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ORIGINAL PAPER

GRAIN YIELD AND NITROGEN USE EFFICIENCY IN SPRING WHEAT (*TRITICUM AESTIVUM* L.) HYBRIDS UNDER DIFFERENT NITROGEN FERTILIZATION REGIMES

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Abstract

Increasing nitrogen use efficiency in modern agriculture is important for obtaining high yields and reducing production costs and environmental pollution. Globally, price reduction and environmental concerns advocate a lower use of nitrogen (N) fertilizer for wheat (*Triticum aestivum* L.) crop, especially for wheat hybrids. The objective of this study was to assess combining ability at different N levels for agronomic traits and nitrogen use efficiency (NUE) via diallel analysis in wheat hybrids. Four spring wheat cultivars were used to produce a 4 × 4 full diallel cross with the reciprocals. Parents of various origins and their diallel F_2-hybrids were evaluated in field under 0, 120 and 240 kg ha^{-1} N doses. The results showed that there was much genotypic variance among nitrogen doses for the NUE, grain yield, agronomic and quality traits. Significant genotypic differences in the yield, protein yield, protein content and NUE were identified among hybrids. General combining ability effect of parents for the grain yield and protein content, and specific combining ability effect of hybrids for the NUE and grain yield significantly changed depending on nitrogen levels. Both genetic and reciprocal effects showed interaction with nitrogen doses in determining the NUE of wheat. Because of the reciprocal x N interaction, the hybrids' reciprocal responses to increasing nitrogen levels revealed positive or negative changes in the yield and NUE characteristics. The winner among hybrids was identified for grain yield and grain nitrogen yield (GNY) at the optimum N level according to the GGE biplot analysis. Inqualab91 x Chils was found to be desirable for selecting NUE traits.

Keywords: wheat, nitrogen, diallel, biplot.

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INTRODUCTION

Globally, wheat (*Triticum aestivum* L.) ranks high among staple crops, and is also classified as cash crop cultivated on all habitable continents of the world (Alam et al. 2021, Chowdhury et al. 2021, Iqbal et al. 2021, Kizilgeci et al. 2021). It constitutes the third leading crop after maize and rice with respect to area under cultivation (225 m ha) globally, and one-fifth of the world's wheat production is traded on the international market (Alghawry et al. 2021, El Sabagh et al. 2021, Sorour et al. 2021). It provides food calories (21%) and protein (20%) to more than 4.5 billion people in over 100 countries, and thus contributes vitally to food security of many countries, especially Asian ones. The annual global wheat production is estimated to be around 775 million Metric tons (El Sabagh et al. 2021, Zahoor et al. 2021). The grain yield of wheat has remained suboptimal and much lower than varietal potential, which contributes to food and nutritional insecurity. The decreasing area of agricultural land due to human settlements triggered by the skyrocketing increase in the global population, and the worsening scenario of climate change along with abiotic stresses have been projected to adversely affect C3 cereals productivity (Afzal et al. 2015, Iqbal et al. 2018, El Sabagh et al. 2019). Among abiotic stresses, suboptimal plant nutrition seriously compromises the growth and development of wheat plants, which leads to a significant reduction in yield despite the presence of favourable agro-climatic conditions. Wheat is regarded to be comparatively more sensitive to suboptimal plant nutrition, which significantly hampers the vegetative growth of crop plants, thereby inducing suppressed reproductive growth phases (Iqbal et al. 2018, Siddiqui et al. 2019).

Nitrogenous (N) fertilizers play a vital role in boosting the vegetative growth of crop plants and ultimately determine the grain yield of wheat. The optimization of application timing, technique, form and doses of N fertilizer may assist in the enhancement of the nitrogen use efficiency (NUE). The split N application remains effective in attaining higher N uptake efficiency for many crop plants (Shi et al. 2012, Walsh et al. 2012). Wheat cultivars respond differently to fertilization regimes, and it has been inferred that superior genotypes selected on the basis of better resource use efficiency might facilitate attaining food security and curbing nutrient losses (Siddiqui et al. 2019). Iqbal et al. (2021) also reported similar findings whereby wheat genotypes performed differently under varying doses of N, and concluded that wheat genotypes performed differently in terms of the NUE and grain yield of wheat owing to the varied genetic potential, which was manifested through superior agro-botanical traits, such as better root architecture, leaf area, photosynthetic rate and the potential to tolerate biotic and abiotic stresses under varying agro-ecological conditions. Therefore, it is pertinent to evaluate cultivars having higher potential for the N use efficiency. In the context of boosting the NUE, very few breeding programs involving combining-ability analyses (general combining ability as well as specific combining ability) have been executed in order to obtain genetic information required for genetic-diversity evaluation, parental selection and hybrid development, etc. It is interesting to note that combining-ability analyses tend to be performed with the diallel mating methods developed by Griffing (Griffing 1956, De La Fuente et al. 2020).

There is a consensus on increasing the nitrogen use efficiency (NUE) in wheat by breeding, but nitrogen use efficiency has not been put into the goals of many advanced breeding programs yet. Cultivars have been generally improved in breeding programs through indirect selection methods based on yield (Sadras, Richards 2014). In recent years, many studies have focused on improving the nitrogen use efficiency in wheat (Kizilgeci et al. 2019). NUE improvement in wheat was defined as 0.13 kg DM kg^{-1} N/year between 1985 and 2010 in France (Cormier et al. 2013). At the end of the 10-year breeding process, improving the NUE saved 60-70 kg nitrogen per hectare. It is also economically important to increase the N/grain price ratio by improving the NUE. All these results signify that the annual NUE increase rate should be improved more effectively in wheat breeding programs for high yield. Keeping in view the up-to-date research and the current gap in knowledge, we hypothesized that wheat hybrids might respond differently in terms of the NUE under different doses of N fertilizer. The principal aim of the study was to find the most superior wheat hybrid having a higher genetic potential for nutrient use efficiency as well as grain yield.

MATERIAL AND METHODS

Details of the experimental location and meteorological features

This study was carried out at the Dicle University Research Station, Diyarbakir, Turkey (37°53′N, 40°16′E, 669 m above sea level). The soil of the experimental field had pH between 7.5 and 7.7, thus being slightly alkaline. The soil was clay loam with low salinity. Total organic matter and total phosphorus content were very low, while total potassium (K) was very high. The magnesium content was moderate (616 mg L^{-1}). The soil contained between 10.0-11.0% of lime at a depth of 0-60 cm. Precipitation from sowing to physiological maturity was 283.1 mm, lower than the long-term average (Table 1). The amount of precipitation before planting was 143.6 mm, and it was sufficient for healthy emergence. The temp. was 1-2°C higher than the long-term average for the March-May period in Diyarbakır.

The experiment's details

A one-year experiment was conducted in 2015-2016, in order to evaluate bread wheat F_2 segregating populations obtained from a 4x4 full diallel cross

Table 1

Meteorological data of the 2015-2016 wheat-growing season in Diyarbakir

Month	Avarage temperature		Precipitation (mm)	
	2015-2016	long-term (1923-2014)	2015-2016	long-term (1923-2014)
November	9.8	9.2	10.4	51.8
December	3.9	4	31.6	71.4
January	1.1	1.8	77.2	68
Feburary	7.9	3.5	69.2	68.8
March	9.7	8.5	55.6	67.3
April	15.7	13.8	29	68.7
May	19.9	19.3	41.4	41.3
June	26.8	26.3	18.4	7.9
Average/Total	11.85	10.8	332.8	445.2

combination for nitrogen utilization efficiency (NUE), grain yield and quality traits under different nitrogen treatments. The parents were Inqualab-91(1), 84ÇZT84 (2), Chil's (3), and Balatilla (4), all representing spring-type wheat. In the text and tables, these genotypes are denoted by the numbers 1, 2, 3, and 4, respectively. Each plot consisted of two, two-meter-long rows containing 20 plants spaced at 25 cm within the rows. The sowing was done on 11 December 2015. The wheat hybrids were evaluated in split plots with three replicates at three nitrogen doses (0, 120 and 240 kg N ha^{-1}), where the nitrogen doses were the main factor and the genotypes were sub-factors. The general N recommendation for Diyarbakir region is to apply 120 kg N ha^{-1}. 60 kg P_2O_5 ha^{-1} was applied to all plots at sowing. Half of the nitrogen dose was applied when the seeds were sown, and the other half was given when the plants were in the tillering stage. Combined fertilizer containing phosphorus (P_2O_5) and nitrogen (NH_4) was used at sowing. NH_4NO_3 was applied as top fertilizer. The experiment was conducted under rainfed conditions without irrigation.

Experimental variables

The plant height and spike length (SL) were determined by sampling 20 plants from each plot, including the main stem and tillers in each sample. Plant grain yield (g plant^{-1}) was determined by dividing the value obtained after threshing all the plants in the plot by the number of plants. The values found were then converted to plot yields (kg ha^{-1}).

Protein content, starch content, ash content and crude fat content were measured using a Rapid Content Analyzer XDS near-infrared spectrometer (FOSS Analytical, Hilleroed, Denmark).

SPAD was determined using a portable chlorophyll meter (SPAD-502; Minolta, Osaka, Japan), which can measure leaf chlorophyll content indirectly. The SPAD measurements were taken at the heading, on the midpoint of the flag leaf of ten plants in each plot.

Grain N yield (GNY) – kg ha^{-1} was computed from grain yield and grain nitrogen content (grain yield × GNC 100^{-1}).

The N use efficiency for grain yield (NUEgy) – kg grain kg^{-1} was defined as grain dry weight/N supplied (Ehdaie et al. 2001).

The N use efficiency for grain N yield (NUEgny) – kg grain kg^{-1} was defined as grain N yield /N supplied (Le Gouis et al. 2000, Yildirim et al. 2007).

Statistical analyses

Data were analyzed using the split plot analysis of variance (ANOVA), and the Tukey's test was used to determine which treatment means were significantly different from each other (SAS 1998). General (GCA) and specific (SCA) combining ability estimates were made according to Griffing (1956), using diallel cross analysis designated as Model I, Method 1 for each experiment. Genotype main effect plus genotype by environment interaction (GGE) biplot analyses were made using the software GenStat 12th (Genstat 2009) package program.

RESULTS AND DISCUSSION

Differences among the nitrogen doses were found to be significant for all examined traits except SPAD in F_2 segregating populations (Table 2). Differences between genotypes were found to be significant for the grain yield, grain nitrogen yield (GNY), grain yield NUE (NUEgy), grain nitrogen yield NUE (NUEgny), protein, ash content and crude fat content of grain. Genotypes × N interactions were significant for the grain yield, GNY, NUEgy and NUEgny. General combining ability (GCA) effects were significant for the grain yield, protein, ash and crude fat content, while specific combining ability (SCA) effects were significant for the grain yield and grain yield NUE.

The GCA×N level interaction was significant for the grain yield, GNY and NUEgy, while the SCA×N level interaction was significant only for NUEgy. Reciprocal effect (REC) was significant for the difference in grain yield and GNY. REC×N level interaction was highly significant for the difference in grain yield, GNY and NUEgny.

Spike length, plant height and SPAD values

The results revealed that N application doses had significant influence on spike length, plant height and SPAD values of wheat hybrids (Table 3). The spike length has been recognized among vital yield contributing attributes of wheat owing to its association with the grain holding plant part. It directly influences the number of grains per spike and thus may serve as a reliable indicator to estimate the grain yield of wheat. Cultivars or geno-

Table 2

Analysis of variance for GCA, SCA and REC of investigated traits in parents and their F_2 populations at different N levels

Source	DF	Spike length	Plant height	SPAD	Protein conent	Starch content	Crude fat content	Ash content	GY	GNY	NUEgny	NUEgn
Nitrogen	2	***	***	ns	***	**	***	***	***	***	***	***
Replication	6	**	***	ns	***	***	***	***	ns	**	**	***
Genotype	15	ns	ns	ns	*	ns	**	*	**	**	**	ns
N×G	30	ns	ns	ns	ns	ns	ns	ns	***	***	***	**
GCA	3	ns	ns	ns	**	ns	***	**	*	ns	ns	ns
SCA	6	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns
GCA×N	3	ns	ns	ns	ns	ns	ns	ns	**	*	**	ns
SCA×N	6	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns
REC	6	ns	ns	ns	ns	ns	ns	ns	*	**	ns	ns
REC×N	6	ns	ns	ns	ns	ns	ns	ns	**	**	**	ns
Error	87	1.40	111.34	7.176	0.58	0.988	0.002	0.011	255.5	536.5	0.071	35.5
GCA/SCA		1.30	1.22	0.67	4.86	1.37	11.90	2.87	1.22	0.61	0.54	1.0

*, ** and *** – significance at 5%, 1% and 0.1% levels, respectively, ns – non-significant, GY – grain yield, GNY – grain nitrogen yield, NUEgny – grain nitrogen yield nitrogen use efficiency, NUEgy – grain yield nitrogen use efficiency

Table 3

Means of spike length, plant height and SPAD of parents and their F_2 and reciprocal F_2 (RF_2) progeny in 4 × 4 diallel cross of bread wheat at different nitrogen levels

Parents	Spike length (cm)			Plant height (cm)			SPAD (unit)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2
1	10.04	11.22	10.91	78.67	76.67	81.33	45.1	47.1	50.5
2	9.00	11.56	10.44	68.33	71.67	86.67	47.6	49.5	50.8
3	8.15	10.19	10.40	69.00	89.00	90.00	45.5	49.6	50.3
4	9.14	9.86	9.91	66.67	75.67	79.00	44.8	49.7	50.2
Parent mean	9.08	10.71	10.42	70.67	78.25	84.25	45.75	48.98	50.45
F_2 populations									
1×2	9.48	9.89	9.89	75.33	80.67	84.33	44.6	47.9	53.0
1×3	10.33	10.56	9.89	77.00	79.00	78.33	45.3	47.9	51.5
1×4	10.00	10.22	9.67	65.00	81.00	75.00	43.2	47.1	50.1
2×3	9.11	9.11	10.33	83.33	86.00	85.00	42.5	46.6	49.7
2×4	8.56	9.22	9.78	70.00	83.33	93.67	46.7	48.6	51.9
3×4	9.00	11.00	10.22	80.00	83.33	94.00	46.2	49.6	49.8
F_2 mean	9.41	10.00	9.96	75.11	82.22	85.06	44.8	48.0	51.0
RF_2									
2×1	8.78	9.22	10.33	76.67	81.67	83.33	42.6	49.0	52.3
3×1	7.67	9.66	10.22	71.67	86.67	83.33	44.9	47.5	51.0
3×2	7.78	9.78	10.44	70.00	83.33	75.00	45.6	49.7	50.1
4×1	9.33	10.11	10.56	76.67	78.67	84.67	47.2	50.6	51.4
4×2	9.78	11.00	10.78	71.67	85.00	81.67	44.1	50.5	48.7
4×3	8.44	9.78	9.33	78.33	78.67	88.33	43.0	46.3	49.7
RF_2 mean	8.63	9.93	10.28	74.17	82.34	82.72	44.6	48.9	50.5
L_{SD} ($P<0.05$)	ns	ns	ns	ns	ns	ns	ns	ns	ns

genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil's, and Balatilla, respectively, ns – non-significant

types having greater spike length are quite desirable, and the spike length remains a target trait in various breeding programs. The findings of this study reveal that N application is instrumental in causing a significant increase in the spike length of wheat hybrids under rainfed conditions. The spike length increased under increasing N levels, except for 1×1, 1×3, 1×4, 2×2 and 3×4. SPAD, plant height and spike length values have been collated in Table 4. As per general combining ability, G3 and G4 had negative effects, while G1 positively affected the ash content, indicating its genetic superiority and potential use in future breeding programs for developing mineral rich wheat grains. In addition, increasing N fertilization doses positively influenced the plant height of rainfed spring wheat hybrids, except

Table 4

Estimation of GCA, SCA and REC in the F_2 generation for spike length, plant height and SPAD in bread wheat at different nitrogen levels

Parents	Spike length			Plant height			SPAD		
	N0	N1	N2	N0	N1	N2	N0	N1	N2
	general combination effect (GCA)								
1	0.422	0.115	0.104	1.31	0.100	-2.521	-0.171	-0.554	0.621
2	-0.101	0.018	0.111	-0.69	0.003	0.563	0.217	0.333	0.221
3	-0.459	-0.115	-0.039	1.15	-0.130	1.521	-0.113	-0.229	-0.413
4	0.138	-0.018	-0.176	-1.77	0.026	0.438	0.068	0.450	-0.429
F_2 populations	**specific combining ability (SCA)**								
1×2	-0.230	-0.727	-0.297	1.73	-0.712	1.813	-1.358	0.067	1.163
1×3	-0.001	-0.039	-0.204	-1.77	-0.024	-2.146	0.455	-0.088	0.329
2×3	-0.031	-0.608	0.122	2.56	-0.594	-6.063	-1.016	-0.542	-0.621
1×4	0.069	-0.079	-0.010	-2.35	-0.123	-2.063	0.358	0.383	-0.104
2×4	0.095	-0.037	0.148	-0.35	-0.081	2.688	0.170	0.213	-0.188
3×4	0.006	0.372	-0.202	6.15	0.329	5.229	-0.283	-0.858	-0.121
F_2 populations	**reciprocal SCA**								
1×2	0.350	0.332	-0.222	-0.67	0.332	0.500	0.983	-0.550	0.350
1×3	1.332*	0.447	-0.165	2.67	0.447	-2.500	0.233	0.200	0.250
1×4	0.332	0.057	-0.445	-5.83	0.057	-4.833	-2.017	-1.717	-0.633
2×3	0.668	-0.333	-0.055	6.67	-0.333	5.000	-1.550	-1.533	-0.200
2×4	-0.612	-0.888	-0.500	-0.83	-0.888	6.000	1.283	-0.967	1.583
3×4	0.278	0.608	0.443	0.83	0.608	2.833	1.567	1.633	0.050

* significant at 5% probability level, genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil's, and Balatilla, respectively

1×3, 1×4, 3×2 and 4×4. In contrast, the ash content of all wheat hybrids and progenies increased with increasing N application doses, indicating the wheat hybrid potential and responsiveness in terms of the ash content. These findings are in agreement with those of Iqbal et al. (2021), who maintained that N optimization led to significant improvement in yield attributes of wheat, especially the plant height, stem girth and spike length. It was inferred that N promoted the vegetative growth and ultimately stimulated higher translocation of assimilates to reproductive parts, which resulted in comparatively better reproductive attributes, including the spike length and grain weight under rainfed conditions.

Protein, starch, ash and crude fat content

Beside the yield attributes and grain yield of wheat, the nutritional quality parameters wheat grain are equally important for ensuring the nutritional security of the human population. The protein content of wheat constitutes the most vital trait among quality characteristics, and it depends on a multitude of edapho-climatic conditions (Hrušková et al. 2006). Although differences in the protein content are largely due to the genetic structure, environmental factors, including nitrogen fertilization and climate conditions, are also very effective in determining the amount of protein. The increasing dose of N significantly increased the protein content and ash content of spring wheat hybrids and their progenies, while simultaneously a decrease in the starch and crude fat content was recorded (Table 5). The maximum protein content was recorded for 1×4 in response to the highest N dose, while the minimum value was recorded for 4×2. The results obtained in this study pertaining to general combining ability (GCA), specific

Table 5

Means of protein content, starch content, crude fat content and ash content of parents and their F_2 progeny in 4 × 4 diallel cross of bread wheat at different nitrogen levels

Parents	Protein content (g kg^{-1} DM)			Starch content (g kg^{-1} DM)			Crude fat content (g kg^{-1} DM)			Ash content (g kg^{-1} DM)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
1	129.4	165.0	174.6	516.6	517.1	501.8	20.6	19.9	19.5	12.2	13.1	13.7
2	120.7	162.1	167.9	527.8	511.6	504.6	20.8	19.8	19.3	10.7	11.7	12.9
3	118.9	161.1	175.4	529.5	509.6	495.5	20.7	20.7	20.1	10.7	12.8	14.6
4	122.1	161.3	174.8	519.9	510.9	496.1	21.2	21.0	20.3	11.4	13.1	14.3
Parent mean	122.8	162.4	173.2	523.5	512.3	499.5	20.8	20.4	19.8	11.3	12.7	13.9
F_2 populations												
1×2	128.5	170.1	173.5	515.8	506.1	500.4	20.6	20.0	20.2	11.4	13.5	13.8
1×3	121.9	177.0	179.7	509.0	507.5	486.9	21.1	20.2	20.2	13.2	14.0	14.7
1×4	123.0	170.1	183.3	508.1	512.2	490.0	20.5	20.0	20.1	10.7	13.8	15.7
2×3	117.9	163.1	169.3	517.8	513.2	505.0	21.3	20.4	20.1	11.6	12.7	13.8
2×4	121.1	156.4	172.1	520.5	516.0	498.9	20.7	20.6	20.2	10.8	13.1	14.8
3×4	117.2	164.0	180.7	529.4	510.6	490.1	20.7	20.8	20.3	10.5	13.1	15.4
F_2 mean	121.6	166.8	176.4	516.8	510.9	495.2	20.8	20.3	20.2	11.4	13.4	14.7
RF_2												
2×1	132.6	169.6	177.2	514.7	500.0	492.2	20.5	20.0	20.1	10.8	15.1	15.5
3×1	122.8	160.1	178.2	527.0	508.4	493.6	20.8	20.6	20.0	11.1	13.1	14.1
3×2	129.6	162.7	171.8	525.4	509.6	499.6	20.7	20.7	20.2	10.6	12.6	14.1
4×1	126.6	168.9	180.1	523.9	505.7	486.4	20.5	21.0	20.8	11.6	13.9	15.2
4×2	114.3	160.2	178.3	528.9	511.4	495.5	21.8	20.7	19.8	11.9	12.9	14.0
4×3	122.9	156.4	168.2	523.8	515.9	502.1	21.7	21.0	20.3	11.4	12.7	13.4
RF_2 mean	124.8	163.0	175.6	524.0	508.5	494.9	21.0	20.7	20.2	11.2	13.4	14.4
L_{SD} ($P<0.05$)	ns	ns	0.91	ns	ns	ns	ns	ns	ns	ns	ns	ns

[†] genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil's, and Balatilla, respectively, DM – dry matter

combining ability (SCA) as well as reciprocal effects for the protein content, starch content, crude fat content and ash content are given in Table 6. These findings corroborate with those of Iqbal et al. (2021), Siddiqui et al. (2019), who concluded that N dose optimization significantly influenced the protein content of wheat grains although, contrary to our findings, these authors inferred that the starch content and crude fat content of wheat were also affected by N fertilization regimes, depending on the soil fertility status and agro-climatic conditions.

Grain yield, nitrogen yield, NUEgy and NUEgny

The grain and nitrogen yields were improved significantly with increasing doses of N application, as shown in Table 7, while NUEgny and NUEgn were decreased. The maximum grain yield was recorded for 2×1 under N dose of 120 kg, and it was followed by 3×1 under the maximum N application dose. In contrast, 4×2 remained superior in terms of N yield. As determined, NUEgn and NUEgny continued to decline with the increasing N doses despite a significant increment in their values from N0 to N1. The combination effects, especially the general combination effect, remained significant for G1 and G2 (Table 8), indicating their superiority and a good prospect for use in future breeding programs.

The reciprocal effects for the grain yield, GNY and their N interactions were significant. Thus, the use of parents in crosses, whether female or male, should increase the performance of wheat progenies. Furthermore, significant reciprocal effects were not observed in the other traits.

Previously, in line with our findings, it has been reported that the NUE (grain yield per unit of the soil N) and crop plants' potential to survive suboptimal N regimes have complex interrelationships with various exogenous and internal mechanisms involved in hybrids (Martre et al. 2003, Coque, Gallais 2007, Hirel et al. 2007). A number of morpho-physiological traits tend to have associations with the uptake capacity (proportion of total N uptake to N availability in the soil) of wheat hybrids and the efficiency of N utilization in grain formation (the grain mass formed per unit of N absorbed), which seem to be critical components of the NUE (Huggins, Pan 2003). Numerous studies on the genotypic variation of cereal hybrids in connection with the N efficiency use inferred that this genetic knowledge holds promising prospects for wheat improvement (Kichey et al. 2007, Baresel et al. 2008, Barraclough et al. 2010), comparatively fewer studies have been conducted to breed wheat hybrids displaying improved N use efficiency (Löschenberger et al. 2008, Wolfe et al. 2008).

Biplot analyses

Biplot analysis has emerged as an effective method to explore the interrelationships between wheat hybrids and their agro-botanical traits (Kizilgeci et al. 2019, Kizilgeci 2020) This analysis represents graphically various charac-

Table 6

Estimation of GCA, SCA and REC in the F_2 generation for protein content, starch content, crude fat content and ash content in bread wheat at different nitrogen levels

Parents	Protein content			Starch content			Crude fat content			Ash content		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
	general combination effect (GCA)											
1	0.370**	0.398*	0.234*	-0.466*	-0.109	-0.202	-0.023	-0.026**	-0.003	0.035	0.049*	0.021
2	0.009	-0.098	-0.306**	0.119	-0.043	0.392*	0.002	-0.022*	-0.019**	-0.021	-0.029	-0.040
3	-0.185	-0.108	-0.049	0.280	0.019	-0.013	0.006	0.017	0.006	-0.007	-0.022	-0.005
4	-0.194	-0.192	0.121	0.067	0.134	-0.177	0.015	0.031**	0.016	-0.006	0.001	0.024
F_2 population	**specific combining ability (SCA)**											
1×2	0.370	0.259	0.078	-0.242	-0.578	-0.178	-0.010	0.004	0.030*	-0.030	0.088*	0.050
1×3	-0.258	0.140	0.178	-0.126	-0.153	-0.374	0.023	0.003	-0.004	0.056	0.009	-0.011
2×3	0.238	0.071	-0.122	-0.352	0.127	0.231	0.003	0.014	0.018	0.010	-0.001	0.002
1×4	-0.004	0.322	0.287	-0.114	-0.166	-0.415	-0.029	0.000	0.024	-0.044	0.013	0.065
2×4	-0.355	-0.306	0.171	0.170	0.244	-0.115	0.019	0.007	-0.004	0.036	0.006	0.017
3×4	0.074	-0.108	-0.162	0.199	0.138	0.181	0.008	-0.004	-0.004	-0.020	-0.009	-0.021
F_2 population	**reciprocal (SCA)**											
1×2	-0.205	0.028	-0.185	0.052	0.308	0.407	0.007	0.002	0.003	0.032	-0.078	-0.087
1×3	-0.043	0.845	0.075	-0.902*	-0.045	-0.335	0.017	-0.017	0.008	0.105*	0.043	0.028
1×4	-0.182	0.060	0.160	-0.787	0.327	0.180	0.000	-0.053*	-0.037*	-0.047	-0.003	0.027
2×3	-0.585*	0.018	-0.128	-0.382	0.178	0.268	0.028	-0.015	-0.003	0.047	0.005	-0.017
2×4	0.337	-0.193	-0.312	-0.420	0.230	0.172	-0.057	-0.005	0.018	-0.053	0.012	0.040
3×4	-0.282	0.382	0.625**	0.277	-0.268	-0.598	-0.050	-0.010	0.000	-0.048	0.017	0.101*

* and ** significance at 5% and 1% levels, genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil's, and Balatilla, respectively

Table 7

Means of grain yield, nitrogen yield, NUEgy and NUEgny of parents and their F_2 progeny in 4 × 4 diallel cross of bread wheat at different nitrogen levels

Parents	Grain yield (kg ha^{-1})			Nitrogen yield (kg ha^{-1})			NUEgny (kg grain kg^{-1} N)			NUEgn (kg grain kg^{-1}N)		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
1	830.6	1121.7	1431.3	94.22	162.70	219.03	67.60	13.56	9.96	3.46	0.47	0.32
2	783.9	1462.4	1403.1	83.31	207.35	206.92	60.67	17.28	9.41	3.27	0.61	0.32
3	808.7	1341.3	1425.1	84.31	188.90	219.27	61.14	15.74	9.97	3.37	0.56	0.32
4	848.9	1354.2	1479.1	91.21	191.62	226.77	64.22	15.97	10.31	3.54	0.56	0.34
Parent mean	818.03	1319.9	1434.7	88.26	187.64	218.00	63.41	15.64	9.91	3.41	0.55	0.33
F_2 populations												
1×2	923.4	985.6	1287.2	104.03	146.66	195.75	75.99	12.22	8.90	3.85	0.41	0.29
1×3	1092.0	1123.5	1205.1	116.82	174.39	189.33	84.65	14.53	8.61	4.55	0.47	0.27
1×4	987.8	1093.7	1240.0	107.19	164.08	198.62	79.21	13.67	9.03	4.11	0.45	0.28
2×3	833.2	1229.0	1503.0	86.61	175.01	222.36	65.13	14.59	10.11	3.47	0.51	0.34
2×4	979.1	1485.2	1469.1	104.05	203.27	221.83	76.37	16.94	10.08	4.08	0.62	0.33
3×4	877.5	1498.2	1420.6	90.98	215.57	224.93	62.02	17.96	10.22	3.66	0.63	0.32
F_2 mean	948.83	1235.8	1354.1	101.61	179.83	208.80	73.90	14.99	9.49	3.95	0.52	0.31
RF_2												
2×1	815.8	1569.4	1349.9	95.17	233.92	210.68	68.20	19.49	9.58	3.40	0.65	0.31
3×1	853	1358.7	1557.5	91.28	192.63	243.31	67.83	16.05	11.06	3.56	0.57	0.36
3×2	666.5	1416.9	1385.0	75.55	201.72	208.06	55.46	16.81	9.46	2.78	0.59	0.31
4×1	941.3	1261.7	797.0	104.84	187.08	124.74	74.62	15.59	5.67	3.92	0.53	0.18
4×2	1000.3	1367.5	1485.3	99.89	193.09	231.78	72.55	16.09	10.53	4.17	0.57	0.34
4×3	742.5	1061.6	1523.9	80.03	144.96	224.79	58.19	12.08	10.22	3.09	0.44	0.35
RF_2 mean	836.57	1339.3	1349.7	91.13	192.23	207.23	66.14	16.02	9.42	3.49	0.56	0.31
L_{SD} ($P<0.05$)	19.86	25.26	34.64	ns	47.94	50.81	ns	4.00	2.31	0.83	0.11	0.08

genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil's, and Balatilla, respectively, ns – non-significant

Table 8

Estimation of GCA, SCA and REC in the F_2 generation for grain yield, nitrogen yield, NUEgy and NUEgny in bread wheat at low and high nitrogen levels

Parents	Grain yield			Nitrogen yield			NUEgny			NUEgn		
	N0	N1	N2	N0	N1	N2	N0	N1	N2	N0	N1	N2
	general combination effect (GCA)											
1	3.537	-9.115**	-8.524	6.629*	-8.415	-10.449	4.846*	-0.701	-0.474	0.147	-0.039**	-0.020*
2	-2.584	7.664**	3.808	-2.852	90.613*	2.528	-1.485	0.802*	0.115	-0.108	0.032**	0.008
3	-3.870	0.065	5.802	-5.608*	-1.176	8.404	-3.921*	-0.098	0.382	-0.161	0.001	0.014
4	2.917	1.386	-1.087	1.831	-0.022	-0.483	0.560	-0.002	-0.023	0.121	0.006	-0.002
F_2 population	**specific combining ability (SCA)**											
1×2	-1.402	-0.365	-0.695	1.481	20.656	0.628	0.368	0.222	0.029	-0.059	-0.001***	0.000
1×3	10.236**	3.595	3.585	8.685	60.666	7.857	6.947*	0.555	0.357	0.425**	0.014	0.009
2×3	-5.974	-5.002	-2.472	-4.801	-6.506	-6.233	-2.667	-0.541	-0.284	-0.249	-0.021	-0.005
1×4	2.591	-4.067	-25.805***	3.212	-2.418	-37.901**	3.144	-0.200	-1.723**	0.108	-0.017	-0.059**
2×4	11.229**	4.019	7.735	8.647	20.15	14.250	7.021*	0.179	0.647	0.469**	0.016	0.017
S3×4	-5.463	-3.030	5.248	-5.062	-4.72	6.427	-4.901	-0.414	0.292	-0.228	-0.011	0.013
F_2 population	**reciprocal SCA**											
1×2	5.380	-29.186**	-3.133	4.432	-4.628***	-7.467	3.897	-3.635**	-0.338	0.223	-0.122	-0.007
1×3	11.883*	-11.759	-17.623	12.768*	-9.120	-26.992*	8.410*	-0.762	-1.227*	0.497	-0.050	-0.042
1×4	2.327	-8.397	22.152	1.178	11.503	36.940**	2.295	-0.960	1.678	0.095*	-0.037	0.052*
2×3	8.337	-9.397	5.902	5.532	-13.355	7.148	4.835	-1.112	0.325	0.345	-0.038	0.015
2×4	-1.060	5.889	-0.810	2.082	50.092	-4.979	1.912	0.425	-0.225	-0.042	0.023	-0.002
3×4	6.750	21.829	-5.166**	5.477	35.302**	0.068	1.917	2.942**	0.003	0.282	0.092*	-0.013

* and ** significance at 5% and 1% levels, genotype number of 1, 2, 3 and 4 represent Inqualab-91, 84ÇZT84, Chil’s, and Balatilla, respectively

teristics of hybrids for visually comparing the relationships between hybrids and agro-botanical traits (Yildirim et al. 2018, Kendal 2019, Kendal et al. 2019, Ahmed et al. 2020). The research findings revealed a significant association between spring wheat hybrids and nitrogen levels as 1st main component (PC1) variation remained at 61.5%, while 2nd main component (PC2) variation was 26%, thus making 87.5% overall variation (PC1 + PC2) for spring rainfed wheat hybrids (Figure 1). Figure 1 shows the "which-won-where" view of the GGE biplot for hybrid and parent grain yield at different N levels. The biplot was divided into seven sectors delimited by lines. The three N applications fell into three of the seven sectors. For N levels within a sector, the nominal "winner" is at the vertex. 84ÇZT04 × Balatilla is the best progeny for N2 level (optimum N condition) and Chils × Balatilla was suitable for N3 level (high N conditions). However, Chils × Inqualab91, Balatilla × 84ÇZT04 and 84ÇZT04 × Inqualab91 were outstanding hybrids in the sector containing the N1 (poor N conditions). Regarding all investigated traits, 1st main component (PC1) variation remained at 37.9%, while 2nd main component (PC2) variation was 22.3%, and thus making the overall variation up to 60.2% (PC1 + PC2) – Figure 2. Grain yield and GNY were

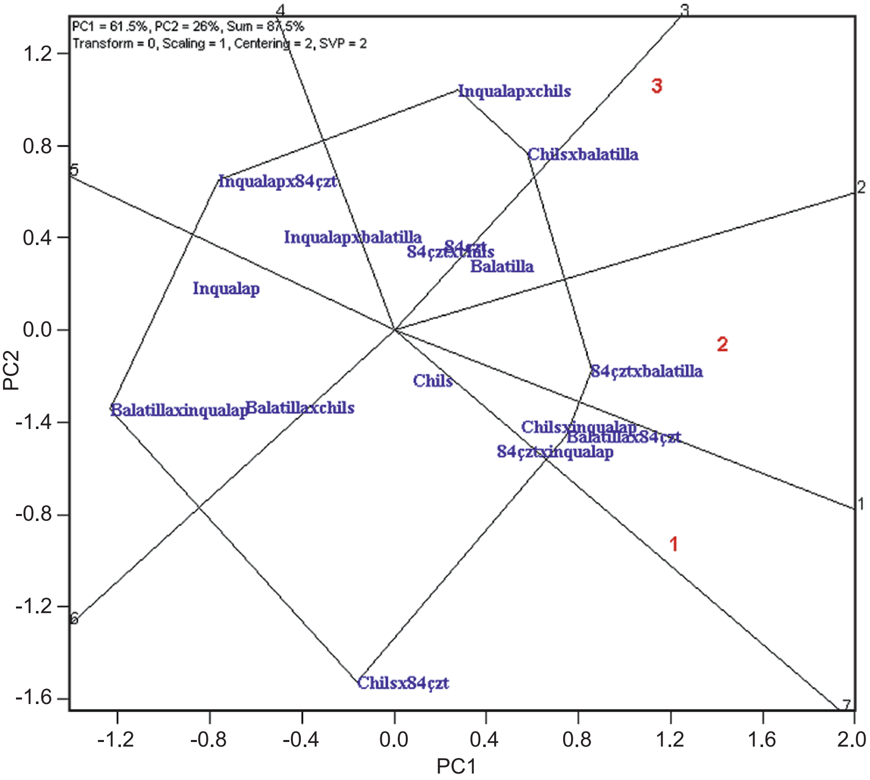

Fig. 1. GGE biplot analysis graph illustrating the relationship between genotypes and nitrogen levels: 1, 2 and 3 – N0, N1 and N2 respectively

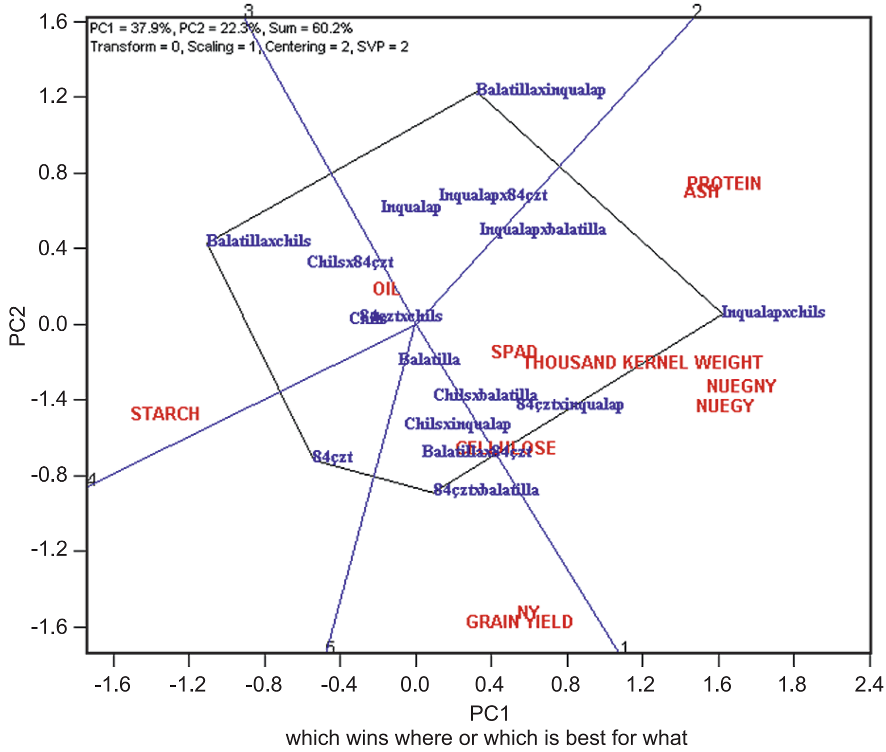

Fig. 2. GGA biplot analysis graph illustrating the relationship between genotype and investigated traits

in the same sectors, and 84ÇZT04 × Balatilla was the winner. Other traits, except the starch and crude fat content, fell into one sector and Inqualab91 × Chils was the winner, especially in terms of the NUE traits. The results showed that the GGE biplot method is useful for analysis of diallel cross data, and will help breeders to extract much more information from their data (Yan, Kang 2003).

CONCLUSIONS

The findings proved to be in line with the postulated hypothesis as spring wheat hybrids varied significantly in terms of yield attributes, grain yield and N use efficiency under varying doses of soil applied N. As a result, it would be desirable to evaluate breeding lines under various nitrogen levels in order to improve nitrogen use efficiency. It may also be inferred that wheat hybrids having higher nitrogen use efficiency and yield in early segregation can be determined by implementing the GGE methodology under different nitrogen levels.

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