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HETEROSIS OF NEW MAIZE HYBRIDS IN YIELD, YIELD COMPONENTS, PHYSIOLOGICAL TRAITS AND SOME GENETIC PARAMETERS UNDER LOW AND HIGH NITROGEN CONDITIONS

ABDEL-MONEAM M.A.[1]* AND IBRAHEEM F.[2,3]

[1]Agronomy Department, Faculty of Agriculture, Mansoura University, Mansoura, Egypt.
[2]Botany Department, Faculty of Science, Mansoura University, Mansoura, Egypt.
[3]AlQunfodha Rresearch Center, Umm Al-Quora University, Mecca, Saudi Arabia.
*Corresponding Author: Email- maaelmoneam@mans.edu.eg

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Abstract- Heterosis has been the biggest motivation for improving maize grain yield. Thirteen new maize single cross hybrids were developed via cross combinations between B73 inbred line and some American and Egyptian inbred lines. The field performance of these new hybrids was evaluated along with two commercial varieties (Pioneer SC 3084 and SC 10) under low (30 Kg N/fed=71.4 Kg N/ha) and high (120 Kg N/fed=285.7 kg N /ha) nitrogen (N) fertilization rates to study heterosis over commercial varieties, phenotypic, physiological, and genotypic correlations, as well as heritability and anticipated gain from direct and indirect selection for yield and its related traits under low and high N conditions. The results indicated that mean squares of crosses were highly significant for all studied traits under both low and high N fertilization rates, indicating significant genotypic differences among the studied crosses and suggest that almost all variables exhibited some degree of heterosis. Crosses no. 6 (B73 x CML103) and no. 7 (B73 x Tzi8) were the best crosses and recorded the highest percentages of heterosis over the studied commercial check varieties (Pioneer SC 3084 and SC 10) with significant values in grain yield per plant and most of studied yield components and yield-related physiological traits under both low and high N conditions.

Phenotypic and genotypic correlation coefficients were positive and highly significant (strong correlation) between grain yield plant^{-1} and each of ear diameter and kernel depth under both low and high N conditions. Whereas, such correlation coefficients were positive and significant (moderate correlation) between grain yield plant^{-1} and each of ears number plant^{-1}, kernels number row^{-1}, ear length, and shelling %, under both low and high N conditions. Interestingly, the phenotypic and genotypic correlation coefficients between grain yield plant^{-1} and the tested yield-related physiological traits were positive and strongly correlated with N-use efficiency (NUE), crop growth rate (CGR) under both limited and adequate N conditions as well as with relative potential photosynthesis for grain yield ($RPP_{G.Y.}$) under high N input only. On the other hand, such correlation was positive and moderate with harvest index (HI) under both N rate as well as with $RPP_{G.Y.}$ under N stress. The results suggest that, to increase grain yield plant^{-1}, selection should be carried out for most of the studied yield components especially; ears number plant^{-1}, rows number ear^{-1}, ear diameter, ear length and kernel depth under both low and high N conditions as well as tested yield-related physiological traits such as NUE, CGR, $RPP_{G.Y}$ and HI. The present results also showed that genetic variance (σ^2g) of the new maize hybrids were higher than environmental (σ^2e) variance in all studied traits at both low and high N conditions. Therefore, broad-sense heritability estimates for all studied traits exhibited high percentages and ranged from 70.2% to 99.9%.

The values of expected gains in grain yield from indirect selection for related traits, and their percentages to direct selection were lower at low N than at high N conditions for all studied traits, except for traits of rows number ear^{-1} and ear diameter. The results also showed that direct selection for grain yield plant^{-1} was likely to be more efficient than indirect selection for all studied traits. It is concluded that for studied traits, the expected gain from direct selection would improve the trait under consideration in a way better than the indirect selection.

Keywords- Maize, Heterosis, Correlation, Heritability, Expected gain from selection, nitrogen

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Introduction

Grain yield of maize (*Zea mays* L.) is a complex inherited trait. Grain yield has been improved significantly since the discovery of the phenomenon of hetrosis where hybrid plants exhibit superiority over their parental inbred lines in both grain yield and vigor [1]. The genetic, physiological and molecular basis of hererosis is far from clear. However, dominance and over-dominance hypothesis have been proposed as possible mechanisms underlying heterosis. The dominance hypothesis refers heterosis to the accumulation of favorable alleles and masking harmful recessive alleles in hybrids.

Whereas, the over-dominance hypothesis suggests that the heterozygosity of alleles at individual loci is superior over the homozygosity at these loci and such superiority stands behind the heterosis phenomenon. The degree of the hetrotic estimates is influenced by the interaction of numerous genetic and environmental factors throughout the plant' life cycle [2-5]. In addition, such hetrotic changes impact most aspects of plant' life [6,7].

Abiotic stresses have been reported to have significant effects on the allelic contribution to heterosis [8] and consequently physiological processes and grain yield. Nitrogen (N) stress is among the most important environmental abiotic stresses threatening maize growth, physiology and grain production and consequently its contribution to food security and economic growth [9]. In maize, N stress causes an average yield losses ranging from 10-to 50% annually compared to grain yield losses from 17-60% for drought [10,11]. As a result, application of N fertilizers has become indispensable practice in modern agriculture. However, application of synthetic N fertilizers for maize grain yield has been challenging worldwide. The affordability of these fertilizers in the developed countries has led to its misuse and over application has induced growing environmental concerns because of the potential risk of pollution of the world water resources as a result of the increased nitrate leaching [12]. In developing countries the rate of N input for corn production has increased significantly. For example, In Egypt, the rate of N fertilization/hectar increased about twice that in 1980. In fact, Egypt confronted a severe "fertilizer crisis" in 1994 where the prices of inorganic fertilizers increased up to five folds of their 1980s prices and costs of other inputs have considerably increased as well. In most of African countries, application of N fertilizers is considerably low because of the limited access to fertilizers and the low purchasing power of resource-poor farmers due to a high fertilizers/cereal grain price ratio. The limited use of N fertilizer in many African countries resulted in many cereal crops being grown in N-deficient soils producing considerably low yields. As a result, N-deficiency for maize is a widespread problem in most countries of Africa [13,14], Southern Asia [11] and Latin America (e.g. Brazil) [15]. These resource-poor farmers cannot afford the purchase of hybrid maize seed and the large fertilizer inputs required for the high-yielding hybrids.

Several studies have targeted genetic improvement of both grain yield and physiological adaptation of maize in N deficient soil. Many studies have shown that the tolerance of tropical maize to N-stress can be improved more rapidly in selection environments with managed levels of N stress than selection for high yielding germplasm only under optimum N inputs [16-19]. These studies suggested that selection of grain yield under high N input doesn't necessarily mean improved performance and enhanced physiological adaptation of such selected germplasms under low N input [19].

Maize grain yield and many of its related traits are influenced by the responses of a large number of physiological processes to the environment. Therefore, grain yield and its related traits in various environments have been an attractive research topic [1,20]. Whether, direct selection for grain yield or indirect selection for grain yield-related traits with high heritability estimates is the most efficient method for grain yield improvement in maize has received much attention and has been under continuous evaluation [21]. For example, highly significant association has been reported between grain yield and both 100-kernel weight and shelling % under N limited conditions. [22] reported higher heritability estimates under low N than under high N for ear plant^{-1}, rows ear^{-1}, kernels number row^{-1}, kernel depth and shelling percentage. However, the authors reported week association for grain yield plant^{-1}, ear length and N-use efficiency (a physiological trait that describes the physiological ability of a plant to convert soil N into grain yield) [1,23]. They also indicated that selection for grain yield at high N resulted in 77.4 and 69.4% of the gain from direct selection for yield at low N in two successive years. On the other hand, [24] reported that genetic variances and heritability estimates were higher under high N fertilizer input than under stress conditions for inbred lines and hybrids. She also reported that the genetic improvement exhibited higher record under N stress conditions than under optimal N fertilization. She concluded that the genetic improvement for nitrogen related-traits would be effective if selection for higher grain yield is practiced under optimal fertilization. [25] Found that high magnitude of phenotypic and genotypic coefficient of variations as well as high heritability along with high genetic advance recorded for grain yield, total number of grains ear^{-1}, plant and ear heights provide evidence that these parameters were under the control of additive gene effects and effective selection could be possible for improvement for these characters. It is worth mentioning that, most of these experiments were carried out in different environments using different genetic stocks which have been reflected clearly in the reported results.

The objectives of the current study were (1) to study the heterosis of new hybrids over the best of commercial varieties, (2) to investigate the phenotypic and genotypic correlation coefficients between grain yield and other yield components and physiological traits, and identify the most associated characters with grain yield, (3) assess the influence of deficient and sufficient N fertilization on the heterotic responses of a number of physiological processes, grain yield and its related traits via estimation of the heritability under low and high N inputs and (4) compare these N regimes as evaluation environments based on expected genetic advance from direct and indirect selection.

Materials and Methods

Genetic Materials

Thirteen new single cross maize hybrids along with two commercial hybrids (Pioneer 3084 and SC 10) were studied in the current investigation. The new hybrids were produced in summer of 2011 at the Mansoura University, Agronomy Farm, Fac. of Agriculture. These hybrids were developed by crossing the public inbred line, B73 (female parent) to nine inbred lines belonging to various heterotic groups. These parental lines included the recently released ex-pvp lines (PH207, PHJ40 ,and PHG47), diversity inbred lines (B97, CML103, Hp301, NC358, Tzi 8), the public inbred line Mo17, and Egyptian inbred lines (Inb. 209, Sids 63, Rg 5 and Inb. 204). The Egyptian inbred lines were obtained from the Agriculture Research Center in Egypt while other inbred lines were obtained from Dr. Stephen Moose at the University of Illinois. The best combinations of inbred parents were investigated and the hybrids were evaluated for their yield and yield components under low and high soil N availability. The climate of the experimental field is semiarid with hot summer.

Field site, Experimental Design, Cultural Practices and Treatments

Field experiments were conducted in the nitrogen responsive nursery at the Department of Botany, Fac. of Science, Mansoura University, Mansoura, Egypt during summer of the 2012 growing season. The soil of the experimental site was clayey in texture, containing organic matter of 2.68 %, available N of 18 ppm, available P of 7 ppm, available K of 245 ppm and PH 7.9. The field was under a maize-wheat rotation. The experimental field was divided into two main plots for low and high N rates. Each plot contains rows of 3 m long and spaced 70 cm apart. Each plot was subdivided into subplots of four rows for each hybrid. The N rates and hybrids were the two treatment factors. For field evaluation of hybrids performance, hybrid seeds were hand-sown, two seeds per hill, on 24 May 2012. The distance between plants within a row was 0.25 m and thinned to one plant per hill (a stand density of 57142 plants ha^{-1}). Plots were kept weed-free manually and were irrigated every 10-12 days. Each of the hybrids was grown under two rates of fertilizer N [low N: 30 kg N/faddan equivalent to 71.4 Kg N/ha, and high N: 120 kg N /faddan, equivalent to 285.7 kg N /ha]. The fertilizer was applied once down the center of the row as ammonium nitrate. Treatments consisted of sixteen hybrids (13 new hybrids + two control hybrids) and two N fertilizer rates (low and high N) arranged in a randomized complete block design with three replications.

Studied Traits

Yield and Yield-related Traits

To compare yield and yield components among genotypes under different N levels, the grain yield and its related traits were monitored. All measures were recorded using the inner two rows for each plot. Ears number per plant was recorded at harvest by dividing the total number of harvested ears by the total number of plants in the inner rows. Kernel rows number per ear were recorded as the average number of kernel rows measured on the top ear of three plants. The numbers of kernels per row were recorded at harvest for the top ear of three plants. The diameters of three top ears as well as of their cobs from three competitive plants were measured in centimeters using digital Vernier Caliper. The ear length was measured in centimeters using graduated tap after dehusking the ear. The kernel depth was calculated as the half of the difference between ear diameter and cob diameter as the average of three top ears [(ear diameter - cob diameter)/2]. Grain yield was expressed in gram/ plant. Shelling was carried out by separating cobs from three individual plants, grains were manually separated and weighted using sensitive balance then shelling percentage were calculated as the ratio of total grain weight per plant to the total ear weight [100* (ear weight-cob weight)/ear weight)]. The obtained values were used for heterosis studies (see below).

Yield-related Physiological Traits

To investigate heterosis over yield related physiological traits, relative photosynthesis potential for grain yield ($RPP_{G.Y}$), leaf area index (LAI), crop growth rate (CGR), harvest index (HI) and nitrogen use efficiency (NUE) were determined. $RPP_{G.Y}$ was determined by dividing the grain yield per plant by leaf area index (Grain yield $plant^{-1}$/LAI) according to [26]. CGR expressed in g/day was determined according to [27], using the equation $[(W_2-W_1) / (T_2-T_1)]$ where: W_1 and W_2 refer to dry weights of plant at sampling time T_1 (60 day after planting, DAP) and T_2 (120 DAP), respectively. HI was estimated as the proportion of grain weight to total aboveground dry weight for three guarded plants per plot. NUE was determined as grain yield $plant^{-1}$ (GY) x no. of plants ha^{-1} (57142) divided by 1000 x kg N ha^{-1} [22]. The obtained data were used for heterosis studies (see below).

Statistical Analysis

An analysis of variance was performed separately for each low and high N rate using MSTAT-C program. Data on entries in each experiment for each of low and high N rates were subjected to separate analysis of variance of RCBD design and analysis of covariance between grain yield and other traits in the forms given in [Table-1].

Table 1- Mean squares and expected mean squares for variance and covariance components.

S.V	d.f	MS	EMS	MP	EMP
Replicates (r)	r-1				
Crosses (c)	c-1	M_2	$s^2_e + r s^2_G$	MP_2	$s^2e_{ij} + r s^2G_{ij}$
Error	(r-1)(c-1)	M_1	s^2_e	MP_1	s^2e_{ij}

Genetic and phenotypic variances were estimated from expected mean squares as follows:

$$s^2_G = (M_2 - M_1) / r \qquad s^2_P = s^2_G + (s^2_e / r)$$

The percentage of heritability of plot means was estimated as: $h^2_b = (s^2_G / s^2_P) \times 100$

Phenotypic (r_{ph}) and genotypic (r_g) correlations were calculated between grain yield per plant and other traits for low and high N conditions by the following formulae [28]:

$$r_{pij} = s^2p_{ij} / (s^2pi \times s^2p_j)^{1/2} \qquad r_{gij} = s^2Gij / (s^2 G_i \times s^2 G_j)^{1/2}.$$

Where, rp_{ij} and rg_{ij} refer to phenotypic and genotypic correlation coefficient, respectively, s^2p_{ij} and s^2Gij indicate phenotypic and genotypic covariance, respectively, s^2p and s^2G indicate phenotypic and genotypic variance, respectively and subscripts i and j refer to yield and correlated trait, respectively.

Expected gain from direct selection for grain yield/plant under each N treatment was calculated by using the following formula according to [29]:

$$\Delta S = K . h^2_b . s_{Pi} = K s^2_{Gi} / s_{Pi}$$

Where, K is the selection differential; s^2_{Gi} and s_{Pi} are the genotypic and phenotypic standard deviation for grain yield, respectively.

Expected gain in grain yield from selection for a yield-related trait (indirect selection) was calculated by the following formula according to [29]:

$$\text{Indirect selection gain} = k\, s_{Gij} / s_{Pj}$$

Where, s_{Gij} = genetic covariance between yield and related trait j,

s_{Pj} = phenotypic standard deviation for trait j.

A standard value of k = 1 was assumed for both direct and indirect selection.

Heterosis Studies

Heterosis was determined for individual crosses as the percentage deviation of F_1 means from commercial variety means (CV) and expressed as percentages as follows, [30]:

Heterosis over the C.V % = $[(F_1 - CV)/CV] \times 100$

Where, F_1= mean performance of F_1 hybrid and CV = check or commercial variety. The significance of heterosis effect for F_1 values from the commercial variety was tested according to the following formula:

$$\text{LSD for heterosis (CV)} = t_{0.05 \text{ or } 0.01} \times (2MSe/r)^{1/2}$$

Where, t = tabulated "t" value at a stated level of probability for the experimental error degree of freedom, MSe = Mean squares of the experimental error from the analysis of variance and r= Number of replicates.

Results and Discussion

The superiority of F_1 hybrids in grain yield and vigor over their inbred parents was reported early in the twentieth century [1]. Since then, heterosis has been the biggest motivation for maize improvement as well as the major reason for the continuous breeding efforts for yield improvement in maize and many other crops. Although considerable progress has been made in understanding the genetic and physiological basis of heterosis, the full picture is far from clear [6,7,31]. In addition, relatively little information about the physiological, and molecular basis of this event is available. As a result, scientists have been designing experiments to dissect and investigate different mechanisms of heterosis. Heterosis has been attributed to dominance or over dominance of grain yield- and vigor-favoring alleles, and recently epistasis and linkage have been reported as major contributors [32]. Generally, researchers agree that that no one hypothesis of heterosis holds true for every experiment or every organism [31,33]. In the current study, we developed thirteen new maize hybrids with a common female parent (B73) to test the impact of different genomes imported by different male maize genotypes of different climatic zones into the B73 genetic background on heterosis and consequently yield. This was carried out by studying grain yield and its related phenotypic, genotypic and physiological traits under N limiting and sufficient conditions.

Heterosis for Grain Yield and its Related Traits

Ears Number Plant^{-1}

Results given in [Table-2] revealed that five cross combinations manifested positive and significant or highly significant heterosis over the two check varieties (Pioneer SC 3084 and SC10). Heterosis values ranged from 22.0% for cross no. 2 (B73X B97) to 88.7% for crosses no. 6 (B73X CML103) and no. 8 (B73X NC358) under low nitrogen conditions. Whereas, under high nitrogen conditions, seven cross combinations showed positive significant or highly significant heterosis over check variety Pioneer SC 3084 with values ranged from 39.91% for crosses no. 1 and no. 2 to 100% for cross no. 11 (B73X Sids63). One cross combination (B73X Sids63) exhibited positive significant heterosis (24.93%) over SC10 for ears number plant^{-1} under high N conditions. Since the new hybrids share a common female parent, the superiority showed by some of these crosses in ear number plant^{-1} compared with other crosses may be attributed to genetic structure of male parents and its interaction with B73 genome. Therefore, the male inbred parents who have a good specific combining ability effects with the B73 genome, likely gave superiority crosses.

Number of Rows Ear^{-1}

Results shown in [Table-2] revealed positive and significant heterosis over the two check varieties (Pioneer SC 3084 and SC10) by two cross combinations: cross no. 1 (B73X PHG47) and cross no. 7 (B73X Tzi8). These two hybrids recorded the same percentage (14.29%) under low nitrogen conditions. On the other hand, under high N fertilization, two and four cross combinations exhibited positive and highly significant heterosis percentages over Pioneer SC 3084 and SC 10, respectively. Crosses no. 6 (B73X CML103) and no. 11 (B73X Inb209) recorded the same and the highest estimates of heterosis (13.04%, and 18.18%) over the two check varieties Pioneer SC 3084 and SC 10, respectively. These results of ears number per plant and rows number per row are in agreement with [34-37] who found significant heterosis over mid parents, better parents and check varieties for ears number per plant and rows number per ear in their studied crosses.

Table 2- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) for F_1 single crosses for ears number plant^{-1} and rows number ear^{-1} under low and high nitrogen conditions.

Trait	Ears number plant^{-1}				Rows number ear^{-1}			
N-rates	Low N		High N		Low N		High N	
Cross	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	0	0	39.91*	-12.61	14.29*	14.29*	8.7	13.64**
2-B73X B97	22.00*	22.00*	39.91*	-12.61	0	0	-8.69	-4.55
3-B73X PHj40	0	0	0	-37.54**	-14.29*	-14.29*	-21.74**	-18.18**
4-B73X PH207	0	0	0	-37.54**	-9.52	-9.52	-13.04**	-9.1
5-B73X HP301	44.00**	44.00**	80.18**	12.55	0	0	4.35	9.09
6-B73X CML103	88.70**	88.70**	80.18**	12.55	4.76	4.76	13.04**	18.18**
7-B73X Tzi8	0	0	29.73	-18.96	14.29*	14.29*	4.35	9.09
8-B73X NC358	88.70**	88.70**	80.18**	12.55	-14.29*	-14.29*	-17.39**	-13.64**
9-B73X Mo17	0	0	0	-37.54**	-9.52	-9.52	-13.04**	-9.1
10-B73X Inb209	0	0	0	-37.54**	4.76	4.76	13.04**	18.18**
11-B73X Sids63	11	11	100.00**	24.93*	-4.76	-4.76	-4.34	0
12-B73X Rg5	0	0	0	-37.54**	9.52	9.52	4.35	9.09
13-B73X Inb.204	55.30**	55.30**	80.18**	12.55	-9.52	-9.52	-8.69	-4.55
LSD at 0.05	0.196		0.359		1.586		1.464	
at 0.01	0.263		0.482		2.129		1.964	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Number of Kernels per Row

Results presented in [Table-3] revealed that positive and significant or highly significant heterosis estimates were recorded by six and three crosses over the check varieties Pioneer SC 3084 and SC 10, respectively, under low N conditions. Cross no. 7 (B73X Tzi8) recorded the highest estimates of heterosis (31.58% and 22.95%) over Pioneer SC 3084 and SC 10, respectively, under low N conditions. On the other hand, under high N conditions, there were seven crosses (B73X PHG47, B73X B97, B73X Tzi8, B73X NC358, B73X Mo17, B73X Sids63 and B73X Inb.204 and only one cross (B73X Tzi8) showed positive and significant or highly significant heterosis estimates over the check varieties Pioneer SC 3084 and SC 10, respectively. Interestingly, cross no. 7 (B73X Tzi8) also maintained the highest estimates of heterosis (40.0% and 13.51%) over Pioneer SC 3084 and SC 10, respectively under high N fertilization as it did under low N. The high number of kernels per row especially under low N reflects the ability of the hybrid to secure assimilates necessary for growth and development of fertilized ovules and thus minimizes kernel abortion. The consistent superiority of cross no. 7 (B73X Tzi8) over the check crosses as well as over the rest of hybrids in kernels number row^{-1} under both low and high rates suggests its potential as high tolerance and high responsiveness to low and high N fertilization respectively. Supporting to the above results, similar significant heterosis over mid parents, better parents and check varieties for number of kernels per row have been reported [34-37].

Ear Diameter

Results given in [Table-3] showed that the highest positive significant or highly significant heterosis over SC3084 and SC10 were recorded by two and three crosses, respectively, under low N conditions. Cross no. 7 (B73X Tzi8) recorded the highest estimates of heterosis (15.43% and 23.26%) over Pioneer SC 3084 and SC 10, respectively, under low N conditions. Cross no. 6 (B73X CML103) showed similar pattern, however, at slightly lower estimates. Under high N conditions, no crosses showed positive significant or highly significant heterosis estimates over the check variety Pioneer SC 3084, however, four crosses (B73X B97, B73X CML103, B73X Tzi8 and B73X Sids63) showed positive significant or highly significant heterosis estimates for ear diameter over the check variety SC 10. Crosses no. 6 (B73X CML103) and no. 7 (B73X Tzi8) recorded the highest estimates of heterosis (18.99% and 18.83%) over SC 10, respectively under high N conditions.

Ear Length

Results in [Table-4] showed that only cross (B73X Tzi8) exhibited positive (desirable direction) estimates of heterosis over SC3084 and SC10, where it recorded 7.46% (non-significant) and 10.77%, respectively, under low N conditions. On the other hand, under high N conditions, only cross no. 7 (B73X Tzi8) recorded positive estimates of heterosis (8.57% and 7.04%) over Pioneer SC 3084 and SC 10, respectively without reaching the significantly level. In addition, many crosses showed negative (undesirable direction) significant or highly significant heterosis estimates for ear length under both low and high N conditions.

Kernel Depth

Results in [Table-4] revealed that two crosses namely B73X CML103 and B73X Tzi8 exhibited positive (desirable direction) and significant estimates of heterosis over SC3084 and SC10. These crosses recorded 27.28%, 22.90% and 24.55%, 20.26%, respectively, under low N conditions. However under high N conditions, five crosses attained positive estimates of heterosis over Pioneer SC 3084. These estimates ranged from 0.29% to 17.19% without reaching the significant level. Also, two crosses namely B73X Sids63 and B73X CML103 showed positive (desirable direction) significant heterosis estimates over SC 10, which were 21.49% and 19.5%, respectively.

Table 3- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) for F_1 crosses for kernels number row^{-1} and ear diameter under low and high nitrogen conditions.

Trait	kernels number row^{-1}				Ear diameter, cm			
N-rates	Low N		High N		Low N		High N	
Cross	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	14.03*	6.56	13.33*	-8.11	-1.31	5.38	-9.10*	1.64
2-B73X B97	10.53	3.28	16.67**	-5.4	1.91	8.82*	-2.41	9.13*
3-B73X PHj40	-9.65	-15.58**	-8.33	-25.67**	-11.31**	-5.29	-14.84**	-4.78
4-B73X PH207	0	-6.56	-3.33	-21.62**	-5.26	1.17	-10.43**	0.16
5-B73X HP301	-6.14	-12.29*	-6.67	-24.32**	-18.76**	-13.25**	-22.20**	-13.00**
6-B73X CML103	8.77	1.64	5	-14.86**	12.43**	20.06**	6.42	18.99**
7-B73X Tzi8	31.58**	22.95**	40.00**	13.51**	15.43**	23.26**	6.28	18.83**
8-B73X NC358	16.67**	9.01	19.17**	-3.38	-0.57	6.18	-7.70*	3.21
9-B73X Mo17	12.28*	4.92	20.00**	-2.7	-3.57	2.97	-10.37**	0.22
10-B73X Inb209	-14.03*	-19.67	8.33	-12.16**	-6.42	-0.07	-8.22*	2.62
11-B73X Sids63	19.30**	11.47*	20.00**	-2.7	-4.45	2.04	-0.08	11.73**
12-B73X Rg5	7.02	0	9.17	-11.49*	-2.41	4.21	-8.22*	2.62
13-B73X Inb.204	24.56**	16.39**	20.00**	-2.7	-12.40**	-6.46	-16.24**	-6.35
LSD at 0.05	4.097		4.424		0.34		0.385	
at 0.01	5.498		5.937		0.456		0.517	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Grain Yield (g/plant)

Results given in [Table-5] revealed that positive (desirable direction) highly significant heterosis percentages over commercial check varieties Pioneer SC 3084 and SC 10 were recorded in five and seven crosses, respectively, under low N conditions. The highest percentages were recorded by cross no. 6 (74.84% over SC3084 and 112.34% over SC 10) followed by cross no. 7 (32.39% over SC3084 and 60.78% over SC 10). Under high N conditions, seven crosses (B73X PHG47, B73X CML103, B73X Tzi8, B73X NC358, B73X Mo17, B73X Sids63 and B73X Inb.204) showed maximum positive and significant heterosis over commercial variety Pioneer SC 3084, whereas only one cross (B73X CML103) exhibited significant positive heterosis over the commercial check variety SC 10. In addition, cross no.6 (B73X CML103) gave the highest estimates of heterosis (71.71% over SC3084 and 13.95% over SC 10). Similar results were reported by and [34,38, 39], who found significant and positive heterosis over mid parents, better parents and check varieties for grain yield per plant in their studied crosses. The obvious differences in heterotic estimates of grain yield among the new hybrids under both low and high N conditions suggest different physiological processes-limiting grain yield such as photosynthetic capabilities, dry matter accumulation and partitioning. In addition, the current results also suggest different mechanisms of interaction between parent's genomes. Consistent with this hypothesis, [21] reported that heterosis for grain yield in maize can be attributed to (i) heterosis for dry matter accumulation prior silking as a result of effective light interception; (ii) heterosis for dry matter accumulation during the grain filling period which is attributed to efficient light interception due to large leaf area index and increased stay green; and (iii) heterosis for harvest index.

Shelling %

Results in [Table-5] revealed positive (desirable direction) highly significant heterosis percentages over commercial varieties Pioneer SC 3084 and SC 10 in three and seven crosses, respectively, under low N conditions. Cross no. 12 exhibited the highest percentages (9.51% over SC3084 and 14.32% over SC 10) followed by cross no. 1 (7.71% over SC3084 and 12.44% over SC 10). On the other side, under high N conditions, twelve and three crosses showed maximum positive and significant heterosis over commercial varieties Pioneer SC 3084 and SC 10, respectively with cross no.10 (B73X Mo17) attaining the highest estimates of heterosis (9.02% over SC3084 and 3.76% over SC 10) among the thirteen hybrids.

Table 4- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) for F_1 single crosses for ear length and kernel depth under low and high nitrogen conditions.

Trait	Ear length, cm				Kernel depth, cm			
N-rates	Low N		High N		Low N		High N	
Cross	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	-7.46	-4.62	-4.29	-5.64	14.38	10.44	0.29	3.96
2-B73X B97	-8.96	-6.16	-8.57	-9.86	5.25	1.62	-1.62	1.98
3-B73X PHj40	-17.91**	-15.39**	-12.86*	-14.09**	-18.47	-21.28*	-18.53*	-15.54
4-B73X PH207	-17.91**	-15.39**	-15.71**	-16.90**	9.86	6.08	-4.78	-1.29
5-B73X HP301	-13.43**	-10.77*	-12.86*	-14.09**	-31.06**	-33.43**	-34.38**	-31.98**
6-B73X CML103	-2.98	0	-4.29	-5.64	27.28*	22.90*	15.28	19.50*
7-B73X Tzi8	7.46	10.77*	8.57	7.04	24.55*	20.26*	12.03	16.14
8-B73X NC358	-2.98	0	0	-1.41	3.15	-0.41	-5.44	-1.98
9-B73X Mo17	-11.94*	-9.23	-4.29	-5.64	18.89	14.79	3.82	7.62
10-B73X Inb209	-14.92**	-12.31*	-10	-11.27*	-5.25	-8.51	-7.35	-3.96
11-B73X Sids63	-8.96*	-6.16	1.43	0	8.39	4.66	17.19	21.49*
12-B73X Rg5	-4.48	-1.54	-4.29	-5.64	5.98	2.33	-8.02	-4.65
13-B73X Inb.204	-7.46	-4.62	-5.71	-7.04	-6.3	-9.52	-11.46	-8.22
LSD at 0.05	2.193		2.387		0.216		0.174	
at 0.01	2.943		3.203		0.29		0.233	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Table 5- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) of F_1 single crosses for grain yield plant^{-1} and shelling % under low and high nitrogen conditions.

Trait	Grain yield plant^{-1}, g				Shelling %			
N-rates	Low N		High N		Low N		High N	
Cross	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	12.09**	36.13**	23.67**	-17.93**	7.71**	12.44**	6.64**	1.50**
2-B73X B97	-8.44**	11.20**	-3.30**	-35.83**	7.51**	12.23**	2.60**	-2.35**
3-B73X PHj40	-48.29**	-37.20**	-36.32**	-57.74**	-8.61**	-4.59*	-5.08**	-9.66**
4-B73X PH207	-34.72**	-20.73**	-28.01**	-52.23**	2.06	6.54**	3.92**	-1.09**
5-B73X HP301	-67.99**	-61.13**	-50.52**	-67.17**	-24.18**	-20.85**	-8.34**	-12.76**
6-B73X CML103	74.84**	112.34**	71.71**	13.95**	1.02	5.45**	2.93**	-2.04**
7-B73X Tzi8	32.39**	60.78**	34.67**	-10.63**	1.24	5.69**	2.50**	-2.44**
8-B73X NC358	18.96**	44.47**	26.64**	-15.96**	-2.66	1.62	2.40**	-2.54**
9-B73X Mo17	-33.42**	-19.15**	8.75**	-27.83**	-14.92**	-11.18**	9.02**	3.76**
10-B73X Inb209	-43.52**	-31.41**	-15.80**	-44.12**	-13.16**	-9.35**	2.61**	-2.34**
11-B73X Sids63	-35.81**	-22.05**	46.62**	-2.70**	-1.71	2.61	5.26**	0.18
12-B73X Rg5	-8.32**	11.34**	-8.86**	-39.52**	9.51**	14.32**	2.89**	-2.07**
13-B73X Inb.204	3.27**	25.42**	48.05**	-1.75**	1.7	6.17**	7.35**	2.17**
LSD at 0.05	0.052		0.017		2.731		0.182	
at 0.01	0.07		0.022		3.664		0.244	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Heterosis for Grain Yield-related Physiological Traits

Relative Potential Photosynthesis for Grain Yield ($RPP_{G.Y}$)

Results in [Table-6] revealed positive (desirable direction) significant or highly significant heterosis percentages over commercial varieties Pioneer SC 3084 and SC 10 by nine and eleven crosses, respectively, under low N conditions. The highest percentages were recorded by cross no. 1 (110.84% over SC3084 and 167.58% over SC 10) followed by cross no. 6 (99.85% over SC3084 and 153.63% over SC 10). On the other hand, under high N conditions, twelve and nine crosses showed maximum positive significant and highly significant heterosis over commercial varieties Pioneer SC 3084 and SC 10, respectively. Cross no.1 (B73X PHG47) gave the highest estimates of heterosis (117.95% over SC3084 and 52.34% over SC 10) followed by crosses no. 12 and 6. The relative photosynthesis potential for grain yield measures the potential of maize hybrids to convert the photosynthetic assimilates into grain yield. Therefore, the reported high $RPP_{G.Y}$ by some hybrids reflects two important points. First, these superior hybrids have efficient photosynthetic machinery capable to provide enough assimilates to support the growth and development of the fertilized ovules. Second, the reproductive sink of these hybrids is capable of accommodation of the provided photoassimlates. These two points indicate efficient coordination between the strong reproductive sink and the photosynthetic source tissues. Results of [40] demonstrated extensive heterosis in photosynthetic rate and other photosynthetic related parameters which, in turn, were also reflected in higher biomass accumulation and yield. However, increased leaf photosynthesis alone did not induce higher grain yield.

Crop Growth Rate (CGR)

Results in [Table-6] revealed that positive (desirable direction) highly significant heterosis percentages over both commercial varieties Pioneer SC 3084 and SC 10 were recorded by two crosses namely B73X CML103 and B73X Tzi8 under low N conditions. These two hybrids gave 38.77% and 12.62% over SC3084 and 40.29% and 13.86 over SC 10, respectively. On the other hand, under high N conditions, three and two crosses showed maximum positive and highly significant heterosis over commercial varieties Pioneer SC 3084 and SC 10, respectively. Cross no.7 (B73X Tzi8) gave the highest estimates of heterosis (67.21% over SC3084 and 31.26% over SC 10) followed by crosses no. 12 (33.86% over SC3084 and 5.08% over SC 10). CGR is one of the most relevant traits in evaluation of hybrid performance as it describes the efficiency of certain hybrids to accumulate more dry matter per certain time period. It is influenced by total incident solar radiation, the amount of incident solar radiation absorbed by plant tissues, and the efficiency of conversion of absorbed solar radiation into plant dry matter. Therefore, the reported high CGR heterotic estimates in hybrids B73X CML103 and B73X Tzi8 suggest that these two hybrids are more efficient than the rest of the tested hybrids in directing large portion of absorbed solar radiation into dry matter. [21] reported that mean heterosis for DMA during the grain-filling period was 134%, which resulted from heterosis for both estimated light interception and leaf photosynthesis and a slightly longer duration of this period for hybrids than for inbred lines.

Table 6- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) of F_1 single crosses for the studied traits under low and high nitrogen conditions.

Traits	Relative potential photosynthesis for grain yield (RPP G.Y)				Crop growth rate (CGR)			
N Rates	Low N		High N		Low N		High N	
Crosses	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	110.84**	167.58**	117.95**	52.34**	-41.64**	-41.01**	-31.80**	-46.46**
2-B73X B97	55.89**	97.84**	67.05**	16.76**	-21.67**	-20.81**	-25.24**	-41.31**
3-B73X PHj40	5.42	33.79**	35.57**	-5.24	-55.70**	-55.22**	-49.05**	-60.00**
4-B73X PH207	46.75**	86.24**	72.27**	20.41**	-52.31**	-51.79**	-51.60**	-62.00**
5-B73X HP301	-53.25**	-40.67**	-27.73**	-49.49**	-60.57**	-60.14**	-50.99**	-61.53**
6-B73X CML103	99.85**	153.63**	94.78**	36.15**	38.77**	40.29**	29.12**	1.36
7-B73X Tzi8	90.41**	141.65**	66.73**	16.54**	12.62**	13.86**	67.21**	31.26**
8-B73X NC358	72.29**	118.66**	85.48**	29.65**	-11.97**	-11.01**	-4.71**	-25.20**
9-B73X Mo17	17.49*	49.11**	79.12**	25.20**	-57.09**	-56.62**	-28.56**	-43.92**
10-B73X Inb209	-17.34*	4.91	21.21*	-15.28*	-53.17**	-52.66**	-52.50**	-62.71**
11-B73X Sids63	-19.97**	1.57	95.60**	36.72**	-27.32**	-26.53**	33.86**	5.08**
12-B73X Rg5	29.88**	64.83**	34.26**	-6.16	-32.42**	-31.67**	-30.54**	-45.47**
13-B73X Inb.204	19.97**	52.25**	85.16**	29.42**	-12.10**	-11.14**	-0.7	-22.05**
LSD at 0.05	3.005		3.458		0.382		0.251	
at 0.01	4.032		4.64		0.512		0.337	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Harvest Index (HI)

Results in [Table-7] revealed that positive (desirable direction) highly significant heterosis percentages over commercial varieties Pioneer SC 3084 and SC 10 were recorded by ten and twelve crosses, respectively, under low N conditions. The highest percentages were recorded by cross no. 1 (55.10% over SC3084 and 72.7% over SC 10) followed by cross no. 6 (37.26% over SC3084 and 52.84% over SC 10). On the other hand, under high N conditions, eleven and three crosses showed positive highly significant heterosis over commercial varieties Pioneer SC 3084 and SC 10, respectively. Cross no.1 (B73X PHG47) attained the highest estimates of heterosis (51.77% over SC3084 and 15.40% over SC 10) followed by cross no. 9 (50.8% over SC3084 and 14.67% over SC 10). Harvest index and its underlying physiological processes are important components of grain yield as they describe the ability of maize plants to allocate their dry matter accumulation to grain yield. Therefore, the reported superiority of some of the new hybrids in harvest index over the commercial hybrids reflects the higher efficiency of their physiological machinery in partitioning of a considerable part of their dry matter to grain yield. [21] showed that mean heterosis across the studied three years was 167% for grain yield and 85 and 53% for its two component processes, dry matter accumulation (DMA) at maturity and harvest index (HI), respectively. And heterosis for harvest index was strongly associated with heterosis for kernel number.

Nitrogen Use Efficiency (NUE)

Results in [Table-7] revealed that positive (desirable direction) significant or highly significant heterosis percentages over commercial varieties Pioneer SC 3084 and SC 10 were recorded by five and seven crosses, respectively, under low N conditions. The highest percentages were recorded by cross no. 6 (74.86% over SC3084 and 112.34% over SC 10) followed by cross no. 7 (32.41% over SC3084 and 60.79% over SC 10). On the other hand, under high N conditions, there were seven crosses and one cross showed maximum positive highly significant heterosis over commercial varieties Pioneer SC 3084 and SC 10, respectively. Interestingly, cross no.6 (B73X CML103) gave the highest estimates of heterosis (71.90% over SC3084 and 13.87% over SC 10) followed by crosses no. 14 and no. 12 which recorded 48.21% and 46.83%, respectively over commercial variety Pioneer SC 3084 only. The high heterosis estimates attained by the above hybrids particularly hybrids 6 and 7 suggest that strong positive interaction between nitrogen use efficiency favoring alleles in the two genomes of their parents. It worth mentioning that the two hybrids share the B73 genome with the rest of the new hybrids which suggests that the superiority of the hybrids over the rest of hybrids is attributed to the positive interaction between NUE favorable alleles from B73 and genomes contributed by their male parents genomes (CML103 and Tzi8) respectively. Interestingly, these hybrids particularly, B73XCML103 attained the highest kernel number per plant, 100 kernel weight, and grain yield per plant among the tested hybrids (data not shown) suggesting the highest sink strength among hybrids. Similar results were reported by [41] who showed that, among the 72 crosses derived from 18 inbred lines, heterosis of seven crosses were 10% higher than that of the control hybrid ND108 at high N and five crosses were 10% higher than that of ND108 at low N (no N added), and most of high NUE hybrids were from the mid-efficient × high-efficient or high-efficient × high-efficient parents.

Association Studies

Genotypic and phenotypic correlation coefficients between grain yield plant^{-1} and the other studied yield components and yield-related physiological traits are shown in [Table-8]. The magnitude of genotypic and phenotypic correlations was nearly the same, indicating minimal influence of environment on the obtained relationships. The phenotypic and genotypic correlation coefficients were positive and non-significant (weak correlation) between grain yield plant^{-1} and only one trait i.e. rows number ear^{-1} under both low and high N conditions. However, the phenotypic and genotypic correlation coefficients were positive and significant (moderate correlation) between grain yield plant^{-1} and each of ears number plant^{-1} (rph= 0.52*, rg= 0.54* and rph= 0.58*, rg= 0.61*), kernels number row^{-1} (rph= 0.53*, rg= 0.56* and rph= 0.62*, rg= 0.66*), ear length (rph= 0.57*, rg= 0.62* and rph= 0.56*, rg= 0.62*), and shelling % (rph= 0.47*, rg= 0.48* and rph= 0.50*, rg= 0.50*) under both low and high N conditions, respectively. Whereas, phenotypic and genotypic correlation coefficients were positive and highly significant (strong correlation) between grain yield plant^{-1} and each of ear diameter (rph= 0.80**, rg= 0.84** and rph= 0.59*, rg= 0.63*) kernel depth (rph= 0.62*, rg= 0.74** and rph= 0.63**, rg= 0.71**), under both low and high N conditions, respectively. Interestingly, the phenotypic and genotypic correlation coefficients between grain yield plant^{-1} and the tested yield-related physiological traits were positive and moderate for HI (rph= 0.53*, rg= 0.53* and rph= 0.43*, rg= 0.43*) under both N rates as well as $RPP_{G.Y}$ (rph= 0.61*, rg= 0.61*) under deficient soil N. On the other hand, positive and strong correlation was observed between $RPP_{G.Y}$ (rph= 0.72**, rg= 0.72**) under high N, as well as CGR (rph= 0.85**, rg= 0.85** and rph= 0.84*, rg= 0.84*) and NUE (rph= 0.99**) under limited and adequate soil N. These results suggest that, in general, to increase grain yield plant^{-1}, selection should be carried out for most of the studied yield components especially; ears number per plant, rows number per ear, ear diameter, ear length and kernel depth as well as for all tested yield-related physiological traits under both low and high N conditions.

Table 7- Estimates of heterosis over commercial varieties (Pioneer SC 3084 and SC 10) of F_1 single crosses for harvest index (HI) and nitrogen use efficiency (NUE) under low and high nitrogen conditions.

Traits	Harvest index (HI)				Nitrogen use efficiency (NUE)			
N Rates	Low N		High N		Low N		High N	
Crosses	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10	SC 3084	SC10
1-B73X PHG47	55.10**	72.70**	51.77**	15.40**	12.10**	36.13**	23.69**	-18.07**
2-B73X B97	27.07**	41.49**	20.90**	-8.07**	-8.42**	11.21**	-3.31**	-35.95**
3-B73X PHj40	10.51**	23.05**	13.18**	-13.94**	-48.29**	-37.21**	-36.36**	-57.85**
4-B73X PH207	24.52**	38.65**	27.01**	-3.42	-34.70**	-20.71**	-27.82**	-52.19**
5-B73X HP301	-45.54**	-39.36**	-28.94**	-45.97**	-68.00**	-61.14**	-50.41**	-67.15**
6-B73X CML103	37.26**	52.84**	35.69**	3.18	74.86**	112.34**	71.90**	13.87**
7-B73X Tzi8	18.47**	31.91**	-10.61**	-32.03**	32.41**	60.79**	34.71**	-10.77**
8-B73X NC358	20.38**	34.04**	26.05**	-4.16*	18.97**	44.47**	26.72**	-16.06**
9-B73X Mo17	22.29**	36.17**	50.80**	14.67**	-33.41**	-19.14**	8.82**	-27.92**
10-B73X Inb209	-1.91	9.22**	25.40**	-4.65*	-43.51**	-31.40**	-15.70**	-44.16**
11-B73X Sids63	-17.20**	-7.80**	15.76**	-11.98**	-35.80**	-22.04**	46.83**	-2.74**
12-B73X Rg5	27.71**	42.20**	21.22**	-7.82**	-8.30**	11.36**	-8.82**	-39.60**
13-B73X Inb.204	21.02**	34.75**	47.59**	12.22**	3.28**	25.41**	48.21**	-1.82**
LSD at 0.05	0.017		0.017		0.052		0.017	
at 0.01	0.022		0.022		0.07		0.022	

*and ** significant at 0.05 and 0.01 level of probability, respectively.

The magnitude of genotypic correlations of yield components were higher than those of phenotypic and environmental correlation coefficients to grain yield, indicating that selection for these traits is expected to improve grain yield. Our analysis also indicated that correlations as well as heritability were suitable as models for yield improvement and selection for N-stress tolerant genotypes. Traits attained higher heritability and positive correlation with grain yield may be considered as important traits in selection program aiming to maize yield improvement and the breeder may consider these traits as main selection criteria. These results are in agreement with those reported by [42, 43].

Genetic and Environmental Variances and Heritability

Results in [Table-9] revealed that genetic variance (σ^2G) of studied maize crosses were higher than environmental (σ^2e) variance in all studied traits at both low and high N conditions. Therefore, broad-sense heritability estimates for all studied traits attained high percentages and ranged from 70.2% for kernel depth to 99.9% for grain yield plant^{-1} at low N conditions, and from 80.4% for kernel depth to 99.9% for each of grain yield plant^{-1} and shelling % at high N conditions.

Higher and relatively moderate broad-sense heritability of the traits revealed that variations were transmissible and the potential for developing high yielding varieties through selection of desirable plants in succeeding generations exist. The varietal differences in maize yield components might be due to differences in genetic makeup, potentiality of these varieties which in turn reflect on yield components, and due to their growth habit and their physiological traits. Therefore, diversity among different crosses is truly expected. This result is in harmony with those obtained by [43].

Table 8- Phenotypic (r_{ph}) and genotypic (r_g) correlations between maize grain yield plant^{-1} and some studied traits under low and high nitrogen conditions.

Trait		Grain yield plant^{-1} Low N	Grain yield plant^{-1} High N
Ears number plant^{-1}	r_{ph}	0.52*	0.58*
	r_g	0.54*	0.61*
Rows number ear^{-1}	r_{ph}	0.27	0.14
	r_g	0.3	0.14
kernels number row^{-1}	r_{ph}	0.53*	0.63*
	r_g	0.56*	0.66*
Ear diameter, cm	r_{ph}	0.80**	0.59*
	r_g	0.84**	0.63*
Ear Length, cm	r_{ph}	0.57*	0.56*
	r_g	0.62*	0.62*
Kernel depth, cm	r_{ph}	0.62*	0.63*
	r_g	0.74**	0.71**
Grain yield plant^{-1}, g	r_{ph}	0.99**	0.99**
	r_g	0.99**	0.99**
Shelling %	r_{ph}	0.47*	0.50*
	r_g	0.48*	0.50*
Relative potential photosynthesis for grain yield (RPP $_{G.Y}$)	r_{ph}	0.72**	0.61*
	r_g	0.72**	0.61*
Crop growth rate (CGR)	r_{ph}	0.85**	0.84**
	r_g	0.85**	0.84**
Harvest index (HI)	r_{ph}	0.53*	0.43*
	r_g	0.53*	0.43*
Nitrogen use efficiency (NUE)	r_{ph}	0.99**	0.99**
	r_g	0.99**	0.99**

*and ** significant at 0.05 and 0.01 level of probability, respectively.

Table 9- Genetic variance (σ^2 G), environmental variance (σ^2 e) and heritability (h^2) for maize crosses for all studied traits under low and high nitrogen conditions.

Trait	Genetic variance (σ^2 G)		Environmental variance (σ^2 e)		Heritability (h^2_b) %	
N rate	Low N	High N	Low N	High N	Low N	High N
Ears number plant^{-1}	0.088	0.145	0.005	0.016	95.0	90.3
Rows number ear^{-1}	1.275	2.277	0.305	0.260	80.7	89.8
kernels number row^{-1}	16.248	19.606	2.037	2.375	88.9	89.2
Ear diameter, cm	0.114	0.118	0.014	0.018	89.1	86.8
Ear Length, cm	3.514	2.850	0.584	0.691	85.8	80.5
Kernel depth, cm	0.013	0.015	0.006	0.004	70.2	80.4
Grain yield plant^{-1}, g	3216.927	3663.0	0.00033	0.0001	99.9	99.9
Shelling %	43.895	10.714	0.905	0.004	98.0	99.9
Relative potential photosynthesis for grain yield (RPP$_{G.Y}$)	96.345	69.746	1.095	1.451	98.9	98.0
Crop growth rate (CGR)	4.523	7.007	0.018	0.008	99.6	99.9
Harvest index (HI)	0.005	0.004	0.00001	0.00001	99.9	99.8
Nitrogen use efficiency (NUE)	2058.663	146.64	0.00033	0.0001	99.9	99.9

Expected Gain from Direct and Indirect Selection

Expected gains from direct selection for grain yield plant^{-1} at low N environment (64.312 g/plant) were lower than at high N environment (70.098 g/plant) [Table-10]. Results in [Table-10] indicated that the expected gains in grain yield from indirect selection for related traits, and their percentages to direct selection were ranged from 17.27 g/plant and 26.9% for rows number ear^{-1} to 51.12 g/plant and 79.5% for ear diameter at low N conditions. While, at sufficient N input, the expected gains in grain yield from indirect selection for related traits, and their percentages to direct selection were ranged from 9.56 g/plant and 13.6% for rows number ear^{-1} to 69.79 g/plant and 99.6% for nitrogen use efficiency (NUE).

Generally, the values of expected gains in grin yield from indirect selection for related traits, and their percentages to direct selection were lower at low N than at high N environment for all studied traits, except traits of rows number ear^{-1} and ear diameter. Similar results were reported by [22,24,25].

In general, a value of 100% for indirect selection/direct selection (100 x IR/R) indicates that indirect and direct selections are predicted to be equally efficient. While, when this percent is less than 100%, direct selection is predicted to be more efficient than indirect selection, and vice versa when this percent is more than 100%. Thus, our results show that direct selection for grain yield plant^{-1} was likely to be more efficient than indirect selection for all studied traits. It is concluded that for studied traits, the expected gain from direct selection would improve the trait under consideration in a way better than the indirect selection.

Table 10- Expected gain in yield from indirect selection for maize studied traits and indirect gain in percent of direct gain from selection for grain yield under low and high nitrogen conditions.

Trait	Expected gain from indirect selection		Indirect gain / direct gain (%)	
N rate	Low N	High N	Low N	High N
Ears number plant^{-1}	33.67	40.74	52.4	58.1
Rows number ear^{-1}	17.27	9.56	26.9	13.6
kernels number row^{-1}	33.85	43.86	52.6	62.6
Ear diameter, cm	51.12	41.37	79.5	59
Ear Length, cm	36.62	39.22	56.9	56
Kernel depth, cm	39.67	44.35	61.7	63.3
Grain yield plant^{-1}, g	63.58	69.79	98.9	99.6
Shelling %	30.54	34.76	47.5	49.6
Relative potential photosynthesis for grain yield ($RPP_{G.Y}$)	46.07	42.57	71.6	60.7
Crop growth rate (CGR)	54.77	58.53	85.2	83.5
Harvest index (HI)	34.35	29.93	53.4	42.7
Nitrogen use efficiency (NUE)	63.58	69.79	98.9	99.6

*Expected gains from direct selection for grain yield plant^{-1} were 64.312 g/plant and 70.098 g/plant under low and high N rates, respectively.

Conclusion

The mean values of all studies hybrids exhibited significant difference for all tested yield related parameters. These results indicate that most of the tested yield-related traits showed some degree of heterosis [Table-2]-[Table-10].

For all tested hybrids, the heterosis estimates showed significant difference in response to low and high N inputs especially for grain yield and many of its related traits such as, ears number per plant, rows number per ear, kernel number per row, kernels number per plant, ear length and diameter, and 100-kernel weight. These results indicate significant effect of N availability (environment) on hetrosis for the studied traits. These results are supported by the fact that maize grain yield and growth is generally responsive to N availability which will be translated into variation in heterotic estimates. Some a discrepancy in the heterotic estimates of different hybrids in response to N availability was reported. Such discrepancy reflects the dynamic and the complex nature of heterosis.

Interestingly, B73XCML103 and B73XTzi8 exhibited consistent superior heterosis for most of the studied traits under both low and high N levels [Table-2]-[Table-10], including grain yield, the most economic trait. The reasons underlying such superiority might include that the parental lines, B73, CML103, and Tzi8 might have significantly diverse genetic background. However, such genetic difference between B73 and CML103 seems to be higher than that between B73 and Tzi8. According to the dominance hypothesis of heterosis, the parental lines of these two hybrids might have different grain yield favoring dominant alleles that complement the unfavorable alleles in the other line which ultimately lead to the observed improvement heterosis in the studied traits. It is also possible that the parental lines of each of these hybrids exhibit significant allelic interaction at one or more loci that are critical for grain yield and its related traits (the over dominance hypothesis). In addition, no information is available on the degree of colinearity among B73, CML103 and Tzi8 genomes. It is possible that high degree of non-colinearity might exist among the genomes of these lines which will partially explain the exceptionally high degree of heterosis estimate in hybrids 6 and 7. Further, the superiority of hybrid 6 over 7 suggests that either certain alleles favoring high yield are present in CML103 and absent in Tzi8 or the yield favoring alleles show better interaction in B73xCML103 hybrid than in B73xTzi8 hybrid [32].

Finally, the reported differences in the heterotic estimates suggest that the new hybrids employ different physiological mechanisms in response to both N availability and their genetic makeup. Therefore, it will be interesting to select a subgroup including hybrids with contrasting heterotic responses and carry out more focused physiological studies to dissect the physiological processes operating in critical metabolic processes and underlying the reported heterosis. This will be critical for increasing our understanding of how these new hybrids differentially respond to soil nitrogen.

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