British Biotechnology Journal
10(4): 1-12, 2016, Article no.BBJ.21916
ISSN: 2231–2927, NLM ID: 101616695

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Heterobeltiosis in Wheat (*Triticum aestivum* L.) F_1 Diallel Crosses under Contrasting Soil-N Conditions

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Authors' contributions

This work was carried out in collaboration between all authors. Author AMMAN designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors RS and MMAEA managed the analyses of the study. Author ZAER managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BBJ/2016/21916
Editor(s):
(1) Standardi Alvaro, Department of Agricultural and Environmental Sciences, University of Perugia, Italy.
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Complete Peer review History: http://sciencedomain.org/review-history/12150

Original Research Article

Received 9th September 2015
Accepted 23rd October 2015
Published 7th November 2015

ABSTRACT

Breeding wheat cultivars with improved adaptation to low soil-N, has gained importance worldwide in order to decrease N fertilizer consumption and overcome the ecological and economic problems of the misuse of this fertilizer. Identification of wheat crosses that show useful heterosis (heterobeltiosis) is an important issue in breeding programs. The main objective of the present investigation was to estimate heterobeltiosis for nitrogen use efficiency and other studied traits of F_1 diallel crosses among six wheat parents in order to identify the superior ones for future use in breeding programs. Genetic materials were evaluated at two seasons (2007/2008 and 2008/2009) in a split-plot design with randomized complete block arrangement, using three replications. Main plots were assigned to N levels (0 and 75 kg N/fed), while sub plots were devoted to genotypes. Data combined across the two seasons were presented. In general, low N caused a significant reduction in 9 out of 14 studied traits. These reductions were relatively high in magnitude for

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number of spikes/ plant (SPP) for parents (23.65%) and F_1's (23.99%). On the contrary, low–N caused increases in the averages of nitrogen use efficiency (NUE) by 89.5 and 97.60% for parents and F_1's, respectively. Averages of heterobeltiosis for all studied characters were either non-significant or significant but non favorable, except for plant height under both low and high N, NUPE under high N and GPS under low N. However, some crosses for each trait showed significant and favorable heterobeltiosis. Under low–N, the highest favorable and significant heterobeltiosis estimate was shown by L27 x Gem 7 for GYPP (14.94%), NUTE (44.81%) and GPS (25.82%), L25 x L26 for 100 GW (13.87%), L 25 x L 27 for SPP (12.53%), L 27 x Gem 9 for GPS (26.19%) and Gem 7 x Gem 9 for BYPP (28.99%).

Keywords: Heterosis; bread wheat; nitrogen use efficiency; low-N.

1. INTRODUCTION

Nitrogen (N) is one of the major inputs in wheat production systems. But, low-N availability in soils in Egypt is an important yield- limiting factor frequently found in farmers' fields, since the smallholder farmers cannot afford additional inputs. Today, elevated nitrogen level in water, as result of leaching, is an important component of agricultural pollution [1] causing major problems in marine ecosystems and eutrophication of freshwater [2]. Moreover, N fertilization increases emissions of the greenhouse gas nitrous oxide (N_2O) from agricultural soils [3]. Volatile ammonia emissions from fertilizer contribute to deposition of N in unmanaged ecosystems [4].

While wheat yields often increase at higher N rates, there can also be negative environmental consequences associated with high N inputs to agriculture. Based on these essential economic and ecological grounds, an increased interest is being shown worldwide in wheat cultivars that are more efficient in utilizing soil resources and better fitted to water and nutrient limitations [5-11].

Among cereals, hexaploid wheat is commonly identified as a species with higher requirements for nutrients, especially nitrogen. Thus, breeding wheat cultivars with improved adaptation to less favorable, but more optimized N fertilization regimes has gained importance. In Egypt, such breeding strategies are also justified by problems of nitrogen that is a major constraint limiting grain production.

Recent discoveries have stimulated interest in and speculation as to the possibility of commercial production of hybrid wheat [12]. Many reports have been published establishing the fact that heterosis does occur with proper combinations of parents [13,14]. Parental selection represents the major step in the development of new high-yielding cultivars, and the efficient identification of superior hybrid combinations is a fundamental issue in wheat breeding programs [15]. The breeding value of genotypes is evaluated based on the analysis of hybrids. These data facilitate the choice of parental genotypes with a high probability of heterosis in their F_1 progeny [16,17].

The performance of the hybrids is estimated in terms of the percentage increase or decrease of their performance over the mid-parent (heterosis) and better parent (heterobeltiosis). From the perspective of the breeder, heterobeltiosis is more effective than heterosis, particularly in the breeding of self-pollinating crops, where the objective is to identify superior hybrids [18].

Previous studies on wheat have reported extreme positive values of heterobeltiosis and heterosis (48 and 60%, respectively) for grain yield [19-21]. Since the discovery of male sterility controlled *via* cytoplasmic genes [22] or chemical agents [23,24], hybrid development has been considered to be promising approach to increasing the grain yield and stability of crop wheat [25-27].

Selection of parents is the most vital stage in any breeding program. For this purpose, many researchers have used parents with contrasting traits such as combination of hard red and soft white wheat, winter and spring wheat cultivars [27], old and modern day wheat cultivars [28], short and tall [29]. According to Morgan et al. [30], parents utilized in breeding programs may show less heterosis for grain yield because they already have several valuable genes in homozygous state. In addition to that, Fabrizius et al. [31] have reported that the parents with greater genetic differences may produce more hybrid vigor for grain yield. Singh et al. [32] have recommended heterobeltiosis as being valuable for influencing true heterotic cross combinations.

The objectives of the present study were (i) to study the effect of low-N on the means of agronomic, grain yield and nitrogen efficiency traits of six wheat parents and their F_1 and F_2 diallel crosses and (ii) to estimate heterobeltiosis percentages for such traits of F_1 crosses in order to identify the best ones and their parents for future use in breeding programs.

2. MATERIALS AND METHODS

This study was carried out at Giza Research Station of the Agricultural Research Center(ARC), Giza Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 22.50 meters above sea level), in 2005/2006 season and at Noubarya Research Station of the ARC, Noubarya, Egypt (30° 66'N latitude and 30° 06' E longitude with an altitude of 15.00 meters above sea level), in 2006/2007, 2007/2008 and 2008/2009 seasons.

2.1 Materials

Six bread wheat genotypes (*Triticum aestivum* L.) were chosen for their divergence in tolerance to low nitrogen, based on previous field screening carried out by Wheat Res. Dept., Field Crops Res. Inst., ARC, Egypt (Table 1).

2.2 Making the F_1 Diallel Crosses

In season 2005/2006, a half diallel of crosses involving the six parents (without reciprocals) was done at Giza Agric. Res. Stat., Agric. Res. Center, to obtain the F_1 seeds of 15 crosses. In season 2007/2008, the half diallel of crosses was again done to increase quantity of F_1 seeds.

2.3 Field Evaluation of 6 Parents and 15 F_1's

In the seasons 2007/2008, 2008/2009, parents (6) and F_1's (15) were sown on 17th of November each season in the field of Noubarya Res. Stat., under two levels of nitrogen fertilizer; the low level was without fertilization (LN) and the high level was 75 kg Nitrogen/ feddan (HN); this is the recommended level of Ministry of Agriculture. This level of nitrogen fertilizer (168 kg Urea/fed) was added in two equal doses, the first dose was added just before the sowing irrigation and the second dose just before the second irrigation (21 days after irrigation). In this experiment, a split plot design in randomized complete block arrangement was used with three replications. The two levels of nitrogen were allotted to the main plots and the genotypes to the sup plots. Each parent or F_1 was sown in two rows; each row was three meter long; spaces between rows were 30 cm and 10 cm between plants, and the plot size was 1.8 m^2. All other agricultural practices were done according to the recommendation of Ministry of Agriculture for growing wheat in Noubarya region.

Available soil nitrogen in 30 cm depth was analyzed immediately prior to sowing and N application at the laboratories of Water and Environment Unit, ARC, Egypt in the two seasons. Soil nitrogen was found to be 55 and 57 kg N/ fed in the seasons 2007/2008, 2008/2009, respectively. Available soil nitrogen after adding nitrogen fertilizer was therefore 55 and 130 kg N/fed in the first season and 57 and 132 kg N/fed in the second season for the two treatments, i.e. LN and HN, respectively. The available nitrogen to each plant (including soil and added N) was calculated for each environment to be 0.79, 1.85 g/plant in

Table 1. Designation, pedigree and tolerance to low N of the six promising lines and Egyptian cultivars of wheat used for making diallel crosses of this study

Designation	Pedigree	Tolerance to low nitrogen
Line 25 (L25)	MYNA/VUL//TURACO/3/TURACO/4/Gem7.	Tolerant
Line 26 (L26)	MUNIA/CHTO//AMSEL.	Tolerant
Line27 (L27)	Compact-2/Sakha//Sakha61.	Tolerant
Gemeiza7(Gem7)	CMH74A.630/SX//Seri82/3/Agent.	Sensitive
Gemeiza9(Gem9)	Ald "s"/HUC "s;;//CMH74A.630/SX.	Sensitive
Giza168 (Gz168)	MRL/BUC//Seri.	Sensitive

Source: Wheat Res. Dept., Field Crops Res. Inst., ARC, Egypt

2007/2008 season and 0.81 and 1.89 kg/fed in 2008/2009 season, with an average across the two seasons of 0.80 and 1.87 g/plant for the two environments LN and HN, respectively. The soil analysis of the experimental soil at Noubarya Research Station, as an average of the two growing seasons, indicated that the soil is sandy loam (67.86% sand, 7.00% silt and 25.14% clay), the pH is 8.93, the EC is 0.55 dSm^{-1}, the soluble cations in meq l^{-1} are Ca^{2+} (5.30), K^+ (0.70), Na^+ (0.31), Mg^{2+} (2.60) and the soluble anions in meq l^{-1} are CO_3^{2-} (0.00), HCO_3^- (2.10), Cl^- (5.30) and SO_3^{2-} (1.51).

2.4 Data Collection

A random sample of 10 plants of each genotype of parents and F_1's and 30 plants of F_2's was used to collect data for 14 traits: days to 50% heading (DTH) as number of days from sowing date to the date at which 50% of main spike awns/ plot have completely emerged from the flag leaves, days to maturity (DTM) measured as number of days from sowing date to the date at which 50% of main peduncles/ plot have turned to yellow color (physiological maturity), plant height (PH) measured as plant length from the soil surface to the tip of the spikes, excluding awns, number of spikes/plant (SPP) as number of fertile spikes per plant, number of grains/ spike (GPS), 100 grain weight (100 GW) measured as weight of 100 grains taken from each guarded plant, grain yield/ plant (GYPP) measured as weight of the grains of each individual plant, biological yield/ plant (BYPP) measured as weight of the grains and stem of each individual plant and harvest index (HI%) according formula: HI= 100 (GYPP/ BYPP). At physiological maturity stage, five random guarded plants were removed from each plot by cutting at the soil surface. The plants were bulked as one sample per plot. They were separated into straws (including leaves, stems and spike residues) and grains. Samples were oven dried at 70℃ to a constant weight and each part was weighed separately. Samples were ground in powder and nitrogen of straws (N straw) and grains (N_g) was determined using Kjeldahl procedure according to A.O.A.C. [33]. Total plant nitrogen (N_t) was calculated as follows: $N_t = N_g + N_{straw}$. Data were collected for: nitrogen use efficiency (NUE) g/g= (GYPP / N_s), nitrogen uptake efficiency (NUPE)% =100 (N_t / N_s), nitrogen utilization efficiency (NUTE) (g/g)= (GYPP/N_t), nitrogen harvest index (NHI%)= 100(N_g/ N_t), and grain protein content (GPC) measured as follows: GPC%= N_g x 5.70 according to AACC [34], where GYPP is grain yield/ plant in gram, N_t is total nitrogen in the whole plant (grains and straw), N_s is available nitrogen in the soil for each plant, and N_g is grain nitrogen content. Nitrogen efficiency parameters were estimated according to Moll et al. [35].

2.5 Biometrical Analysis

The analysis of variance (ANOVA) of the split plot design was performed on the basis of individual plot observation using the MIXED procedure of SAS ® [36]. Moreover, each environment (HN and LN) was analyzed separately as lattice design for the purpose of determining genetic parameters using Genestat10th addition windows software. Least significant differences (LSD) values were calculated to test the significance of differences between means according to Steel et al. [37].

2.6 Heterobeltiosis

Percentages of F_1 relative to the better parent (heterobeltiosis) for studied traits of the F_1 diallel were calculated as follows: Heterobeltiosis (%) = 100 (F1– BP)/BP, Where: F1 = mean of the BP = mean of the better parent. The significance of heterobeltiosis was determined as the least significant differences (L.S.D) at 0.05 and 0.01 levels of probability according to Steel et al. [37] using the following formula: LSD 0.05 = t0.05(edf) x SE and LSD 0.01 = t0.01(edf) x SE Where: edf = the error degrees of freedom, SE = the standard error SE for heterobeltiosis = (2MSe/r)1/2 Where: t0.05 and t0.01 are the tabulated values of 't' for the error degrees of freedom at 0.05 and 0.01 levels of probability, respectively Table 2. r: Number of replications.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Combined analysis of variance across years (Y) of the split plot design in randomized complete block arrangement across 2008/2009 and 2009/2010 seasons for the studied 21 wheat genotypes (6 parents and 15 F_1's) under two levels of nitrogen was performed (data not presented). Mean squares due to years were highly significant for nine studied traits and non significant for five traits, *i.e.* days to maturity (DTM), harvest index (HI), nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUPE) and grain protein content (GPC), indicating significant effect of climatic conditions on most studied traits, namely days to heading (DTH), plant height (PH), spikes/plant (SPP), grains/ spike (GPS), 100 grain weight (100GW), grain yield/ plant (GYPP), biological yield/ plant (BYPP, nitrogen utilization efficiency (NUTE) and nitrogen harvest index (NHI).

Results also exhibit that mean squares due to nitrogen levels (N) were highly significant for all studied traits, indicating that the N level has an obvious effect on all studied traits of studied wheat genotypes. Mean squares due to genotypes (G) were highly significant for all studied traits, indicating that wheat genotypes used in this study were significantly ($P\leq 0.01$) different for all studied traits. Mean squares due to the interaction N x Y were highly significant for number of grains / spike (GPS), biological yield/ plant (BYPP), harvest index (HI), nitrogen use efficiency (NUE) and grain protein content (GPC) and significant for grain yield / plant (GYPP) and non significant for other traits. Moreover, mean squares due to genotypes x nitrogen levels, *i.e.* G x N were significant ($P \leq 0.01$ or 0.05) for all studied traits, indicating that genotypes ranks differ from one nitrogen level to another and that selection can be done under a specific soil nitrogen environment as proposed by Al-Naggar et al. [38-44]. The significant G×N interaction for grain yield was also a good evidence for varying responses of these wheat genotypes at various N levels [45,46]. The interactions G x Y and G x Y x N were also significant ($P \leq 0.01$ or 0.05) for all studied traits, indicating that genotypes ranks differ from one combination of Y x N to another.

Combined analysis of variance of randomized complete block design for all studied traits under each environment (high N and low N) across two seasons was performed (data not presented). Mean squares due to genotypes, parents and F_1's under the two levels of nitrogen were highly significant for all studied traits. Significant differences among parents of diallel crosses in all studied traits are pre-requisite for performing the diallel analysis for estimating the inheritance of studied traits under different N- application rates.

Mean squares due to parents *vs*. F_1's were highly significant for all studied traits under the two levels of nitrogen, indicating the presence of significant heterosis for all studied traits. Mean squares due to the interaction P x Y under high level of nitrogen were significant or highly significant for 10 studied traits and non significant for DTH, BYPP, NUE and GPC. Mean squares due to the interactions F_1's x Y under high-N were significant or highly significant for all studied traits, except NUPE for F_1's x Y, which were not significant. Mean squares due to the interactions F_1's x Y were significant or highly significant for all studied traits under low N, except for 100GW, GYPP, NUE, NUPE, NUTE and GPC for F_1's x Y. Mean squares due to the interactions P's *vs* F_1's x Y under the two levels of nitrogen were significant and highly significant for all studied traits, except NHI. The significance of the interactions P's *vs* F_1's x Y indicates that heterosis differs from season to season in most studied traits.

3.2 Effect of Low-N on Performance of P's and F_1's

A comparative summary of means of all studied traits across all 21 genotypes (6 parents and 15 F_1's) subjected to two levels of nitrogen conditions and across two years is presented in Table 2. In general, low N caused a significant reduction in 9 out of 14 studied, namely (GYPP, SPP, 100 GW, GPS, GPC, GYPP, HI, DTH and DTM). Mean grain yield/plant (GYPP) was significantly decreased due to low-N by an average of 18.96 and 21.17% for parents and F_1's, respectively. Reduction in grain yield of wheat due to low soil nitrogen was reported by several investigators. A positive relationship between N application levels and the grain yield has already been shown in many studies [46,47].

Significant reduction in grain yield as a result of low-N was associated with significant reductions in all yield components traits, *i.e.* SPP, 100GW and GPS. These reductions were relatively high in magnitude for number of spikes/ plant (SPP) for parents (23.65%) and F_1's (23.99%). This indicates that SPP is the most determining component of grain yield / plant of wheat under low-N stress. The importance of this trait (number of spikes or fertile tillers per plant) in wheat for grain productivity under abiotic stress conditions was previously reported by several investigators [41-44,48,49]. Hussain et al. [19] observed that increasing nitrogen application increased the number of fertile tillers per unit area. Geleto et al. [50] reported that grain yield is closely related to the number of spikes per unit area. Fertilized plots produced more spikes than control. Such response can be attributed to the adequate nitrogen availability which might facilitate the tillering ability of plants, resulting in a greater spike population. Ayoub et al. [51] also reported that spike population increased with increase in nitrogen level.

Table 2. Means of studied wheat traits under low–N (0 Kg N/fed) and high–N (75 Kg N/fed) and relative reduction compared to high–N combined across parents and F_1's across two seasons

Traits	Parameter	Parents		F_1 crosses	
		High-N	Low-N	High-N	Low-N
DTH	Average	88.64	87.94	89.61	85.11
	Reduction%	---	0.78	---	4.95**
DTM	Average	132.33	128.17	133.33	126.17
	Reduction%	---	3.13*	---	5.33**
PH(cm)	Average	82.74	81.21	89.54	83.96
	Reduction%	---	1.74	---	6.22**
GPS	Average	80.23	69.81	79.95	71.76
	Reduction%	---	13.47**	---	9.80**
100GW(g)	Average	4.66	4.05	4.33	3.84
	Reduction%	---	12.96**	---	10.51**
SPP	Average	11.88	9.11	12.13	9.14
	Reduction%	---	18.96**	---	23.99**
GYPP(g)	Average	27.53	22.41	29.12	22.83
	Reduction%	---	18.96**	----	21.17**
BYPP(g)	Average	63.14	54.98	64.87	56.78
	Reduction%	---	12.94**	---	12.27**
HI(%)	Average	43.67	40.73	45.11	40.51
	Reduction%	----	6.57**	---	8.97**
NUE(g/g)	Average	14.72	28.03	15.57	28.53
	Reduction%	----	-.89.56**	----	-97.60**
NUPE(%)	Average	16.00	26.87	16.14	29.43
	Reduction%	-----	-65.87**	-----	-83.08**
NUTE(g/g)	Average	0.94	1.07	0.98	1.00
	Reduction%	----	-14.39**	----	-3.93
GPC(%)	Average	14.35	11.33	14.61	12.64
	Reduction%	------	21.3**	-------	14.71**
NHI(%)	Average	56.10	55.94	56.21	58.08
	Reduction%	-----	0.28	-----	-3.33

*N= nitrogen, * and** indicate significance at 0.05 and 0.01 probability levels, respectively.*
Reduction%= 100[(HN-LN)/HN]

Moreover, low nitrogen caused a significant reduction in biological yield / plant (BYPP) by 12.49 and 12.27%, grain protein content (GPC) by 25.06 and 29.18% and harvest index (HI) by 6.57 and 8.97% for parents and F_1's, respectively. It was observed that low- N caused slight but significant earliness of DTM by 3.13 and 5.33% (4.17 and 7.16 days) and DTH by 0.70 and 4.50 days for parents and F_1's, respectively.

On the contrary, low–N caused increases in the averages of nitrogen use efficiency (NUE) by 89.56 and 97.60% for parents and F_1's, respectively. Significant increase in NUE due to low- N stress was associated with significant increases in averages of NUPE and NUTE. In agreement with these results, Ortiz-Monasterio et al. [52] also reported significant influence of N application rate on NUTE in which the highest efficiencies were measured at the lowest application rate. Van Sanford and MacKown [53] and Sinebo et al. [54] also found similar results in which they reported NUTE values of 29.3- 43.9 and 31.8-48.3 kg kg-1 N, respectively.

In the present study, magnitude of increase in NUPE (65.87 and 83.08%) was much higher than that in NUTE (14.39 and 3.93%) for parents and F_1's, respectively. This indicates that NUPE is the most determinant component of NUE Sieling et al. [55], and Al-Naggar et al. [40,43,44,56] showed that N efficiency diminishes as N fertilizer rates increase. Nitrogen uptake efficiency declined as N fertilizer rates increased [57-59] reported that NUPE, NUTE and NHI tended to increase under low-N. According to Le Gouis et al. [60], in wheat, Al-Naggar et al*.* [42,44] in maize and Al-Naggar et al*.* [38,49] in grain sorghum, N uptake in biomass was the most important factor in NUE determination regardless of N level. Abeledo et al. [61] reported that both N conversion and N capture have played a role in the improvement of NUE.

On the contrary, Gaju et al. [62] found that NUPE effect explained only a small amount of phenotypic variance in NUE amongst cultivars, but NUTE affected it up to 61% and 77% under high-N low-N, respectively. In the present study, it is also observed that low-N stress caused a significant (but slight) increase in plant height of F_1's (6.80%).

3.3 Effect Low-N on Heterobeltiosis

Estimates of better parent heterosis (heterobeltiosis) across all F_1 crosses, for all studied traits under high- N and low–N across two seasons are presented in Table 3. Favorable heterosis in the studied crosses was considered negative for DTH and DTM and positive for the remaining studied traits under high–N and low–N conditions. In general, the highest average significant favorable heterobeltiosis was shown by plant height (10.82 and 5.21%) under high–N and low–N, respectively. Averages of heterobeltiosis of all other studied characters under high–N and low–N were either non-significant or significant but non favorable, except, NUPE under high–N and GPS under low–N which showed significant favorable average heterobeltiosis (3.17 and 8.55%, respectively). However, some crosses for each studied trait showed significant and favorable heterobeltiosis. The largest number of crosses showing significant favorable heteorobeltiosis was shown for plant height (13 and 12 crosses) under high–N and low–N, respectively. Maximum favorable heterosis relative to better parent (53.11%) was shown by L25 x Gem 9 for spikes/ plant under high–N and L27 x Gem 7 for nitrogen utilization efficiency (NUTE) under low–N (44.81%).

Table 3. Estimates of heterosis (%) relative to better parent in wheat F_1 crosses and number (No.) of crosses showing favorable heterosis under two levels of nitrogen across two seasons

F_1 crosses	**DTH**		**DTM**		**PH**	
	High N	**Low N**	**High N**	**Low N**	**High N**	**Low N**
L25 X L26	-3.53**	-3.11**	1.82	-1.13	17.55**	-0.87
L25 X L27	-8.01**	-6.07**	-2.01	1.16	12.73**	6.84**
L25X Gem 7	-1.68	-3.41**	-1.03	-1.51	13.81**	4.23**
L25 X Gem 9	-3.79**	5.63**	-0.79	2.05	-0.08	3.01**
L25 X Gz 168	0.79	9.80**	1.20	1.39	0.66	7.67*
L 26X L 27	-4.10*	-0.74	-5.64**	2.84*	8.95**	4.73**
L26 X Gem 7	-4.36**	1.52	-0.26	-2.22	12.84**	8.60**
L 26 X Gem 9	-3.16**	7.0**	-0.66	0.79	17.19**	5.21**
L 26 X Gz 168	1.18	2.75*	-3.44**	-3.23*	10.54**	-0.72
L 27X Gem 7	-3.79*	2.27	-2.51	5.28**	18.14**	2.75**
L 27 X Gem 9	0.20	6.02**	1.46	5.03**	12.15**	10.49**
L27 X Gz168	4.14**	6.27**	2.38	6.31**	8.01**	3.34**
Gem 7 X Gem9	0.99	6.21**	-1.20*	4.74**	12.43**	17.96**
Gem 7 X Gz 168	-4.73**	6.67**	-1.46	2.14	8.48**	4.22**
Gem 9 X Gz 168	0.00	5.88**	2.26	-0.13	8.91**	0.71
Aver (F_1' s).	-1.99	3.11	-0.66	1.57	10.82**	5.21**
No.	8	3	3	1	13	12
	GPS		**100GW**		**SPP**	
L25 X L26	-4.71**	-0.93	-4.42**	13.87**	-8.77**	1.12**
L25 X L27	18.01**	0.11	22.15**	-5.4**	-7.62**	12.53**
L25X Gem 7	-20.1**	-6.62**	-28.65**	-18.6**	-32.72**	-2.23**
L25 X Gem 9	24.28**	-28.15**	3.22**	-33.3**	53.11**	-6.70
L25 X Gz 168	29.79**	-19.74**	-2.75**	-34.3**	34.40**	-12.03**
L 26X L 27	-11.7**	0.84	-3.12**	5.6**	14.94**	9.38**
L26 X Gem 7	-5.9**	-6.96**	-22.84**	-28.8**	-13.72**	-6.30**
L 26 X Gem 9	-24.7**	-24.59**	-17.61**	-18.7**	-17.38**	-8.45**
L 26 X Gz 168	-22.8**	-1.06	-25.28**	-27.1**	-24.70**	1.47**
L 27X Gem 7	-6.68**	25.82**	-27.67**	-29.6**	-20.12**	-5.46**
L 27 X Gem 9	-19.6**	26.19**	-11.83**	-14.9**	-8.91**	-12.82**

L27 X Gz168	-11.0**	-11.17**	-11.83**	-13.6**	-18.13**	12.48**
Gem 7 X Gem9	-7.15**	-1.13	-6.73**	-8.66**	10.25**	-0.85**
Gem 7 X Gz 168	13.09**	0.42	-9.26**	7.57**	-16.76**	-7.32**
Gem 9 X Gz 168	8.91**	6.65**	-0.54*	-12.0**	-0.56	-15.09**
Aver (F_1' s).	-2.68*	8.55**	-9.81**	-14.53**	-3.78**	-2.68*
No.	5	3	2	3	4	5
F_1 crosses	**GYPP**		**BYPP**		**HI%**	
	High N	**Low N**	**High N**	**Low N**	**High N**	**Low N**
L25 X L26	6.13**	-1.76	-1.08	-0.10	7.09**	0.82
L25 X L27	-2.52*	-13.67**	-4.40**	-2.93*	1.98	-12.47**
L25X Gem 7	-6.78**	-3.24**	-24.59**	-4.12**	23.66**	-5.86**
L25 X Gem 9	9.16**	1.16	9.04**	-1.95	-0.14	0.58
L25 X Gz 168	42.26**	4.43**	13.62**	-1.45	25.52**	-10.63**
L 26X L 27	2.28**	2.36*	2.05	4.75**	-1.95	-2.20
L26 X Gem 7	-15.73**	-6.13**	0.91	7.27**	-13.76**	-12.48**
L 26 X Gem 9	-21.96**	-1.94	-3.80**	-0.23	-18.80**	-1.47
L 26 X Gz 168	-17.99**	6.79**	0.20	-0.06	-18.18**	4.81*
L 27X Gem 7	-8.06**	14.94**	-4.94**	-5.48**	-3.33	-10.95**
L 27 X Gem 9	-19.59**	-0.41	4.65**	-0.53	-25.42**	0.19
L27 X Gz168	-9.67**	2.44*	6.73**	3.09**	-15.49**	-3.72
Gem 7 X Gem9	-3.25**	-4.14**	-5.37**	-2.77*	-17.85**	-5.20**
Gem 7 X Gz 168	-3.36**	-52.93**	10.38**	28.99**	-22.81**	9.79**
Gem 9 X Gz 168	5.51**	1.50	-6.41**	-14.01**	9.59**	2.11
Aver (F_1' s).	-2.91*	-3.37*	-0.20	0.70	-4.66**	-3.11*
No.	5	5	4	4	4	2
	NUE		**NUPE**		**NUTE**	
L25 X L26	6.06**	-1.80	-1.02*	-5.66**	7.58**	4.18**
L25 X L27	-2.50**	-13.62**	-23.4**	-4.36**	27.23**	-9.83**
L25X Gem 7	-6.79**	-3.21**	-1.14*	-2.66	-6.09**	-8.91**
L25 X Gem 9	9.01**	1.15	36.20**	-3.40*	-19.29**	-14.88**
L25 X Gz 168	42.18**	4.49**	-0.033	-0.72	-30.02**	-15.31**
L 26X L 27	2.23**	2.38**	6.64**	2.61	-18.19**	-1.82**
L26 X Gem 7	-15.71**	-6.15**	-14.94**	3.14	-11.96**	-11.23**
L 26 X Gem 9	-21.92**	-1.94	-8.00**	-11.08**	-41.14**	-4.46**
L 26 X Gz 168	-17.98**	6.8**	-16.85**	-16.23**	-15.00**	9.58**
L 27X Gem 7	-8.12**	14.95**	-18.88**	-21.5**	13.68**	44.81**
L 27 X Gem 9	-21.83**	-0.42	16.92**	-26.7**	-33.59**	19.50**
L27 X Gz168	-9.75**	2.48	-21.75**	-8.32**	14.80**	-2.06**
Gem 7 X Gem9	-27.45**	-4.14**	-6.19**	0.96	5.11**	-1.53**
Gem 7 X Gz 168	-3.37**	0.06	10.58**	-13.4**	-12.86**	1.04**
Gem 9 X Gz 168	5.43**	1.34	-14.96**	-4.06	-0.99**	1.29**
Aver (F_1' s).	-4.70**	0.16	3.17**	-7.43**	-8.05**	0.69
No.	5	4	5	---	5	6

crosses	**GPC**		**NHI**	
	High N	**Low N**	**High N**	**Low N**
L25 X L26	-12.51**	-18.59**	-7.04**	-1.50
L25 X L27	-3.93	-9.15**	0.48	-0.23
L25X Gem 7	-0.82	-2.30	0.63	-2.21**
L25 X Gem 9	1.91	5.50*	2.96**	1.22
L25 X Gz 168	3.95	14.26**	0.83*	1.57
L 26X L 27	7.49**	8.29**	-4.47**	3.84**
L26 X Gem 7	-1.06	-17.35**	-3.92**	-2.80**
L 26 X Gem 9	-13.23**	-7.31**	-2.32**	-3.85**
L 26 X Gz 168	-19.02**	-11.48**	-3.14**	6.75**
L 27X Gem 7	-19.42**	-31.84**	2.73**	0.58
L 27 X Gem 9	-25.64**	21.93**	0.56	-2.04*
L27 X Gz168	-9.84**	-15.62**	-3.88**	6.81**

Gem 7 X Gem9	3.48	-2.62	1.06^{**}	-0.30
Gem 7 X Gz 168	1.78	21.28^{**}	3.46^{**}	9.08^{**}
Gem 9 X Gz 168	-1.80	-3.21	0.63	7.82^{**}
Aver (F_1' s).	-5.91	-3.21	-0.76	1.65
No.	1	5	5	5

and indicate significant at 0.05 and 0.01 probability levels, respectively*

The F_1 cross L25 x Gz 168 showed the highest favorable heterobeltiosis for grain yield (42.26%), nitrogen use efficiency (42.18%), HI (25.52%), GPS (29.79%), SPP (34.40%) under high – N. The highest heterobeltiosis under high–N was also shown by L25 x L27 for NUTE (27.23%) and 100GW (22.15%) and L25 x Gem 9 for NUPE (36.20%). Under low–N, the highest favorable significant heterobeltiosis estimate was shown by L27 x Gem 7 for GYPP (14.94%), NUTE (44.81%) and GPS (25.82%), L25 x L26 for 100 GW (13.87%), L 25 x L 27 for SPP (12.53%), L 27 x Gem 9 for GPS (26.19%) and Gem 7 x Gem 9 for BYPP (28.99%).

In general, wheat hybrids typically exhibited little higher yield over their parents. Duvick and Cassman [23] suggested that a cross of two high yielding lines might exhibit less heterosis but nevertheless produce a high yielding hybrid. Beside, a hybrid is superior not only due to heterosis but also due to other heritable factors that are not influenced by heterosis. Significant favorable heterobeltiosis was reported in some wheat crosses [39,44,48,63] for plant height and grain yield. In the present study, some crosses showed significant high-in-magnitude heterosis over the better parent, such as L25 x Gz168 for GYPP and NUE, L25 x Gem 9 for NUPE, L25 x L27 for NUTE under high-N, L27 x Gem 7 for NUPE and NUTE under low-N conditions. These results suggest the possibility of the commercial exploitation of hybrid wheat, as previously reported by several other studies [15,19,64].

The commercial utilization of heterosis depends upon the superiority of hybrids over the better parents and it is also important for identifying the parental combinations capable of producing the highest level of transgressive segregants. In the current study, some crosses were obtained and they have showed significant heterobeltiosis for some important traits both under high-N and low-N conditions. Additive and non-additive effects have been reported for grain yield and its components in wheat in studies throughout the world [16]. However, the selection of promising parents to obtain superior hybrids primarily depends on the predominance of the genes for the additive effect due to heterobeltiosis [15].

4. CONCLUSIONS

The combined analysis of variance of the present study indicated the presence of heterosis and that such heterosis differs from one season to another in most studied traits. The study concluded that number of spikes/plant (SPP) and nitrogen uptake efficiency (NUPE) could be recommended to wheat breeder as good selection criteria for improving low-N tolerance in bread wheat. Some crosses for each studied trait showed significant and favorable heterobeltiosis**.** Under low–N, the highest favorable and significant heterobeltiosis estimate was shown by L27 x Gem 7 for grain yield/plant, nitrogen utilization efficiency and grains/spike, ~~(~~L25 x L26~~)~~ for 100 grain weight, L 25 x L 27 for spikes/plant, L 27 x Gem 9 for GPS and Gem 7 x Gem 9 for biological yield/plant. These crosses are of great value for wheat breeder, since their parents accumulate in the hybrid additive genes for respective traits. The heterobeltiosis shown in the present study in some crosses could offer a promising approach to increasing grain yield of wheat crop under varying N environments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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