GENETIC ANALYSIS OF SEED MORPHOMETRIC OF YELLOW KERNEL SINGLE CROSS HYBRID MAIZE

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ABSTRACT

Seed dimension improvement requires an assessment of seed metrics and the relationships among the seed traits. Therefore, the objectives of this study were to detect the basic principles underlying seed shape in maize, determine the relationships among the elements of the seed dimension and examine heterosis in the seed morpho-traits. Seeds of 50 yellow kernel single cross hybrid maize were subjected to morphometric analysis in three replications along with their parents in a laboratory experiment using digital imaging system. Data on seed angle (SA), seed embryo angle (SEA), seed diameter (SD), seed perimeter (SP), seed thickness (ST), seed width (SW) and seed length (SL) were collected while seed area (SAR), seed shape factor (SSF), flatness index (FI) and eccentric index (SI) were estimated. The data were subjected to variance and Pearson's correlation analyses. Heterosis was estimated for the seed morpho-traits and index score method was employed to rank the hybrids for heterosis. High significant variation existed for the seed morpho-traits among the hybrids. Seed diameter, seed perimeter, seed width, seed length and seed area distinguished and rated TZEI13×BD74-161, BD74-165×BD74-161, TZEI124×BD74-161 and TZEI146×BD74-161 high in seed morphometric. Seed angle correlated with the SEA; the SD associated with SP, SL, SW, SAR and SSF whereas SP can be selected for SSF and flatness index. The SD, SW and SL can be improved through heterosis. The crosses involving inbred lines TZEI13 and BD74-161 expressed high vigour over their parents. Hence, they can be explored in hybrid maize seed production.

Key words: Heterosis, hybrid maize, morphometric, seed dimension, seed metric, seed quality

INTRODUCTION

Seeds of maize (*Zea mays* L.) exist in varied shapes and sizes in different genotypes of the crop. The dimension of the seeds may also vary based on their positions on the ear. However, the seeds tend to be similar in dimension as they approach the middle of the ear from both the axial and distal ends. Hence, the seeds at the middle of the ear can be regarded to be similar in size and shape. It has been reported that farmers widely believe that large and flat seeds germinate faster and produce larger seedlings than other sizes or shapes (El-Abady, 2015). On the contrary, Lafond and Baker (1986) found that smaller seeds of wheat cultivars germinate faster and their seedlings grow more quickly than large seeds.

Seed quality provides information on the effective seeds placement which may affect rate, volume and uniformity of seed emergence as well as growth of the resultant seedlings. Seed size is an important target in crop improvement because of the requirements of both the end-use quality and consumer preference (Gupta *et al.*, 2006). Apart from suitability for mechanization in terms of sowing and processing, the morphology of the seed may influence the market value as well as consumer preference for a particular maize genotype. Seed size has also been proposed to be a key contributor to grain yield in cereals (Kesavan *et al.*, 2013). Understanding the determinants of seed size is, therefore, essential to meet increasing demand for food staples and renewable energy by the ever-growing human population.

Heterosis, which is increase of size, yield and vigour through cross-breeding is a popular method of crop improvement. It induces increase in the parameters in crop (Shull, 1948). Heterosis breeding could be a potential alternative for achieving significant increases in performance or expression in traits of crop. This crop improvement technique had been used for many agronomic traits including crop yield and its related traits in many crops. Wali *et al.* (2010) reported that heterosis has been successfully harnessed in maize improvement than in any other crop species. Maize seed dimension is crucial to grain yield in the breeding programmes (Chen *et al*., 2016), but reports on the use of heterosis for maize seed dimension improvement are scanty. Hence, this will be a step forward in maize improvement achievable through hybridization which ultimately results in heterosis.

Seed morphometric (dimension of length, width, angle and area of seed) is an important tool in the study of morphological traits of crops which has been widely and successfully used to discriminate cultivars of many crops (Apuan *et al*., 2011; Daniel *et al*., 2012). The dimension measurement and analysis are possible for a single seed by the use of image analysis technique or machine vision systems. This technique has gradually replaced manual inspection of samples for the seed traits, especially where the information could be visually obtained repeatedly. The image analysis technique is faster, more reliable and involves non-destructive inspection of the specimens (Geetha *et al*., 2011; Grillo *et al*., 2011; Sumathi and Balamurugan, 2013).

Seed size and shape have been reported as important grading parameters of seed grains of many crops especially cereals and pulses (Graven and Carter, 1990; Shahin *et al*., 2006). Therefore, breeding for seed quality in terms of size, shape and thickness and determining some seed shape factors requires a fundamental assessment of the seed metrics and the relationships among the traits.

Hence, the objectives of this study were to detect the basic principles underlying seed size in maize, determine the relationships among the elements of the seed dimension and specifically elucidate heterosis caused by increase in the frequency of favourable alleles of the crop through hybridization.

MATERIALS AND METHODS

A total of 50 yellow kernel hybrid maize were tested along with their respective parents in a laboratory experiment conducted at Institute of Agricultural Research and Training, Obafemi Awolowo University, Ibadan. The 50 hybrids were selected based on their comparatively high grain yield and ear aspect as well as availability of seeds from 66 hybrids generated from 12 inbred lines using non-reciprocal diallel mating system. All the 12 parental lines were evaluated with the selected 50 hybrids in the study. Samples were drawn from the seed lot of each of the hybrids and parental lines for morphometric analysis.

Forty whole and intact consecutive kernels were obtained at 10 per ear column from four consecutive ear rows in the middle of the uppermost or only ear of each selected hybrid and each parent line of the maize.

The seeds were subjected to morphometric analysis using Completely Randomized Design in three replicates. Sample from each replicate containing 10 seeds of each hybrid or parent line were viewed under digital imaging using Universal Serial Bus microscope (Veho™ UK). The seeds were placed one after the other with their embryo axes facing the lens of the camera under light. The light on the USB microscope was calibrated by adjusting its magnification to ×35 to obtain the brightest image before measuring the parameters.

Morphometric data were taken according to Grillo *et al*. (2011) and Geetha *et al*. (2011) as follows: seed length (SL) was measured as the distance between the base of the embryo axis to the tip of the endosperm of the seed; seed width (SW) was measured across the middle, and at right angle to the length of the seed; seed thickness (ST) was measured across the middle, and at right angle to the width of the seed using digital vernier callipers; the seed perimeter (SP) was the perimeter of a circle drawn around the seed ensuring the line touches all edges of the seed; while seed diameter (SD) was the length of a line drawn across the circle made round the seed.

Other parameters measured were seed angle (SA) which was the angle created in between two lines touching each other at the tip where the seed is attached to the husk, and seed embryo angle was the angle formed in between two lines touching the edge of the embryo on the seed endosperm. Estimations was made on seed area (SAR) as the seed length × seed width; shape factor (SSF) as using $4\pi A/C^2$, where A is the seed area, C = seed perimeter (Grillo *et al*., 2011; Geetha *et al*., 2011); flatness index (FIX) as the ratio of seed length to seed width and seed thickness using FI= SL+ SW/2ST according to Adewale *et al*. (2010) and eccentric index (EIX) was the ratio of SL to SW according to Balkays and Odabas (2002).

Mid-parent heterosis (MPH) and better-parent heterosis (BPH) were estimated for each seed morpho-trait according to Comstock and Robinson (1952) as:

$$\text{MPH} = \frac{F_1 - \text{MP}}{\text{MP}} \times 100$$

and

$$\text{BPH} = \frac{F_1 - \text{BP}}{\text{BP}} \times 100$$

Where, F_1 was the value for a seed trait of a hybrid, MP = $(P_1 + P_2) \div 2$ in which P_1 and P_2 were the values for the seed trait of a given pair of inbred parents and BP was the value for the seed trait of the better parent.

Data collected were subjected to analysis of variance and Pearson's correlation analysis using SAS (2009) to determine the relationships among the seed morpho-traits. Least significant difference was employed to separate means among hybrids. Index score method as proposed by Anderson (1957), reported and explained by Singh and Chaudhary (1977) was employed to rank the hybrids based on their ability to express heterosis for the seed morpho-traits.

RESULTS

Mean values for seed morphometric of the hybrid maize

Highly significant variation ($p < 0.001$) existed for all the seed morphometrics among the hybrid maize tested (Table 1). The CVs were generally low across the seed morphometric (less than 15%) except for SEA where CV was 20.82%. The SA ranged from 14.48 to 89.66° whereas SEA ranged from 79.71 to 178.88°. The ranges for SD, SP, ST, SW, SL and SAR were respectively 5.84 to 9.64 cm, 19.07 to 31.02 cm, 3.47 to 6.00 cm, 5.28 to 8.34 cm, 6.03 to 7.93 cm and 31.33 to 65.45 cm^2 whereas respective ranges for SSF, FIX and EIX were 0.74 to 1.22, 1.13 to 1.88 and 0.89 to 1.32.

Similarly, Table 1 shows that significant differences existed in the morpho-metric traits except in SEA and SW of the parent lines. The variations were highly significant for SP, ST, SL and FI *(p < 0.001*) as well as SD and SAR *(p < 0.01*) whereas SA, SSF and EI had *(p < 0.05*) significant variations. The CVs for all the traits were found to be low. The parameter was less than 10.0% for all the traits except flatness index that had 11.47%. The maximum and minimum values for the traits are also presented in the Table 1.

Table 2 shows hybrid TZEI12×TZEI11 was among the hybrids that had highest SA (89.25°) and SEA (178.88°), whereas TZEI12×TZEI16 and TZEI11×TZEI8 respectively had the least SA (74.48°) and SEA (79.71°). Hybrids TZEI16×BD74-161, TZEI13×BD74-161, TZEI10×TZEI8 and TZEI124×BD74-161 had the highest SD which were greater than 9 cm whereas TZEI13×TZEI128 and TZEI11×TZEI16 had the least (less than 6 cm).

The SP was highest in TZEI124×BD74-161, TZEI13×BD74-161 and TZEI16×BD74-161 (greater than 30 cm) but least in TZEI11×TZEI16 (less than 20 cm). Only TZEI146×BD74-161 had ST equal to 6.0 cm and TZEI10×TZEI124, TZEI12×TZEI124, TZEI12×BD74-165 and TZEI128×TZEI11 had least ST which were less than 4.0 cm. For SW, TZEI13×BD74161, TZEI124×BD74-161 and TZEI146×BD74-161 had the highest whereas TZEI124×BD74-161, TZEI13×BD74-161, TZEI16×BD74-161 and BD74-165×BD74-161 were among the hybrids that had highest SL. It was also found that TZEI13×BD74-161 and TZEI 124×BD74-161 had the highest SAR with each having greater than 6 mm^2.

The variations in the morpho-metric traits of the parent lines are presented in Table 3. Mean values for the traits indicated that SA and SEA were 82.15° and 11.02°, respectively. Parent TZEI128 was prominent among the lines with high SD (7.13 mm), SP (21.92 mm), SL (6.56 mm) and SAR (12.83 mm^2). Mean values for traits of the lines were 6.84 mm, 20.44 mm, 3.93 mm, 5.99 mm, 6.25 mm and 11.35 mm for SD, SP, ST, SW, SL and SAR, respectively.

Table 1: Mean squares and other parameters of some seed morpho-traits of selected yellow kernel hybrid maize

Source of variation	df	Seed angle	Seed embryo angle	Seed diameter	Seed perimeter	Seed thickness	Seed width	Seed length	Seed area	Seed shape factor	Flatness index	Eccentric index
Hybrids												
Genotype	49	1603.87***	834.65***	2.49***	19.10***	0.90***	1.18***	0.53***	133.69***	0.03***	0.12***	0.02***
Replicate	2	3.61	538.10	2.34	2.81	0.02	0.09	0.02	8.28	0.03	0.003	0.003
Error	98	26.68	584.28	0.75	1.40	0.13	0.16	0.08	10.84	0.01	0.02	0.008
CV (%)		7.18	20.82	11.60	4.88	7.62	6.02	4.16	7.20	10.02	8.97	8.51
R^2		96.78	42.23	63.26	87.29	77.73	78.61	76.53	86.09	62.14	77.62	55.04
Maximum		89.25	178.88	9.64	31.02	6.00	8.34	7.93	65.45	1.22	1.88	1.32
Minimum		72.74	79.71	5.84	19.07	3.47	5.28	6.03	31.83	0.74	1.13	0.89
Parent (inbred lines)												
Genotype	11	43.40*	90.56	0.05**	1.16***	0.01***	0.07	0.90***	2.51**	0.03*	34.01***	0.007*
Replicate	2	22.39	114.19	0.01	0.17	0.0003	0.001	0.01	0.11	0.02	3.53	0.001
Error	22	15.42	57.00	0.01	0.16	0.002	0.04	0.008	0.61	0.01	1.80	0.003
CV (%)		4.78	6.80	5.52	3.51	9.01	5.84	2.83	6.92	3.06	11.47	6.03
R^2		60.62	50.60	69.49	78.69	81.54	44.80	84.41	67.23	57.17	82.95	54.56
Maximum		77.7	102.68	1.70	10.70	0.27	3.26	3.00	9.84	3.49	12.80	0.87
Minimum		90.76	117.34	2.13	12.92	0.52	3.68	3.56	12.83	3.88	25.23	1.03

df= degree of freedom, CV=coefficient of variation and R^2=coefficient of determination

Table 2: Variation in means of some seed morpho-traits of selected yellow kernel single cross hybrid maize

Hybrid	SA (°)	SEA (°)	SD (mm)	SP (mm)	ST (mm)	SW (mm)	SL (mm)	SA (mm²)	SSF	FIX	EIX
TZEI13×TZEI10	80.85	108.27	7.62	24.43	4.33	6.79	6.88	46.69	0.98	1.58	1.01
TZEI13×TZEI12	81.12	134.75	6.73	25.12	4.20	6.86	6.99	47.98	0.96	1.65	1.02
TZEI13×TZEI128	81.40	161.23	5.84	25.81	4.07	6.95	7.11	49.35	0.93	1.74	1.02
TZEI13×TZEI11	79.79	134.11	7.79	24.79	5.37	6.43	6.94	44.61	0.91	1.27	1.08
TZEI13×TZEI16	78.22	108.82	7.45	24.21	4.47	6.71	6.77	45.38	0.97	1.56	1.01
TZEI13×TZEI124	80.14	106.86	7.68	26.21	4.53	6.65	6.92	45.99	0.86	1.50	1.04
TZEI13×BD74-165	88.77	116.88	6.74	22.40	5.50	6.60	6.56	43.30	1.08	1.20	0.99
TZEI13×BD74-161	84.65	107.21	9.47	30.53	4.67	8.34	7.85	65.45	0.88	1.73	0.94
TZEI13×BD74-222	83.35	123.23	8.04	26.11	5.07	7.23	7.15	51.91	0.95	1.42	0.99
TZEI146×TZEI10	78.62	139.24	7.15	23.26	5.20	6.27	6.69	41.99	0.98	1.25	1.07
TZEI146×TZEI12	82.89	112.84	7.09	22.99	4.70	6.61	6.65	44.02	1.05	1.42	1.01
TZEI146×TZEI128	78.80	101.94	8.07	26.27	4.60	6.98	7.17	50.07	0.91	1.54	1.03
TZEI146×TZEI 11	84.41	116.94	6.13	21.70	4.10	6.17	6.45	39.79	1.06	1.55	1.05
TZEI146×TZEI8	75.94	99.42	7.69	24.91	4.47	6.27	6.95	43.56	0.88	1.48	1.11
TZEI146×TZEI16	86.66	116.24	7.53	21.95	5.10	5.95	6.49	38.61	1.01	1.22	1.12
TZEI146×TZEI124	86.23	118.88	6.87	23.00	5.27	6.65	6.65	44.18	1.05	1.27	1.00
TZEI146×BD74-165	86.96	116.74	7.26	23.53	4.73	6.88	6.74	46.38	1.05	1.44	0.98
TZEI146×BD74-161	86.55	113.82	7.88	26.42	6.00	7.89	7.19	56.73	1.02	1.26	0.91
TZEI10×TZEI12	82.99	127.18	7.29	23.83	4.77	7.12	6.81	48.46	1.07	1.47	0.96
TZEI10×TZEI128	80.83	112.85	7.01	22.98	4.80	6.38	6.65	42.40	1.01	1.36	1.04
TZEI10×TZEI8	72.74	94.92	9.37	25.53	4.27	5.75	7.34	41.66	0.81	1.54	1.32
TZEI10×TZEI16	77.10	115.67	6.69	21.35	4.33	6.65	6.48	43.11	1.19	1.54	0.98
TZEI10×TZEI124	80.39	144.74	6.25	20.37	3.93	5.74	6.24	35.80	1.09	1.53	1.09
TZEI10×BD74-165	83.32	111.52	6.49	22.15	4.33	6.42	6.51	41.82	1.07	1.49	1.01
TZEI10×BD74-161	81.09	121.97	8.01	25.94	4.80	7.05	7.10	50.04	0.94	1.47	1.01
TZEI12×TZEI128	76.25	112.24	7.37	23.24	4.20	6.21	6.69	41.51	0.97	1.56	1.08
TZEI12×TZEI11	89.25	178.88	7.37	23.26	4.10	7.01	6.85	47.97	1.12	1.70	0.98
TZEI12×TZEI8	76.00	115.79	7.07	21.97	4.50	6.23	6.47	40.32	1.05	1.41	1.04
TZEI12×TZEI16	74.48	97.60	8.31	26.41	4.00	6.24	7.19	44.84	0.81	1.68	1.15
TZEI12×TZEI124	80.16	108.22	7.99	25.77	3.87	7.47	7.07	52.76	1.00	1.88	0.95
TZEI12×BD74-165	79.99	105.57	7.09	25.94	3.87	6.73	6.56	44.55	0.83	1.72	0.97
TZEI12×BD74-161	78.65	105.57	8.35	27.10	5.23	7.10	7.29	51.74	0.89	1.38	1.03
TZEI128×TZEI11	80.01	112.45	7.26	22.73	3.47	6.21	6.66	41.34	1.01	1.87	1.07
TZEI128×TZEI8	76.13	111.26	7.11	23.88	4.57	6.77	6.21	42.08	0.93	1.42	0.92
TZEI128×TZEI16	84.18	116.94	7.56	24.18	5.43	6.48	6.75	43.73	0.95	1.22	1.05
TZEI128×TZEI124	79.26	110.12	6.71	22.33	4.77	6.23	6.55	40.76	1.03	1.34	1.05
TZEI128×BD74-165	82.45	131.79	7.04	22.93	5.10	6.52	6.69	43.60	1.04	1.30	1.03
TZEI11×TZEI8	75.25	79.71	8.29	26.03	5.60	5.56	7.14	39.70	0.74	1.13	1.28
TZEI11×TZEI16	79.71	102.29	5.91	19.07	4.40	5.28	6.03	31.83	1.10	1.30	1.14
TZEI11×TZEI124	79.72	114.05	7.33	23.35	5.63	6.40	6.71	42.97	0.99	1.17	1.05
TZEI11×BD74-165	87.78	115.80	6.68	23.09	4.80	6.63	6.65	44.03	1.04	1.39	1.00
TZEI11×BD74-161	79.68	97.34	8.46	26.64	4.63	6.89	7.23	49.87	0.88	1.53	1.05
TZEI8×TZEI16	81.22	109.63	6.94	22.33	4.83	6.13	6.55	40.11	1.01	1.31	1.07
TZEI8×BD74-165	86.63	131.67	6.79	22.61	5.40	7.49	6.59	49.39	1.22	1.31	0.89
TZEI16×TZEI124	84.30	108.07	6.29	20.41	5.20	5.57	6.25	34.79	1.05	1.14	1.13
TZEI16×BD74-165	79.96	127.73	6.37	21.73	5.40	6.64	6.45	42.81	1.14	1.21	0.97
TZEI16×BD74-161	77.03	108.53	9.64	30.49	4.20	7.55	7.83	59.07	0.87	1.83	1.04
TZEI124×BD74-165	84.31	110.68	8.80	22.64	4.83	6.65	6.83	45.37	1.11	1.40	1.03
TZEI124×BD74-161	77.35	94.47	9.21	31.02	4.30	8.17	7.93	64.83	0.85	1.88	0.97
BD74165×BD74-161	88.83	131.80	8.68	27.85	5.00	7.40	7.72	57.12	0.93	1.52	1.04
Mean	**81.25**	**116.09**	**7.46**	**24.26**	**4.70**	**6.66**	**6.84**	**45.73**	**0.99**	**1.46**	**1.04**
LSD	**8.29**	**39.13**	**1.43**	**1.94**	**0.58**	**0.65**	**0.46**	**5.32**	**0.16**	**0.21**	**0.14**

SA=seed angle, SEA=seed embryo angle, SD=seed diameter, SP=seed perimeter, ST=seed thickness, SW=seed width, SL= seed length, SAR=seed area, SSF=shape factor, FIX=flatness index, EIX=eccentric index, LSD=Least significant difference

Table 3: Variation in means of some seed morpho-traits of selected yellow kernel single cross hybrid maize

Inbred line	SA (°)	SEA (°)	SD (mm)	SP (mm)	ST (mm)	SW (mm)	SL (mm)	SA (mm^2)	SSF	FIX	EIX
TZEI13	79.60	102.68	6.78	20.21	3.93	5.99	6.10	10.82	3.69	15.45	0.89
TZEI146	85.15	115.64	6.82	20.57	4.00	6.02	6.42	12.04	3.77	14.02	0.97
TZEI10	79.60	104.29	6.87	20.76	3.99	6.18	6.25	11.93	3.70	14.14	0.89
TZEI12	81.65	108.96	6.73	19.90	3.93	6.11	6.14	11.35	3.88	15.56	0.87
TZEI128	77.70	117.34	7.13	21.92	3.93	6.10	6.56	12.83	3.49	16.79	1.00
TZEI11	80.72	110.02	6.70	19.70	3.94	5.76	6.02	9.84	3.68	14.31	0.93
TZEI8	77.73	106.85	6.89	20.87	3.95	6.10	6.18	11.43	3.58	15.28	0.89
TZEI16	80.23	104.58	6.72	19.84	3.89	5.83	6.00	9.98	3.66	16.29	0.90
TZEI124	85.56	114.86	6.96	20.53	3.77	6.01	6.37	11.83	3.75	25.23	0.96
BD74-165	90.76	117.14	6.73	19.91	4.02	5.76	6.34	10.89	3.80	12.80	1.03
BD74-161	84.57	112.84	6.86	20.26	3.91	5.92	6.19	10.91	3.69	16.27	0.93
BD74-222	82.51	117.05	6.88	20.86	3.86	6.17	6.38	12.40	3.73	20.35	0.92
Mean	**82.15**	**111.02**	**6.84**	**20.44**	**3.93**	**5.99**	**6.25**	**11.35**	**3.70**	**16.38**	**0.93**
LSD	**6.65**	**12.78**	**0.17**	**0.68**	**0.07**	**0.35**	**0.16**	**1.33**	**0.19**	**3.18**	**0.10**

SA=seed angle, SEA=seed embryo angle, SD=seed diameter, SP=seed perimeter, ST=seed thickness, SW=seed width, SL= seed length, SAR=seed area, SSF=shape factor, FIX=flatness index, EIX=eccentric index, LSD=Least significant difference

Association among the seed morphometric traits of the hybrid maize

Pearson's correlations coefficients of the seed morpho-traits of the maize were presented in Table 4. Seed embryo angle moderately correlated with SD (r = -0.40; $p < 0.01$), SSF (r = 0.47; $p < 0.001$) but weak correlation was observed between SEA and EIX (r = -0.34; $p < 0.01$). However, SD correlated with all other traits except ST and FIX. The correlation of SD with SP, SL, SAR and SSF was strong and positive. Moreover, the correlation of SD was moderate and positive with SW but weak with EIX (r = 0.14; $p < 0.05$). The SP was found to have strong correlation with SW, SL, SAR, SSF and FIX. The correlation of the SP with these traits were positive except with SSF which was negative. The ST had strong and negative correlation with FIX (r = -0.85; $p < 0.001$) only. Highly significant correlation was observed between SW and each of SL, SAR and EIX (r = -0.74; $p < 0.001$), but positive significant correlation of SW with FIX was moderate. The SL had a strong positive correlation with SAR (r = 0.87; $p < 0.001$); moderate correlation with FIX (r = 0.48; $p < 0.001$) but strong highly significant negative correlation with SSF. Table 4 also shows that SAR correlated moderately with FIX (r = 0.50; $p < 0.0001$) and EIX (r = -0.49; $p < 0.001$) whereas SSF had weak negative correlation with FIX and EIX.

Heterosis estimates for seed morphometric of yellow kernel hybrid maize

The estimates of MPH and BPH, total heterosis scores and ranks of the hybrid maize based on their heterosis estimates were presented in Table 5. Positive and negative estimates were recorded for all the seed morphometric as expressed by the hybrids. The ranges of MPH and BPH for SA were -7.21% to 6.60% and -11.90% to 4.92% respectively, whereas MPH ranged from -26.49% to 63.38% and BPH ranged from -37.55% to 62.59% for SEA. The MPH for SD, SP, ST, SW and SL respectively ranged from -16.03% to

41.97%, -3.54% to 54.48%, -11.82% to 51.71%, -8.89% to 40.05% and -2.51% to 28.47% whereas the ranges for the BPH for the respective traits were -18.09% to 40.52%, -3.88% to 53.11%, -11.93% to 50.00%, -9.43% to 39.23% and -5.34% to 26.82%. A total of 20 hybrids had positive MPH for SA but only 12 had positive BPH estimates for the trait. Hybrid TZEI8×TZEI161 top the list with greater than 5% MPH and BPH and the trend was similar for SEA.

Hybrids TZEI16×BD74-161, TZEI13×BD74-161, TZEI10×TZEI8 and TZEI124× BD74-161 had highest heterosis estimates for SD with MPH and BPH greater than 30% whereas TZEI13×TZEI128 had the least MPH (-16.03%) and TZEI146×BD74-165 had the least BPH (-18.09%) for the trait. The trend of the estimates of MPH was similar to that of BPH for SP for all the hybrids with TZEI124×BD74-161, TZEI16×BD74-161 and TZEI13×BD74-161 having greater than 50% heterosis percentage. The MPH estimates for ST in all the hybrids were positive except for TZEI12×BD74-165 and TZEI128×TZEI11 which also had negative BPH estimates. Hybrids TZEI146×BD74-161, TZEI11×TZEI8, TZEI11×TZEI124 had the highest estimates (> 40%) recorded for the trait. The trend of SW was similar to SL where TZEI13×BD74-161, TZEI13×BD74-161 and TZEI16×BD74-161 were among the hybrids that had the highest MPH and BPH for the traits.

Based on the rank of the total score due to heterosis estimates, TZEI13×BD74-161, BD74-165×BD74-161, TZEI124×BD74-161 and TZEI146×BD74-161 were rated best among the 50 yellow kernel hybrid maize (Table 5). Appendix 1 shows the score index for heterotic ranks of the selected yellow kernel single cross hybrid maize whereas Appendix 2 presents the range of means and score index of heterosis estimates of some seed morphometric of hybrid maize.

Table 4: Pearson's correlation of some seed morpho-traits of selected yellow kernel single cross hybrid maize

Seed morphometric	Seed angle	Seed embryo angle	Seed diameter	Seed perimeter	Seed thickness	Seed width	Seed length	Seed area	Shape factor	Flatness index
Seed embryo angle	0.19									
Seed diameter	0.08	-0.40**								
Seed perimeter	0.11	-0.24	0.81***							
Seed thickness	0.18	-0.03	0.02	-0.06						
Seed width	0.19	0.13	0.48***	0.71***	0.05					
Seed length	0.18	-0.17	0.85***	0.94***	-0.03	0.67***				
Seed area	0.21	0.01	0.67***	0.87***	0.02	0.95***	0.87***			
Seed shape factor	0.04	0.47***	-0.62***	-0.74***	0.12	-0.09	-0.63***	-0.32		
Flatness index	-0.04	0.03	0.33	0.51***	-0.85***	0.44***	0.48***	0.50***	-0.28***	
Eccentric index	-0.07	-0.34**	0.14*	-0.12	-0.06	-0.74***	0.00	-0.49***	-0.23***	-0.19

Table 5: Heterosis estimates for some seed morpho-traits and heterotic ranks of selected yellow kernel single cross hybrid maize

Hybrid	Seed angle		Seed embryo angle		Diameter		Perimeter		Thickness		Width		Length		THS	RBH
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	PH	MPH	BPH	PH	PH	MPH	H		
TZEI13×BD74-161	3.12	0.09	-0.51	-4.99	38.86	38.05	50.88	50.69	19.13	18.83	40.05	39.23	27.75	26.82	36	1
BD74165×BD74-161	-4.37	-7.64	14.62	12.51	27.74	26.53	38.66	37.46	26.10	24.38	26.71	25.00	23.22	21.77	34	2
TZEI124×BD74-161	-5.54	-6.09	-17.02	-17.75	33.29	32.33	54.48	53.11	11.98	9.97	36.97	35.94	26.27	24.49	33	3
TZEI146×BD74-161	1.99	1.64	-0.37	-1.57	15.20	14.87	29.41	28.44	51.71	50.00	32.16	31.06	14.04	11.99	31	4
TZEI13×TZEI11	-0.46	-1.15	26.10	21.90	15.58	14.90	24.23	22.66	36.47	36.29	9.45	7.35	14.52	13.77	30	5
TZEI13×BD74-222	2.83	1.02	12.16	5.28	17.72	16.86	27.15	25.17	30.17	29.01	18.91	17.18	14.58	12.07	30	5
TZEI12×BD74-161	-5.37	-7.00	-4.81	-6.44	22.88	21.72	34.96	33.76	33.42	33.08	18.04	16.20	18.25	17.77	30	5
TZEI16×BD74-161	-6.52	-8.92	-0.17	-3.82	41.97	40.52	52.07	50.49	7.69	7.42	28.51	27.53	28.47	26.49	30	5
TZEI12×TZEI11	5.01	4.41	63.38	62.59	9.75	9.51	17.47	16.88	4.19	4.06	18.11	14.73	12.66	11.56	29	9
TZEI13×TZEI128	3.50	2.26	46.56	37.40	-16.03	-18.09	22.53	17.75	3.56	3.56	14.97	13.93	12.32	8.38	28	10
TZEI13×TZEI16	-2.12	-2.51	5.01	4.05	10.37	9.88	20.90	19.79	14.32	13.74	13.54	12.02	11.90	10.98	28	10
TZEI10×TZEI12	2.93	1.64	19.28	16.72	7.21	6.11	11.67	8.71	20.45	19.55	15.87	15.21	9.93	8.96	28	10
TZEI10×BD74-161	-1.21	-4.11	12.35	8.09	16.68	16.59	26.47	24.95	21.52	20.30	16.53	14.08	14.15	13.60	28	10
TZEI11×BD74-161	-3.59	-5.78	-12.64	-13.74	24.78	23.32	33.33	31.49	17.96	17.51	17.98	16.39	18.43	16.80	28	10
TZEI13×TZEI10	1.57	1.57	4.62	3.82	11.65	10.92	19.26	17.68	9.34	8.52	11.59	9.87	11.42	10.08	27	15
TZEI128×TZEI16	6.60	4.92	5.39	-0.34	9.17	6.03	15.80	10.31	38.87	38.17	8.63	6.23	7.48	2.90	27	15
TZEI10×TZEI8	0.35	-0.83	-10.09	-11.17	36.19	35.99	22.65	22.33	7.56	7.02	-6.35	-6.96	18.10	17.44	25	17
TZEI8×BD74-165	2.83	-4.55	17.57	12.40	-0.29	-1.45	10.89	8.34	35.51	34.33	26.31	22.79	5.27	3.94	25	17
TZEI12×TZEI16	-1.80	-2.66	-8.59	-10.43	23.57	23.48	32.91	32.71	2.30	1.78	4.52	2.13	18.45	17.10	24	19
TZEI11×TZEI8	-5.02	-6.78	-26.49	-27.55	22.00	20.32	28.32	24.72	41.95	41.77	-6.24	-8.85	17.05	15.53	24	19
TZEI13×TZEI12	0.61	-0.65	27.34	23.67	-0.37	-0.74	25.26	24.29	6.87	6.87	13.39	12.27	14.22	13.84	24	21
TZEI13×TZEI124	-2.95	-6.33	-1.76	-6.97	11.79	10.34	28.67	27.67	17.66	15.27	10.83	10.65	10.99	8.63	24	21
TZEI13×BD74-165	4.21	-2.19	6.34	-0.22	-0.22	-0.59	11.67	10.84	38.36	36.82	12.34	10.18	5.47	3.47	24	21
TZEI146×TZEI128	-3.22	-7.46	-12.49	-11.85	15.70	13.18	23.65	19.84	16.02	15.00	15.18	14.43	10.48	9.30	24	21
TZEI146×TZEI124	1.03	1.27	3.15	2.80	-0.29	-1.29	11.92	11.81	35.65	31.75	10.56	10.47	3.99	3.58	24	21
TZEI16×BD74-165	-6.47	-11.9	15.22	9.04	-5.28	-5.35	9.33	9.14	36.54	34.33	14.58	13.89	4.54	1.74	23	26
TZEI146×TZEI16	4.80	1.77	5.57	0.52	11.23	10.41	8.64	6.71	29.28	27.50	0.42	-1.16	4.51	1.09	23	26
TZEI146×BD74-165	-1.13	-4.19	0.30	-0.34	7.16	6.45	16.25	14.39	17.96	17.66	16.81	14.29	5.64	4.98	23	26

TZEI11×TZEI124	-4.11	-6.83	1.43	-0.71	7.32	5.32	16.08	13.74	46.04	42.89	8.75	6.49	8.31	5.34	23	26
TZEI11×BD74-165	2.38	-3.28	1.95	-1.14	-0.52	-0.74	16.59	15.97	20.60	19.40	15.1	15.10	7.61	4.89	23	26
TZEI124×BD74-165	-4.37	-7.11	-4.59	-5.51	28.56	26.44	13.74	13.71	24.01	20.15	13.00	10.65	7.47	7.22	23	26
TZEI146×TZEI12	-0.61	-2.65	0.48	-2.42	4.65	3.96	8.21	4.88	18.54	17.50	8.99	8.18	5.89	3.58	22	32
TZEI146×TZEI8	-6.75	-10.82	-10.63	-14.03	12.18	11.61	20.22	19.36	12.45	11.75	3.47	2.79	10.32	8.26	22	32
TZEI12×TZEI124	-4.12	-6.31	-3.30	-5.78	16.73	14.8	27.48	25.52	0.52	-1.53	23.27	22.26	13.03	10.99	22	32
TZEI8×TZEI 16	2.84	1.23	3.70	2.60	1.98	0.73	9.70	7.00	23.21	22.28	2.77	0.49	7.55	5.99	22	32
TZEI146×TZEI10	-4.56	-7.67	26.62	20.41	4.46	4.08	12.56	12.04	30.16	30.0	2.79	1.46	5.60	4.21	21	36
TZEI12×BD74-165	-7.21	-11.87	-6.62	-9.88	5.35	5.35	30.32	30.29	-2.64	-3.73	13.40	10.15	5.13	3.47	21	36
TZEI128×BD74-165	-2.11	-9.16	12.41	12.31	1.59	-1.26	9.63	4.61	28.30	26.87	9.95	6.89	3.72	1.98	21	36
TZEI10×TZEI128	2.77	1.55	1.84	-3.83	0.14	-1.68	7.69	4.84	21.21	20.30	3.91	3.24	3.83	1.37	20	39
TZEI10×TZEI16	-3.52	-3.90	10.76	10.60	-1.55	-2.62	5.17	2.84	9.90	8.52	10.74	7.61	5.80	3.68	20	39
TZEI12×TZEI8	-4.63	-6.92	7.31	6.27	3.82	2.61	7.78	5.27	14.21	13.92	2.05	1.96	5.03	4.69	20	39
TZEI128×TZEI8	-2.04	-2.06	-0.74	-5.18	1.43	-0.28	11.61	8.94	15.99	15.70	10.98	10.98	-2.51	-5.34	20	39
TZEI16×TZEI124	1.69	-1.47	-1.50	-5.91	-8.04	-9.63	1.11	-0.58	35.77	33.68	-5.91	-7.32	1.05	-1.88	20	39
TZEI11×TZEI16	-0.95	-1.25	-4.67	-7.03	-11.92	-12.05	-3.54	-3.88	12.39	11.68	-8.89	-9.43	0.33	0.17	18	44
TZEI146×TZEI 11	1.78	-0.87	3.64	1.12	-9.32	-10.12	7.77	5.49	3.27	2.50	4.75	2.49	3.70	0.47	17	45
TZEI10×TZEI124	-2.65	-6.04	32.09	26.01	-9.62	-10.20	-1.33	-1.88	1.29	-1.50	-5.82	-7.12	-1.11	-2.04	17	45
TZEI128×TZEI11	1.01	-0.88	-1.08	-4.17	4.99	1.82	9.23	3.70	-11.82	-11.93	4.72	1.80	5.88	1.52	17	45
TZEI10×BD74-165	-2.18	-8.20	0.73	-4.80	-4.56	-5.53	8.93	6.70	8.11	7.71	7.54	3.88	3.42	2.68	16	48
TZEI12×TZEI128	-4.30	-6.61	-0.80	-4.35	6.35	3.37	11.14	6.02	6.87	6.87	1.72	1.64	5.35	1.98	16	48
TZEI128×TZEI124	-2.90	-7.36	-5.15	-6.15	-4.76	-5.89	5.21	1.87	23.90	21.37	2.89	2.13	1.31	-0.15	16	48
Maximum	**6.60**	**4.92**	**63.38**	**62.59**	**41.97**	**40.52**	**54.48**	**53.11**	**51.71**	**50.00**	**40.05**	**39.23**	**28.47**	**26.82**		
Minimum	**-7.21**	**-11.90**	**-26.49**	**-27.55**	**-16.03**	**-18.09**	**-3.54**	**-3.88**	**-11.82**	**-11.93**	**-8.89**	**-9.43**	**-2.51**	**-5.34**		

MPH= mid-parent heterosis, BPH= better parent heterosis, THS= total heterosis score and RBH=rank by heterosis

DISCUSSION

Variability in traits of crops creates option from which breeders draw samples for their breeding programmes. Existence of highly significant differences for all the seed morpho-traits among the hybrid maize is an indication of presence of large variability from which distinctiveness of the seeds can be determined. Harnessing the variability for the traits can facilitate identification and distinguishing among the various hybrids. Consequently, hybrid maize can be reliably distinguished and classified with the use of seed morphometric analysis.

Adetumbi (2013) had observed variability in the morphometrics of maize seeds. Though the seed morphometrics of the hybrids differ considerably for all the traits, their CVs were low. High coefficient of determinations and low CVs for all the seed traits confirm homogeneity, consistency and stability of the values obtained (Shukla and Chandel, 2009). However, existence of wide ranges of values in most cases underscore inherent variations among the traits. This, therefore, suggests that distinguishing and selection of the hybrids should take into consideration multiple traits as selection indices.

Significant differences have been observed in seed metric traits of several crops. For instance, Ogunmefun (2013) observed significant differences in some morphotypes of fluted pumpkin with respect to seed metrics and suggested that variation could be due to differences in the genetic constitution. Adetumbi *et al*. (2012) also found significant variation among seed morphometric of kenaf as attributed to the effects of genotypes.

None of the hybrids had greater than right angle for SA but the SEA were obtuse except TZEI11×TZEI8 which SEA was an acute angle. This distinguishes TZEI11×TZEI8 from other hybrids. Some of the seed morphometric traits considered especially the SD, SP, SW, SL and SAR effectively described and distinguished the hybrids. The traits distinguished hybrids TZEI124×BD74-161, TZEI10×TZEI8, TZEI13×BD74-161 and TZEI16×BD74-161, TZEI146×BD74-161 from the rest in respect of their seed dimension. The hybrids can be regarded as having big seeds in comparison with the rest based on their relatively larger size in the entire seed dimension. Hence, the seeds are expected to have comparatively higher germinability as found in some other studies.

Various studies had proven the effect of the seed dimension on seed physical quality of hybrid maize (Peterson *et al*., 1995; Varga *et al*., 2012). Peterson *et al*. (1995) and Varga *et al*. (2012) found that seed dimension had effect on seed physical quality. They also added that medium and small–round grades were lower in germination, seed and seedling vigour than flat one. Larger seeds tend to germinate more successfully in the field and produce more vigorous seedlings (Bockstaller and Girardin, 1994). Large seeds have been observed to germinate earlier and more vigorously than medium or small seeds, even at different planting depths and temperatures (El-Abady, 2015). El-Abady (2015) also recorded higher seed emergence and seedling vigour of round seeds than flat ones suggesting superiority of larger seeds to small and medium-sized seeds, when planted at deeper depths and lower temperatures. Peterson *et al*. (1995) had also declared that round seeds are more susceptible to mechanical damage than the flat ones.

Associations among the seed morpho-traits observed in this study are adequate to provide conditions for concurrent selection using most of the traits. For instance, SA can be selected in place of the SEA for their high correlation. The SD can be reliably selected simultaneously with any or couple of SP, SL, SW, SAR and SSF because the relationship between the SD and other traits are high. The SL and SW are expected to have a positive and strong relationship with the SAR and SSF probably because the duo of SL and SW are factors of the SAR and SSF.

Adetumbi *et al*. (2012) found significant and positive correlation among seed width, seed length and seed area in kenaf. Similarly, the SP can be selected for SW, SL, SAR, SSF and FIX because of the high correlation of the SP with the traits. This implies that the cost and time of selection during improvement programme can be reduced by the use of any of the related traits having proportional performance. Based on the result of this study, the SL can be selected for SAR and FIX but for SSF, the SL should be selected against due to their inverse relationship.

The positive and negative estimates of the seed morphometric expressed by the crosses signify the various favourable and adverse contributions of the respective parents of the hybrids. Positive and negative heterosis estimates have been observed in agronomic, physiological and flowering traits of several crops. Both positive and negative heterosis had been found for grain yield in maize (Amiruzzaman *et al.*, 2010; Wali *et al*., 2010), fruit yield and other horticultural traits in pepper (Sood and Kumar, 2010). The wide ranges of both MPH and BPH for the traits of the maize in this study suggest that estimates can be harnessed for improvement of the crop through seed morphometric. Only 20 of the 50 hybrids had positive MPH, and 12 had positive BPH, estimates for SA meaning that greater than 60% of the hybrid maize expressed negative MPH and BPH for the trait. Thus, only a little can be expected in the use of this attribute to improve SA of maize seeds. The trend is similar for SEA but SD, SW and SL can be better improved through heterosis.

A connection can be inferred between seed morpho-traits association and the heterosis expression for SA, SEA, SD, SW and SL of the seeds. Based on the rank of the total score due to heterosis estimates, it is evident that TZEI13×BD74-161, BD74-165×BD74-161, TZEI124×BD74-161 and TZEI146×BD74-161 are promising hybrids with respect to expression of hybrid vigour in seed morphometric. Hybrids TZEI13×TZEI11, TZEI13×BD74-222, TZEI12×BD74-161 and TZEI16×BD74-161 are also high rated genotypes. With the occurrence of BD74-161 in six (75%) of eight highest vigour expressing hybrids, the inbred line can be a reliable female parent in crosses for maize seed morphometric improvement.

Based on the foregoing, seed morphometric can be reliably used to identify and distinguish hybrid maize in breeding for seed physical quality. The seed diameter is a versatile seed morpho-trait that can be selected in place of the seed perimeter, seed length and seed width. Morpho-traits have significant relationship with the hybrids' ability to express heterosis of the traits of the hybrid maize. The crosses involving inbred lines TZEI13 and BD74-161 are capable of expressing high vigour over their parents. Hence, they are recommended for hybrid maize development for seed production.

REFERENCES

Adewale, B.D., Kehinde, O.B., Aremu, C.O., Popoola, J.O., Dumet, D.J. 2010. Seed metrics for genetic and shape determinations in African yam bean (Fabaceae) (*Sphenostylis stenocarpa* Hochst. Ex. A. Rich.). *African Journal of Plant Science*, 4:107-115.

Amiruzzaman, M., Islam, M.A., Hassan, L., Rohman, M.M. 2010. Combining ability and heterosis for yield and component characters in maize. *Academic Journal of Plant Science*, 3(2): 79-84.

Adetumbi, J.A., Adekoya, M.A., Adeyeye, O.O., Ogunbiyi, B. 2012. Seed morphometric studies of some Kenaf (*Hibiscus canabinus*) accessions. *Journal of Research in Agriculture*, 1: 29-33.

Adetumbi, J.A. 2013. Genetic purity of parental inbred lines, commercial hybrids and open pollinated maize (*Zea mays* L.) seed in Nigeria. *A Ph.D. thesis* submitted to the Department of Plant Breeding and Seed Technology, Federal University of Agriculture, Abeokuta. Nigeria. 142p.

Anderson, E. 1957. A semi-graphical method for the analysis of complex problems. *Proceedings of National Academy of Science, U.S.A.*, 43:923-927.

Apuan, D.A., Torres, M.A.G., Casimero, M. Sebastian, L.S., Demayo, C.G. 2011. Describing phenotypic variability in seed shapes of weedy rice types in comparison to cultivated and wild rice types using elliptic fourier analysis. *International Journal of Agricultural Biology*, 13:857-864.

Balkaya, A., Odabas, M.S. 2002. Determination of the seed characteristic in some significant snap beans varieties grown in Samsum, Turkey. *Pakistan Journal of Biological Sciences*, 5:382-387.

Bockstaller, C., Girardin, P. 1994. Effects of seed size on maize growth from emergence to silking. *Maydica*, 39: 213-218.

Chen J., Zhang, L., Liu, S., Li, Z., Huang, R., Li, Y., Cheng, H., Li, X., Zhou, B., Wu, S., Chen, W., Wu, J., Ding, J. 2016. The genetic basis of natural variation in kernel size and related traits using a four-way Cross population in maize. *PLoS ONE* 11(4): e0153428. doi:10.1371/journal.pone.0153428

Comstock, R.E., Robinson, H.F. 1952. Estimation of average dominance of genes. In. *Heterosis*, Iowa State College Press, Ames, pp. 494-516.

Daniel, I.O., Adeboye, K.A., Oduwaye, O.O., Porbeni, J. 2012. Digital seed morphometric characterization of tropical maize inbred lines for cultivar discrimination. *International Journal of Plant Breeding and Genetics*, 6: 245-251.

El-Abady, M.I. 2015. Influence of maize seed size/shape, planted at different depths and temperatures on seed emergence and seedling vigour. *Research Journal of Seed Science*, 8: 1-11.

Geetha, V.V., Balamurugan, P., Bhaskaran, M. 2011. Characterization of mustard genotypes through image analysis. *Research Journal of Seed Science* 4:192-198.

Graven, I.M., Carter, P.R. 1990. Seed size/shape and tillage system effect on corn growth and grain yield. *Journal of Production Agriculture*, 3: 445-452.

Grillo, O., Miceli, C., Venora, G. 2011. Computerized image analysis applied to inspection of vetch seeds for varietal identification. *Seed Science and Technology*, 39:490-500.

Gupta, P.K., Rustgi, S., Kumar, N. 2006. Genetic and molecular basis of grain size and grain number and its relevance to grain productivity in higher plants. *Genome*, 49: 565–571.

Kesavan, M., Song, J.T., Seo, H.S. 2013. Seed size: A priority trait in cereal crops. *Physiologia Plantarum*, 147: 113–120.

Lafond, G.P., Baker, R.J. 1986. Effects of temperature, moisture stress and seed size on germination of nine spring wheat cultivars. *Crop Science* 26: 563-567.

Ogunmefun, F. 2013. Effect of pod size and seed location in pods on seedling growth and development in fluted pumpkin. *Project Report* to the Department of Plant Breeding and Seed Technology, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. 50p.

Peterson, J.M., Perdomo, J.A., Burris, J.S. 1995. Influence of kernel position, mechanical damage and controlled deterioration on estimates of hybrid maize seed quality. *Seed Science and Technology*, 23: 647-657.

SAS. 2009. *SAS Institute user's guide: Statistics*, version 9.0. SAS Institute Incorporated, Cary, North Carolina, USA, 1028p.

Shahin, M.A., Symons, S.J., Poysa, V.W. 2006. Determining soyabean seed size uniformity with image analysis. *Biosystems Engineering*, 94: 191-198

Shull, G.H. 1948. What is heterosis. *Genetic*s, 33(5): 439–446.

Shukla, R.S., Chandel, P.S. 2009. *Cytogenetics, evolution, biostatistics and plant breeding*. S. Chand and Company Ltd, Ram Nagar, New Delhi-110055. 569p.

Singh, R.K., Chaudhary, B.D. 1977. *Biometrical methods in Quantitative genetic analysis*. Kalyani Publishers. New Delhi. 304p.

Sood, S., Kumar, N. 2010. Heterosis for fruit yield and related horticultural traits in Bell pepper. *International Journal of Vegetable Science* 16(4): 361-373.

Sumathi, S., Balamurugan, P. 2013. Characterization of oats (*Avena sativa* L.) cultivars using machine vision. *Pakistan Journal of Biological Sciences*, 16: 1179-1183.

Varga, P., Berzy, T., Anda, A., Ertsey, K. 2012. Relationship between seed harvesting method and seed physiological quality for a number of Pioneer maize hybrids. *Maydica Electronic Publication*, 57: 220-225.

Wali, M.C., Kacapur, R.M., Chandrashekhar, C.P. Kulkarni, V.R. Devaranavadagi, S.B. 2010. Gene action and combining ability studies in single cross hybrid maize (*Zea mays*). *Karnataka Journal of Agricultural Science*, 23(4):557-562.

Appendix 1: Score index for heterotic ranks for some morpho-traits of selected yellow kernel single cross hybrid maize

Hybrid	Seed angle		Seed embryo angle		Diameter		Perimeter		Thickness		Width		Length		THS	RBH
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH		
TZEI13×BD74-161	3	3	1	1	3	3	3	3	2	2	3	3	3	3	36	1
BD74165×BD74-161	1	1	2	2	3	3	3	3	2	2	3	3	3	3	34	2
TZEI124×BD74-161	1	2	1	1	3	3	3	3	2	2	3	3	3	3	33	3
TZEI146×BD74-161	2	3	1	1	2	2	2	2	3	3	3	3	2	2	31	4
TZEI13×TZEI 11	2	2	2	2	2	2	2	2	3	3	2	2	2	2	30	5
TZEI13×BD74222	3	3	2	2	2	2	2	2	2	2	2	2	2	2	30	5
TZEI12×BD74-161	1	1	1	1	3	3	2	2	3	3	2	2	3	3	30	5
TZEI16×BD74-161	1	1	1	1	3	3	3	3	1	1	3	3	3	3	30	5
TZEI12×TZEI11	3	3	3	3	2	2	1	2	1	1	2	2	2	2	29	9
TZEI13×TZEI128	3	3	3	3	1	1	2	2	1	1	2	2	2	2	28	10
TZEI13×TZEI 16	2	2	2	2	2	2	2	2	2	2	2	2	2	2	28	10
TZEI10×TZEI12	3	3	2	2	2	2	1	1	2	2	2	2	2	2	28	10
TZEI10×BD74-161	2	2	2	2	2	2	2	2	2	2	2	2	2	2	28	10
TZEI11×BD74-161	1	2	1	1	3	3	2	2	2	2	2	2	3	2	28	10
TZEI13×TZEI10	2	3	2	2	2	2	2	2	1	1	2	2	2	2	27	15
TZEI128×TZEI16	3	3	2	1	2	2	2	1	3	3	2	1	1	1	27	15
TZEI10×TZEI8	2	2	1	1	3	3	2	2	1	1	1	1	2	3	25	17
TZEI8×BD74-165	3	2	2	2	1	1	1	1	3	3	2	2	1	1	25	17
TZEI13×TZEI12	2	2	2	2	1	1	2	2	1	1	2	2	2	2	24	19
TZEI13×TZEI124	1	1	1	1	2	2	2	2	2	2	2	2	2	2	24	19
TZEI13×BD74-165	3	2	2	1	1	1	1	1	3	3	2	2	1	1	24	21
TZEI146×TZEI128	1	1	1	1	2	2	2	2	2	2	2	2	2	2	24	21
TZEI146×TZEI124	2	3	1	2	1	1	1	1	3	3	2	2	1	1	24	21
TZEI12×TZEI16	2	1	1	1	3	3	2	2	1	1	1	1	2	3	24	21
TZEI11×TZEI8	1	1	1	1	2	2	2	2	3	3	1	1	2	2	24	21
TZEI146×TZEI 16	3	3	2	1	2	2	1	1	2	2	1	1	1	1	23	26
TZEI146×BD74-165	2	2	1	1	2	2	2	1	2	2	2	2	1	1	23	26
TZEI11×TZEI124	1	1	1	1	2	2	2	1	3	3	2	1	2	1	23	26
TZEI11×BD74-165	3	2	1	1	1	1	2	2	2	2	2	2	1	1	23	26
TZEI124×BD74-165	1	1	1	1	3	3	1	1	2	2	2	2	1	2	23	26
TZEI8×TZEI 16	3	3	2	2	1	1	1	1	2	2	1	1	1	2	23	26

TZEI146×TZEI12	2	2	1	1	2	2	1	1	2	2	2	2	1	1	22	32
TZEI146×TZEI8	1	1	1	1	2	2	2	2	2	2	1	1	2	2	22	32
TZEI12×TZEI124	1	1	1	1	2	2	2	2	1	1	2	2	2	2	22	32
TZEI16×BD74-165	1	1	2	2	1	1	1	1	3	3	2	2	1	1	22	32
TZEI146×TZEI10	1	1	2	2	2	2	1	1	2	3	1	1	1	1	21	36
TZEI12×BD74-165	1	1	1	1	2	2	2	2	1	1	2	2	1	2	21	36
TZEI128×BD74-165	2	1	2	2	1	1	1	1	2	2	2	2	1	1	21	36
TZEI10×TZEI128	3	3	1	1	1	1	1	1	2	2	1	1	1	1	20	39
TZEI10×TZEI16	1	2	2	2	1	1	1	1	2	1	2	2	1	1	20	39
TZEI12×TZEI8	1	1	2	2	2	2	1	1	2	2	1	1	1	1	20	39
TZEI128×TZEI8	2	2	1	1	1	1	1	1	2	2	2	2	1	1	20	39
TZEI16×TZEI124	2	2	1	1	1	1	1	1	3	3	1	1	1	1	20	39
TZEI11×TZEI16	2	2	1	1	1	1	1	1	2	2	1	1	1	1	18	44
TZEI146×TZEI 11	2	2	2	1	1	1	1	1	1	1	1	1	1	1	17	45
TZEI10×TZEI124	1	2	2	2	1	1	1	1	1	1	1	1	1	1	17	45
TZEI128×TZEI11	2	2	1	1	2	1	1	1	1	1	1	1	1	1	17	45
TZEI10×BD74-165	2	1	1	1	1	1	1	1	1	1	2	1	1	1	16	48
TZEI12×TZEI128	1	1	1	1	2	2	1	1	1	1	1	1	1	1	16	48
TZEI128×TZEI124	1	1	1	1	1	1	1	1	2	2	1	1	1	1	16	48

MPH= mid-parent heterosis, BPH= better parent heterosis, THS= total heterosis score and RBH=rank by heterosis

Appendix 2: Score index of heterosis estimates of some seed morpho-traits of selected yellow kernel single cross hybrid maize

Seed morpho-trait	Type of heterosis	Score 1 (x ≤)	Score 2 (x = from - to -)	Score 3 (x ≥)
Seed angle	Mid-parent	-7.21	-2.60 to 2.00	6.60
	Better parent	-11.90	-6.29 to -0.69	4.92
Seed embryo angle	Mid-parent	-26.49	3.46 to 33.42	63.38
	Better parent	-27.55	2.49 to 32.54	62.59
Seed diameter	Mid-parent	-16.03	3.31 to 22.64	41.97
	Better parent	-18.09	1.44 to 20.98	40.52
Seed perimeter	Mid-parent	-3.54	15.80 to 35.14	54.48
	Better parent	-3.88	15.11 to 34.11	53.11
Seed thickness	Mid-parent	-11.82	9.35 to 30.53	51.71
	Better parent	-11.93	8.72 to 29.36	50.00
Seed width	Mid-parent	-8.89	7.43 to 23.74	40.05
	Better parent	-9.43	6.79 to 23.10	39.23
Seed length	Mid-parent	-2.51	7.81 to 18.14	28.47
	Better parent	-5.34	5.38 to 16.10	26.82