=The variance of F_2 generation
VP_1, VP_2 & VF_1=Variances of non-segregating generations i. e. Parent 1, Parent 2 and F_1, respectively.
VBC_1= The variance of backcross with parent 1
VBC_2= The variance of backcross with parent 2
Genetic advance (G. A.) = K x h (b.s.) x óp , where K óp.
h = Selection of differential expressed in terms of phenotypic standard deviation, using 5 per cent selection in a large sample from normally and independently distributed population, the value of K was 2.06 (Allard, 1960).

Genetic advance as per cent of mean = $\frac{G. A.}{X}$ x 100, where, X=Mean of population

RESULTS AND DISCUSSION

The means of the six generations and range of F_2 with the six crosses (Table 1.) for traits indicated that means of the F_1's were higher than the better parent (parent with highest value) for all the characters under study showing heterobeltiosis for these characters except for phenological characters. For phenological characters the condition was mostly reversed because most of the F1 means were lower than the better parent (parent with lowest value). These results indicated over dominance or partial dominance for most studied characters. For all the characters except phenological characters (days to 50% tasselling, days to 50% silking and days to maturity) the mean values of F_2 generation were lower than F_1 in all the crosses showing partial dominance and inbreeding depression for the characters under study as well as transgressive segregation for all traits was also observed in the F_2 generation. The backcross progenies, in general, tended towards their respective recurrent parents in all the crosses and for all the characters. Similar results were obtained by AL-Ahmad (2004); Ishfaq (2011); Shahrokhi *et al*. (2011) and El-Badawy (2012).

Heterosis and Inbreeding Depression

Heterosis and inbreeding depression for the selfed population in six crosses are given in Table 1. Experimental hybrids, in general, were high yielding, when compared to parents. Further, results denoted

TABLE 1

Estimates of heterosis (over better parent) and inbreeding depression (over F_1) in crosses of maize

Character	Crosses	Mean ±S. E.						Heterosis	I. D.
		P_1	P_2	F_1	F_2	BC_1	BC_2		
Days to 50% tasselling	HKI 209 × HKI 1128	57.20±0.37	53.80±0.37	53.00±0.37	54.36±0.51	57.00±0.31	54.00±0.54	-1.49	-2.57
	HKI 209 × HKI 163	57.33±0.33	53.33±0.33	51.66±0.33	54.50±0.50	57.66±0.33	53.66±0.33	-3.13	-5.50
	HKI 1332 × HKI 1128	54.40±0.24	56.60±0.24	51.60±0.24	53.44±0.30	53.60±0.24	56.80±0.37	-5.15	-3.57
	HKI 1332 × HKI 163	55.80±0.37	52.80±0.37	52.40±0.24	53.16±0.26	55.20±0.20	52.40±0.24	-0.76	-1.45
	HKI 325-17AN × HKI 1128	56.20±0.20	55.00±0.31	51.80±0.20	53.76±0.32	54.20±0.20	56.60±0.40	-5.82	-3.78
	HKI 325-17AN × HKI 163	57.40±0.40	54.00±0.31	52.60±0.24	53.52±0.28	56.40±0.24	53.60±0.24	-2.59	-1.75
Days to 50% silking	HKI 209 × HKI 1128	59.60±0.40	56.80±0.58	57.00±0.31	57.24±0.49	55.60±0.24	56.80±0.37	0.35	-0.42
	HKI 209 × HKI 163	60.00±0.57	55.33±0.33	54.33±0.33	56.70±0.51	60.00±0.00	56.00±0.57	-1.81	-4.36
	HKI 1332 × HKI 1128	56.00±0.44	59.20±0.58	54.00±0.31	55.52±0.32	55.80±0.37	59.40±0.40	-3.57	-2.81
	HKI 1332 × HKI 163	57.80±0.20	58.80±0.37	54.80±0.20	56.12±0.30	57.20±0.49	59.60±0.40	-5.19	-2.41
	HKI 325-17AN × HKI 1128	60.00±0.31	57.00±0.31	55.80±0.37	56.64±0.29	59.40±0.24	56.60±0.24	-2.11	-1.51
	HKI 325-17AN × HKI 163	58.40±0.24	56.20±0.37	55.60±0.24	57.08±0.33	58.20±0.20	55.20±0.37	-1.07	-2.66
Days to maturity	HKI 209 × HKI 1128	87.80±0.37	84.80±0.37	82.60±0.24	82.72±0.52	84.20±0.20	85.60±0.24	-2.59	-0.15
	HKI 209 × HKI 163	86.4±0.24	83.4±0.24	83.4±0.24	85.30±0.53	85.4±0.24	83.6±0.24	0.00	-2.28
	HKI 1332 × HKI 1128	86.80±0.37	91.20±0.58	84.60±0.40	83.40±0.43	86.00±1.18	90.60±0.40	-2.53	1.42
	HKI 1332 × HKI 163	91.20±0.58	88.20±0.37	85.20±0.37	83.96±0.49	86.00±1.18	90.6±0.40	-2.29	1.46
	HKI 325-17AN × HKI 1128	91.00±0.31	87.60±0.40	85.40±0.24	85.28±0.36	90.40±0.24	86.60±0.24	-2.51	0.14
	HKI 325-17AN × HKI 163	92.00±1.15	87.66±0.88	85.66±0.88	85.72±0.28	93.66±0.88	87.00±1.15	-2.28	-0.07
Plant height	HKI 209 × HKI 1128	155.90±2.83	133.30±2.48	209.30±3.86	165.68±7.35	156.20±1.74	134.40±1.36	34.25	20.84
	HKI 209 × HKI 163	140.40±1.63	126.20±1.35	215.40±1.72	191.70±3.48	142.00±1.37	128.40±0.74	53.42	11.00
	HKI 1332 × HKI 1128	122.80±0.37	136.00±0.31	207.00±0.31	173.64±2.54	122.00±0.44	135.00±0.44	52.21	16.12
	HKI 1332 × HKI 163	118.00±1.41	129.80±1.49	196.20±1.35	176.64±2.98	119.20±1.85	132.20±1.49	51.16	9.97
	HKI 325-17AN × HKI 1128	133.40±1.88	139.80±3.90	193.60±3.98	174.90±3.99	135.00±0.447	140.40±2.25	38.48	9.67
	HKI 325-17AN × HKI 163	132.00±2.88	109.33±4.05	225.33±3.18	180.08±4.70	117.00±2.51	135.66±2.33	70.70	20.08
Ear height	HKI 209 × HKI 1128	84.20±1.82	56.00±1.51	94.00±2.41	73.76±3.17	81.40±1.07	55.40±0.74	11.64	21.53
	HKI 209 × HKI 163	73.66±2.33	49.00±2.30	95.00±2.08	88.30±1.11	78.00±1.15	59.00±3.21	5.96	7.05
	HKI 1332 × HKI 1128	62.60±0.40	66.40±0.51	86.80±0.37	75.76±1.31	64.60±1.93	64.60±1.72	30.72	12.72
	HKI 1332 × HKI 163	66.40±0.51	59.20±1.24	79.80±2.41	75.64±1.35	62.40±1.43	60.40±1.72	20.18	5.21
	HKI 325-17AN × HKI 1128	54.20±0.86	64.60±1.16	86.60±0.60	72.72±2.16	56.20±1.56	65.20±0.86	34.06	16.03
	HKI 325-17AN × HKI 163	58.00±4.52	71.80±1.74	82.00±2.66	82.12±1.84	86.60±3.20	53.40±14.58	14.21	-0.15
Cob length	HKI 209 × HKI 1128	14.10±0.06	13.26±0.14	17.02±0.10	14.40±0.19	14.30±0.09	13.42±0.12	20.71	15.39
	HKI 209 × HKI 163	13.16±0.07	13.32±0.08	16.54±0.14	14.42±0.51	13.78±0.10	13.62±0.04	24.17	12.82
	HKI 1332 × HKI 1128	10.48±0.10	10.86±0.06	16.50±0.18	13.55±0.42	11.12±0.15	11.40±0.24	51.93	17.84
	HKI 1332 × HKI 163	10.00±0.14	9.82±0.12	15.54±0.33	14.38±0.36	10.16±0.12	10.34±0.12	55.40	7.46
	HKI 325-17AN × HKI 1128	10.32±0.09	9.64±0.06	16.36±0.06	13.632±0.39	10.32±0.09	9.96±0.07	58.53	16.67
	HKI 325-17AN × HKI 163	11.83±0.20	10.96±0.14	15.83±0.20	14.06±0.09	11.73±0.14	10.66±0.20	33.81	11.18
Cob diameter	HKI 209 × HKI 1128	4.06±0.04	3.62±0.13	4.44±0.14	4.01±0.05	3.72±0.10	3.92±0.0.08	9.36	9.68
	HKI 209 × HKI 163	4.00±0.11	3.40±0.05	4.50±0.17	3.93±0.16	3.66±0.88	3.70±0.15	12.50	12.67
	HKI 1332 × HKI 1128	3.60±0.14	3.42±0.03	4.58±0.11	3.84±0.09	3.68±0.05	3.70±0.08	27.22	16.07
	HKI 1332 × HKI 163	4.46±0.07	4.26±0.08	5.22±0.058	4.328±0.12	4.26±0.08	4.4±0.07	17.04	17.09
	HKI 325-17AN × HKI 1128	3.84±0.07	4.12±0.05	4.44±0.06	4.05±0.05	3.76±0.07	3.92±0.04	7.77	8.65
	HKI 325-17AN × HKI 163	3.72±0.05	3.44±0.04	4.64±0.07	3.76±0.08	3.70±0.05	3.62±0.05	24.73	19.05
No. of grains/cob	HKI 209 × HKI 1128	249.00±12.28	199.40±4.78	393.60±6.49	352.68±18.23	256.00±5.89	202.20±7.43	58.07	10.40
	HKI 209 × HKI 163	239.00±1.70	218.00±1.41	407.20±2.05	352.30±5.15	230.80±1.85	222.80±1.85	70.38	13.48
	HKI 1332 × HKI 1128	210.80±3.55	187.60±2.35	415.00±3.89	309.04±19.69	216.80±4.22	193.80±3.00	96.87	25.53
	HKI 1332 × HKI 163	212.66±6.56	186.66±3.18	443.66±4.48	320.72±19.9	218.66±5.81	191.10±4.35	108.62	27.71
	HKI 325-17AN × HKI 1128	231.2±1.85	217.4±1.72	395.6±2.13	330.44±11.41	226.6±2.89	219.6±1.63	71.11	16.47
	HKI 325-17AN × HKI 163	247.6±8.21	215.2±20.91	440.4±3.22	397.12±13.92	323.8±15.64	207.4±56.14	77.87	9.83

Contd.

Table 1 contd.

100-grain weight	HKI 209 × HKI 1128	21.69±0.36	20.90±0.51	26.16±0.28	22.05±0.40	21.82±0.13	21.06±0.12	20.61	15.71
	HKI 209 × HKI 163	21.19±0.47	17.08±0.77	25.66±0.35	21.04±0.63	17.20±0.72	20.14±1.04	21.09	18.00
	HKI 1332 × HKI 1128	19.91±0.28	17.55±0.51	25.89±0.25	22.12±0.75	19.33±0.80	18.36±0.50	30.05	14.57
	HKI 1332 × HKI 163	21.16±0.28	18.59±0.17	24.73±0.09	22.14±0.48	21.45±0.26	18.71±0.18	16.88	10.49
	HKI 325-17AN × HKI 1128	21.67±0.10	18.98±0.26	25.86±0.16	23.39±0.31	22.16±0.15	19.52±0.17	19.32	9.55
	HKI 325-17AN × HKI 163	21.60±1.08	18.64±1.28	22.87±0.49	22.44±0.59	18.78±0.73	16.53±4.33	5.83	1.86
Grain yield/plant	HKI 209 × HKI 1128	58.22±1.91	45.96±2.12	108.25±2.58	83.21±5.00	46.804±1.84	60.708±1.77	85.93	23.13
	HKI 209 × HKI 163	65.290±0.50	53.657±0.76	120.107±2.16	91.949±2.75	65.810±0.38	55.223±0.59	83.96	23.44
	HKI 1332 × HKI 1128	55.22±0.84	55.42±0.44	115.57±2.20	78.42±2.72	59.20±0.61	55.60±0.72	108.52	32.14
	HKI 1332 × HKI 163	68.00±0.30	60.38±0.57	99.13±0.46	81.14±3.34	68.72±0.50	61.45±0.62	45.78	18.14
	HKI 325-17AN × HKI 1128	65.61±0.42	59.21±0.49	110.10±0.85	92.29±2.48	68.14±0.21	62.45±0.30	67.8	16.18
	HKI 325-17AN × HKI 163	75.44±1.13	66.20±0.97	116.16±2.38	99.26±3.43	81.33±2.935	60.41±15.18	53.96	14.55
Shelling percentage	HKI 209 × HKI 1128	76.03±1.21	74.37±0.51	80.71±0.90	77.26±0.91	75.66±1.03	74.40±0.33	6.16	4.27
	HKI 209 × HKI 163	71.11±2.21	76.96±0.75	80.50±1.08	77.36±0.97	72.25±3.32	77.967±0.81	4.60	3.90
	HKI 1332 × HKI 1128	75.30±0.25	77.19±0.36	81.14±0.30	76.85±0.65	75.67±0.20	77.62±0.27	5.12	5.29
	HKI 1332 × HKI 163	77.57±0.30	75.89±0.34	81.78±0.41	75.94±0.30	77.16±0.08	75.20±0.11	5.44	7.14
	HKI 325-17AN × HKI 1128	78.71±0.16	76.62±0.12	82.31±0.18	79.31±0.37	77.14±0.20	75.62±0.09	4.58	3.64
	HKI 325-17AN × HKI 163	78.27±0.41	77.26±0.279	82.36±0.31	79.98±0.46	78.88±0.384	78.35±0.246	5.23	2.89
Protein content	HKI 209 × HKI 1128	8.66±0.06	9.23±0.18	10.66±0.35	9.67±0.20	8.42±0.11	9.36±0.11	15.49	9.29
	HKI 209 × HKI 163	9.23±0.08	9.90±0.06	11.33±0.21	10.90±0.31	9.32±0.07	9.98±0.03	14.44	3.80
	HKI 1332 × HKI 1128	9.30±0.07	9.84±0.09	11.30±0.14	10.10±0.18	9.67±0.05	9.93±0.07	14.79	10.55
	HKI 1332 × HKI 163	9.23±0.02	8.55±0.03	9.82±0.17	9.04±0.14	9.16±0.02	8.70±0.02	6.39	7.9
	HKI 325-17AN × HKI 1128	8.52±0.04	10.04±0.05	11.30±0.07	9.09±0.08	8.80±0.08	9.59±0.14	12.54	19.52
	HKI 325-17AN × HKI 163	8.40±0.03	8.78±0.18	10.30±0.02	9.80±0.21	8.42±0.03	8.94±0.03	17.24	4.86
Tryptophan content	HKI 209 × HKI 1128	0.49±0.01	0.41±0.02	0.61±0.01	0.49±0.01	0.52±0.01	0.41±0.005	24.49	19.67
	HKI 209 × HKI 163	0.44±0.02	0.33±0.02	0.61±0.02	0.44±0.02	0.45±0.01	0.38±0.02	38.64	27.87
	HKI 1332 × HKI 1128	0.41±0.02	0.34±0.01	0.62±0.02	0.56±0.01	0.46±0.01	0.39±0.02	12.14	9.87
	HKI 1332 × HKI 163	0.59±0.01	0.80±0.01	0.74±0.02	0.68±0.01	0.57±0.01	0.81±0.02	-6.50	8.69
	HKI 325-17AN × HKI 1128	0.53±0.01	0.49±0.009	0.60±0.01	0.59±0.012	0.52±0.012	0.50±0.005	14.72	1.97
	HKI 325-17AN × HKI 163	0.54±0.004	0.60±0.006	0.78±0.003	0.69±0.013	0.56±0.006	0.62±0.002	28.29	10.77
Oil content	HKI 209 × HKI 1128	3.97±0.04	4.49±0.13	4.87±0.04	4.32±0.07	3.96±0.02	4.67±0.052	8.46	11.29
	HKI 209 × HKI 163	3.55±0.04	3.85±0.04	4.96±0.03	3.63±0.08	3.59±0.02	3.84±0.02	28.83	26.81
	HKI 1332 × HKI 1128	3.93±0.05	3.61±0.02	4.70±0.06	4.20±0.11	3.84±0.02	3.64±0.03	13.90	10.52
	HKI 1332 × HKI 163	4.37±0.02	3.77±0.08	4.49±0.01	4.141±0.07	4.36±0.01	3.81±0.02	2.84	7.85
	HKI 325-17AN × HKI 1128	4.57±0.02	4.21±0.03	4.93±0.02	4.62±0.07	4.56±0.15	4.52±0.02	7.96	6.28
	HKI 325-17AN × HKI 163	4.64±0.01	4.80±0.016	5.25±0.018	4.52±0.097	4.95±0.041	4.94±0.017	9.28	13.87
Starch content	HKI 209 × HKI 1128	69.65±0.45	67.18±0.51	73.25±0.19	70.11±0.40	70.20±0.13	67.45±0.755	5.17	4.29
	HKI 209 × HKI 163	68.73±0.09	73.54±0.04	78.52±0.01	76.98±0.97	67.83±0.00	73.72±0.01	6.77	1.96
	HKI 1332 × HKI 1128	72.26±0.05	73.60±0.06	79.05±0.41	76.16±0.70	71.69±0.50	74.03±0.33	7.40	3.66
	HKI 1332 × HKI 163	72.15±0.13	73.24±0.29	81.87±0.75	75.61±0.86	71.23±1.68	73.62±0.04	11.78	7.64
	HKI 325-17AN × HKI 1128	74.68±0.12	76.41±0.05	78.62±0.06	77.12±0.17	67.83±0.03	73.72±0.01	2.89	1.91
	HKI 325-17AN × HKI 163	76.66±0.21	75.42±0.154	77.55±0.149	71.90±0.839	74.66±0.075	76.50±0.015	2.82	7.29

highly significant positive heterosis relative to better parent for most studied traits except days to 50 per cent tasselling, days to 50 per cent silking and days to maturity in all the six crosses, indicating that dominance direction was towards the best parent, with exception for days to 50 per cent tasselling, days to 50 per cent silking and days to maturity which showed highly significant negative heterosis relative to better parent indicating that dominance direction was towards the low respective parent. It is worth noting that heterotic effect for grain yield per plant was larger in magnitude than for any one of its components which is logically expected. The results of heterosis suggested that hybrid vigour was available for the commercial production of maize and selection of desirable hybrids among the crosses having heterotic and heterobeltiotic effects in other characters was the best way to improve the grain yield of maize. The significance of heterotic effects showed that non-additive genetic type of gene action affected such traits. These results were previously reported by Al-Ahmad (2004), El-Badawy (2012) and Elmyhum (2013).

For green fodder, maximum number of days to maturity was desirable. Among all the crosses, the range of heterobeltiosis for days to 50 per cent tasselling was from -5.82 in cross 5 (HKI 325-17AN × HKI 1128) to -0.76 in cross 4 (HKI 1332 × HKI 163) to and for days to 50 per cent silking it was from -5.19 in cross 4 (HKI 1332 × HKI 163) to -0.35 in cross 1 (HKI 209 × HKI 1128). For days to maturity, the range of heterobeltiosis was from -2.59 in cross 3 (HKI 1332 × HKI 1128) to 0.00 in cross 2 (HKI 209 × HKI 163). For plant height trait, for fodder purpose positive heterosis was considered useful and for this trait the range of heterobeltiosis was from 34.25 in cross 1 (HKI 209 × HKI 1128) to 70.70 in cross 6 (HKI 325-17AN × HKI 163). For quality traits, positive heterosis was considered desirable for both human food and cattle feed. For protein content, the range of heterobeltiosis was from 6.39 in cross 4 (HKI 1332 × HKI 163) to 17.24 in cross 6 (HKI 325-17AN × HKI 163) and for oil content the range of heterobeltiosis was from 2.84 in cross 4 (HKI 1332 × HKI 163) to 28.82 in cross 2 (HKI 209 × HKI 163). The range of heterobeltiosis for tryptophan content was from -6.50 in cross 4 (HKI 1332 × HKI 163) to 38.64 in cross 2 (HKI 209 × HKI 163) and for starch content the range of heterobeltiosis was from 2.82 in cross 6 (HKI 325-17AN × HKI 163) to 11.78 in cross 4 (HKI 1332 × HKI 163).

As it is well known, both heterosis and inbreeding depression effects are to coincide to a same particular phenomenon, therefore, it is logical to expect that heterosis in F_1 will be followed by an appreciable reduction in the F_2 performance and vice-versa due to the direct effect of homozygosis. Values of inbreeding depression, which are presented in Table 1, were positive for all studied traits in six crosses, except for days to 50 per cent silking and days to 50 per cent tasselling in all the crosses and for days to maturity in cross 1 (HKI 209 × HKI 1128), cross 2 (HKI 209 × HKI 163), cross 4 (HKI 1332 × HKI 163) and cross 5 (HKI 325-17AN × HKI 1128). The difference in the estimates obtained between populations from different crosses could be due to the difference in the nature and number of genes involved in the control of the characters in the source populations. It could also be due to the interactions between the genotype and the environment.

In all the selfed populations, the estimates of inbreeding depression for grain yield per plant (32.14) was highest in cross 3 (HKI 1332 × HKI 1128) followed by tryptophan content (27.87) in cross 2 (HKI 209 × HKI 163), oil content (26.81) in cross 5 (HKI 325-17AN × HKI 1128), plant height (20.84) in cross 1 (HKI 209 × HKI 1128) and protein content (19.52) in cross 5 (HKI 325-17AN × HKI 1128). The high estimate of inbreeding depression indicates the role of non-additive gene action for the corresponding traits. For days to maturity among all the crosses, the highest inbreeding depression was in cross 4 (HKI 1332 × HKI 163) (1.46) and for starch content it was in cross 4 (HKI 1332 × HKI 163) (7.64). These results are in harmony with previous results obtained by Al-Ahmad (2004) and El-Badawy (2012).

Broad and Narrow Sense Heritability

The broad sense heritability was greater than narrow sense heritability for all traits studied in all the crosses (Table 2) and these results indicated that the environment had an important role in the expression of these traits. For all traits studied in the six crosses, narrow sense heritability values were lower than those of broad sense indicating that most of genetic variance was due to non-additive effects i. e. dominance and/or epistasis. In general, high estimates of broad sense heritability were observed for all the traits studied, except tryptophan content in cross 1 (HKI 209 × HKI 1128) and cross 3 (HKI 1332 × HKI 1128) which showed moderate levels of heritability in broad sense. For grain yield per plant, highest heritability was reported in cross 5 (HKI 325-17AN × HKI 1128) (97.70) followed by cross 4 (HKI 1332 × HKI 163) (96.37), cross 6 (HKI 325-17AN × HKI 163) (95.52), cross 1 (HKI 209 × HKI 1128) (95.38), cross 3 (HKI 1332 × HKI 1128) (94.14) and cross 2 (HKI 209 × HKI 163) (92.69).

This finding ascertained the previously studies on the nature of gene action where the non-additive gene effects were found to have a great role in these traits. There is enough scope for selection based on these characters and the diverse genotypes can provide materials for a sound breeding programme. Such results are in agreement with the earlier findings of Al-Ahmad (2004), Rafiq *et al.* (2010), El-Badawy (2012) and Reddy *et al*. (2013).

Genetic Advance

The genetic advance is a useful indicator of the progress that can be expected as a result of exercising selection on the pertinent population. Johnson *et al*. (1955) reported that effectiveness of selection depended not only on heritability but also on genetic advance. The

TABLE 2
Estimates of heritability and genetic advance for different characters in maize

Character	Crosses	Mean±S. E. (F_2)	Range (F_2)	Heritability (bs) %	Heritability (ns) %	Genetic advance	Genetic advance as % of mean
Days to 50% tasselling	HKI 209 × HKI 1128	54.36±0.52	50-59	90.60	29.67	5.06	9.31
	HKI 209 × HKI 163	54.50±0.50	51-59	86.68	26.64	2.31	4.25
	HKI 1332 × HKI 1128	53.440±0.30	53-63	87.17	42.73	1.13	2.11
	HKI 1332 × HKI 163	53.16±0.27	51-61	83.39	55.34	1.22	2.29
	HKI 325-17AN × HKI 1128	53.76±0.33	51-64	73.46	29.85	1.3	2.42
	HKI 325-17AN × HKI 163	53.52±0.28	52-61	78.93	18.58	1.72	3.22
Days to 50% silking	HKI 209 × HKI 1128	57.24±0.41	53-62	83.84	16.15	4.58	8.00
	HKI 209 × HKI 163	56.70±0.52	52-63	79.26	37.34	2.36	4.16
	HKI 1332 × HKI 1128	55.52±0.32	50-62	67.65	57.84	2.07	3.73
	HKI 1332 × HKI 163	56.12±0.30	54-63	83.89	64.38	1.38	2.46
	HKI 325-17AN × HKI 1128	56.64±0.21	53-65	74.70	26.78	1.6	2.82
	HKI 325-17AN × HKI 163	57.08±0.34	55-65	84.67	31.83	1.46	2.55
Days to maturity	HKI 209 × HKI 1128	82.72±0.52	80-90	91.65	7.36	5.08	6.15
	HKI 209 × HKI 163	85.30±0.54	81-92	64.79	22.58	3.12	3.66
	HKI 1332 × HKI 1128	83.40±0.43	82-90	77.14	65.15	2.26	2.71
	HKI 1332 × HKI 163	83.96±0.49	81-93	83.35	45.07	2.26	2.69
	HKI 325-17AN × HKI 1128	85.28±0.36	84-91	84.20	23.68	1.53	1.79
	HKI 325-17AN × HKI 163	85.72±0.28	82-94	85.31	29.36	1.13	1.32
Plant height	HKI 209 × HKI 1128	165.68±7.35	103-238	96.40	4.34	20.54	12.40
	HKI 209 × HKI 163	191.70±3.48	102-227	71.24	29.11	20.21	10.54
	HKI 1332 × HKI 1128	173.64±2.54	112-236	97.23	12.57	3.13	1.81
	HKI 1332 × HKI 163	176.64±2.98	116-228	74.10	21.50	14.12	8.00
	HKI 325-17AN × HKI 1128	174.88±3.99	122-220	95.79	11.15	7.46	4.26
	HKI 325-17AN × HKI 163	180.08±4.70	124-217	97.26	4.61	6.91	3.84
Ear height	HKI 209 × HKI 1128	73.76±3.17	50-103	92.40	10.98	6.71	9.10
	HKI 209 × HKI 163	88.30±1.11	56-100	34.61	31.29	6.11	6.92
	HKI 1332 × HKI 1128	75.76±1.31	59-98	97.42	40.28	2.11	2.79
	HKI 1332 × HKI 163	75.64±1.36	53-98	72.36	54.47	4.37	5.78
	HKI 325-17AN × HKI 1128	72.72±2.16	56-95	94.92	13.60	5.27	7.25
	HKI 325-17AN × HKI 163	82.12±1.85	62-94	77.37	39.83	6.90	8.40
Cob length	HKI 209 × HKI 1128	14.40±0.19	12.6-17.00	93.57	12.31	2.75	19.07
	HKI 209 × HKI 163	14.42±0.52	12.8-16.5	89.82	29.70	2.73	18.94
	HKI 1332 × HKI 1128	13.55±0.42	12.6-16.4	96.77	15.85	0.76	5.59
	HKI 1332 × HKI 163	14.38±0.36	12.2-16.00	90.39	9.98	0.45	3.11
	HKI 325-17AN × HKI 1128	13.63±0.39	12.6-16.4	97.31	9.61	0.74	5.41
	HKI 325-17AN × HKI 163	14.06±0.10	12.6-15.5	77.32	25.91	0.36	2.54
Cob diameter	HKI 209 × HKI 1128	4.01±0.05	3.5-4.5	74.39	15.21	0.78	19.88
	HKI 209 × HKI 163	3.93±0.16	3.8-4.4	81.91	36.04	0.33	8.28
	HKI 1332 × HKI 1128	3.84±0.09	3.6-4.7	76.81	23.45	0.48	12.4
	HKI 1332 × HKI 163	4.33±0.12	3.4-4.7	88.74	15.98	0.50	11.46
	HKI 325-17AN × HKI 1128	4.05±0.05	3.6-4.7	67.18	62.50	0.27	6.72
	HKI 325-17AN × HKI 163	3.75±0.09	3.4-4.20	92.29	14.51	0.21	5.48
No. of grains/cob	HKI 209 × HKI 1128	352.68±18.23	206-502	95.67	11.19	28.14	7.99
	HKI 209 × HKI 163	352.30±5.15	216-478	72.38	59.62	18.42	5.23
	HKI 1332 × HKI 1128	309.04±19.69	222-496	91.44	17.31	13.32	4.31
	HKI 1332 × HKI 163	320.72±19.98	216-494	92.67	16.01	7.51	2.34
	HKI 325-17AN × HKI 1128	330.44±11.41	222-496	97.79	4.67	18.24	5.52
	HKI 325-17AN × HKI 163	397.12±13.92	228-497	82.29	34.25	73.16	18.42

Contd.

Table 2 contd.

100-grain weight	HKI 209 × HKI 1128	22.05±0.40	19.35-26.3	79.91	37.10	3.57	16.19
	HKI 209 × HKI 163	21.04±0.63	19.22-26.45	55.82	34.02	5.01	23.83
	HKI 1332 × HKI 1128	22.12±0.75	19.24-26.12	74.96	55.88	3.58	16.17
	HKI 1332 × HKI 163	22.14±0.48	18.32-25.80	94.73	19.54	1.36	6.15
	HKI 325-17AN × HKI 1128	23.39±0.31	19.24-26.12	92.80	11.01	1.02	4.36
	HKI 325-17AN × HKI 163	22.44±0.59	17.22-26.15	73.07	53.40	3.51	15.66
Grain yield/plant	HKI 209 × HKI 1128	83.21±5.00	43.73-124.35	95.38	11.07	13.39	16.09
	HKI 209 × HKI 163	91.95±2.75	46.7-122.21	92.69	25.18	10.9	11.85
	HKI 1332 × HKI 1128	78.42±2.72	52.7-120.28	94.14	13.87	4.19	5.34
	HKI 1332 × HKI 163	81.14±3.34	53.66-119.55	96.37	8.83	6.88	8.48
	HKI 325-17AN × HKI 1128	92.29±2.48	59.7-118.8	97.70	10.39	4.50	4.87
	HKI 325-17AN × HKI 163	99.26±3.43	53.7-112.31	95.52	31.73	4.84	4.88
Shelling percentage	HKI 209 × HKI 1128	77.26±0.92	67.88-82.35	69.62	41.85	4.96	6.42
	HKI 209 × HKI 163	77.36±0.97	65.88-81.12	75.33	66.98	2.73	3.52
	HKI 1332 × HKI 1128	76.85±0.65	67.58-80.18	95.54	21.20	1.44	1.88
	HKI 1332 × HKI 163	75.94±0.29	66.78-80.32	70.09	13.80	1.50	1.97
	HKI 325-17AN × HKI 1128	79.31±0.36	65.58-78.28	96.27	7.74	0.72	0.91
	HKI 325-17AN × HKI 163	79.98±0.46	66.28-80.32	89.14	19.63	1.62	2.03
Protein content	HKI 209 × HKI 1128	9.67±0.20	8.20-11.50	74.69	55.18	2.01	20.79
	HKI 209 × HKI 163	10.90±0.32	8.50-11.22	94.27	60.91	0.27	2.49
	HKI 1332 × HKI 1128	10.11±0.19	8.30-11.00	92.64	11.93	0.45	4.42
	HKI 1332 × HKI 163	9.04±0.14	8.6-11.20	89.61	10.26	0.13	1.44
	HKI 325-17AN × HKI 1128	9.09±0.09	7.90-10.20	90.82	69.84	0.3	3.28
	HKI 325-17AN × HKI 163	9.79±0.21	8.72-10.94	94.50	15.96	0.63	6.40
Tryptophan content	HKI 209 × HKI 1128	0.49±0.01	0.36-0.64	66.66	60.00	0.11	23.03
	HKI 209 × HKI 163	0.44±0.03	0.32-0.62	75.00	50.00	0.09	20.93
	HKI 1332 × HKI 1128	0.56±0.015	0.46-0.63	72.22	50.00	0.08	14.1
	HKI 1332 × HKI 163	0.68±0.018	0.42-0.65	83.33	50.00	0.07	9.54
	HKI 325-17AN × HKI 1128	0.59±0.012	0.43-0.62	77.77	33.33	0.05	7.73
	HKI 325-17AN × HKI 163	0.69±0.013	0.35-0.76	75.00	25.00	0.08	11.46
Oil content	HKI 209 × HKI 1128	4.32±0.08	3.73-4.95	77.41	45.80	0.67	15.60
	HKI 209 × HKI 163	3.68±0.08	3.72-4.88	89.18	31.08	0.21	5.67
	HKI 1332 × HKI 1128	4.20±0.12	3.46-4.78	93.97	13.84	0.29	6.92
	HKI 1332 × HKI 163	4.14±0.07	3.83-4.76	90.23	27.85	0.29	6.95
	HKI 325-17AN × HKI 1128	4.62±0.08	3.74-4.88	96.96	74.67	0.15	3.15
	HKI 325-17AN × HKI 163	4.52±0.01	3.42-4.98	98.15	6.80	0.15	3.38
Starch content	HKI 209 × HKI 1128	70.11±0.40	65.86-73.27	79.48	72.19	3.52	5.02
	HKI 209 × HKI 163	76.98±0.97	66.77-73.17	92.85	58.25	0.81	1.05
	HKI 1332 × HKI 1128	76.16±0.71	65.68-72.27	97.63	14.54	0.26	0.34
	HKI 1332 × HKI 163	75.61±0.86	66.82-72.20	97.15	8.06	0.83	1.10
	HKI 325-17AN × HKI 1128	77.12±0.17	64.58-74.27	94.84	9.25	0.27	0.35
	HKI 325-17AN × HKI 163	71.89±0.84	68.17-75.22	97.93	5.17	1.35	1.88

highest genetic advance for days to maturity (5.08) and plant height (20.54) and grain yield per plant (13.39) was recorded in cross 1 (HKI 209 × HKI 1128). Also in cross 1 (HKI 209 × HKI 1128) among all the traits studied, the highest genetic advance was recorded for number of grains per cob (28.14), while among all the six crosses it was recorded in cross 6 (HKI 325-17AN × HKI 163) (73.16). Highest genetic advance for protein content (2.01) and oil content (15.60) was recorded in cross 1 (HKI 209 × HKI 1128). Among all the crosses studied, the genetic advance as per cent of mean was highest in case of 100-grain weight (23.83%) in cross 1 (HKI 209 × HKI 1128). For plant height, it was recorded highest in cross 1 (HKI 209 × HKI 1128) (12.4%) among all the crosses and for grain yield also it was recorded highest in cross 1 (HKI 209 × HKI 1128) (12.4%). For grain yield per plant, the highest genetic advance as per cent of mean was observed in cross 1 (HKI 209 × HKI 1128) (16.09) followed by cross 2 (HKI 209 × HKI 163) (11.85) and cross 4 (HKI 1332 × HKI 163) (8.48).

The information on heritability and genetic advance helps to predict the genetic gain that could be obtained in later generations, if selection is made for improving the particular trait under study. In general, the characters that show high heritability with high genetic advance are controlled by additive gene action and can be improved through simple or progeny selection methods. Selection for the traits having high heritability coupled with high genetic advance is likely to accumulate more additive genes leading to further improvement of their performance. In the present study, high heritability along with high genetic advance was noticed for number of kernels per row in cross 6 (HKI 325-17AN × HKI 163), other characters showed moderate or low heritability along with moderate or low genetic advance which can be improved by inter-mating superior genotypes of segregating population developed through combination breeding.

The inbred lines revealed good potential to be used as parents in the crosses to make single cross hybrid and can also be used to develop improved population through *inter se* matings. The cross combinations exhibiting high heterosis in F_1 coupled with high inbreeding depression in F_2 generation for the traits indicated non-additive gene action. This gene action can be fully exploited only by developing hybrid cultivars.

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