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Original Research Article

ASSESSMENT OF WHEAT GENOTYPES FOR THEIR LOW NITROGEN USE EFFICIENCY UNDER SEMI-ARID CONDITIONS OF PUNJAB, PAKISTAN

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Abstract: *Nitrogen is one of the most important and critical macronutrients needed by plants for their optimal growth and development. The current experimental study was designed to examine the response of wheat variety Akbar-2019 under different nitrogen levels keeping the levels of phosphorus and potassium constant. The study was conducted in Chak No. 169/7.R Fort Abbas, District Bahawalnagar under the supervision of the Department of Soil Fertility (Field) during the crop year 2022-23. The experimental material was comprised of a wheat variety Akbar-2019 and five different treatments of nitrogen consisted of (i) N = 160 kg ha-1 (ii) N = 145 kg ha-1 (iii) N = 131 kg ha-1 (iv) N = 117 kg ha-1 and (v) N = 103 kg ha-1. The experiment was laid out under a randomized complete block design with three replications and 170 m² net plot size par treatment per replication. The results revealed the presence of highly significant variations among nitrogen treatments in wheat variety based on the agronomic and morpho-physiological parameters including flag leaf area, thousand-grain weight, grains per spike, relative water contents, stomatal conductance, net photosynthetic rate, biological yield and gain yield. Furthermore, the results also unveiled that treatments with higher nitrogen dosage produce better results for almost all the study parameters including grain yield. These results were also confirmed through correlation coefficient analysis and bar graph graphical representation based on mean data, where correlation coefficient analysis showed a strong positive correlation of grain yield with studied plant traits except biological yield for which the correlation was positive but non-significant. The results suggest that nitrogen in higher amounts up to a certain level is necessary for obtaining maximum output from wheat crops under semi-arid conditions.*

Keywords: Wheat; Correlation; Bar Graph; Grain Yield; Plant Physiology, Fertilizers

Introduction

Wheat serves as a vital crop globally, providing a significant portion of dietary calories and proteins to the world's population. It contributes about 20% of global dietary energy and protein intake, positioning it as one of the most crucial crops for food security (1). With its origins dating back approximately 10,000 years, wheat has become a staple in various diets around the world, cultivated across diverse climatic regions (2). The crop's adaptability allows it to thrive in numerous environments, from temperate climates to more arid regions, which further emphasizes its global importance. Wheat is cultivated on more than 240 million hectares worldwide, making it the most extensively grown crop compared to any other agricultural product (3). This extensive cultivation results in a global production volume that has surpassed 800 million metric tons in recent years. The production patterns of wheat showcase not just its volume but also its economic significance, as world trade in wheat is greater than that of all other crops combined. Notably, countries such as China, India, Russia, and the United States dominate wheat production, contributing significantly to the global supply (4). Wheat plays an

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indispensable role in ensuring global food security due to its high nutritional value and widespread use in numerous food products. It is a primary source of calories for billions of people, especially in regions where other staple crops may not be as accessible or productive. The increasing global population and rising incomes in developing nations further amplify the demand for wheat, illustrating its essential role in both rural livelihoods and urban food systems.
Nitrogen (N) plays a critical role in wheat growth and development, influencing both yield and quality. Effective nitrogen management and understanding nitrogen use efficiency (NUE) are essential for optimizing wheat production, especially under conditions of limited nitrogen availability (5). Wheat can indeed be grown successfully under low nitrogen conditions through various strategies, although such cultivation may significantly affect grain yield (6). Nitrogen is a fundamental nutrient essential for the normal growth and development of wheat, as it significantly affects grain yield and quality1. It plays an integral role in determining protein content, dough quality, and processing characteristics, which are vital for the overall nutritional value of wheat (7). Adequate nitrogen levels promote the development of a photosynthetically active canopy, directly influencing wheat yield (8).Under optimal nitrogen conditions, wheat plants exhibit enhanced grain size, weight, and protein content, all of which contribute to higher yields (9). Conversely, nitrogen deficiency results in decreased chlorophyll synthesis and photosynthetic activity, leading to lower grain yield and compromised quality (10). Specifically, studies have indicated that nitrogen-deficient wheat can experience reductions in grain yield by as much as 19.3% compared to nitrogen-sufficient conditions (11). Growing wheat under low nitrogen conditions can be achieved by implementing several management strategies. Adjusting the timing of nitrogen application to coincide with critical growth stages has proven effective, as delaying nitrogen application until the first hollow stem stage can enhance grain yield and protein content (12). Additionally, developing wheat cultivars with improved nitrogen use efficiency is vital, as these cultivars can perform better under sub-optimal nitrogen conditions (13).

Addressing nitrogen limitations while maintaining or enhancing wheat yields will require innovative approaches, including evaluation of existing germplasm and testing the strength of the germplasm for nitrogen application for breeding high NUE cultivars and improving management practices. These strategies can contribute to sustainable agricultural systems where nitrogen inputs are minimized, yet wheat productivity is maintained, ensuring food security amid challenges like climate change. Therefore, the current study was designed to evaluate the nitrogen use efficiency in modern wheat cultivars.

Methodology

The experimental study was conducted in Chak No. 169 / 7.R Fort Abbas, District Bahawalnagar under the supervision of the Department of Soil Fertility (Field) during the crop year 2022-23. The experimental material consisted of wheat variety (Akbar-2019) while the varying amounts of nitrogen were used as treatments. Five nitrogen treatments were used to evaluate wheat performance, keeping the potassium and phosphorus levels the same (60 kg ha^{-1}, 114 kg ha^{-1}), respectively. The five treatments of nitrogen were (i) 160 kg ha^{-1}, (ii) 145 kg ha^{-1}, (iii) 131 kg ha^{-1}, (iv) 117 kg ha^{-1} and (v) 103 kg ha^{-1}. The sowing of experimental material was done 14th of November, 2022 with the help of a dibbler. The sowing was done in a randomized complete block design on an area of 800 m^2. All the standard agronomic, cultural and plant protected measure were kept the same for all the treatments across all replications.
To evaluate wheat genotype under high to low nitrogen availability the data was recorded for key agronomic and yield-related traits including flag leaf area (FLA), thousand grain weight (TGW), grains per spike (GPS), relative water content not photosynthetic rate stomatal conductance biological yield and green yield. The physiological data including net photosynthetic rate stomatal conductance were measured using an infrared gas analyzer i.e., CI-320 handheld photosynthetic system. Moreover, the data regarding physiological traits were measured from 10:00 a.m. to 12:30 p.m. The data was recorded for soil macro and micronutrients including electric conductivity (EC), pH organic matter percentage (OM %), soil phosphorus (P ppm), soil potassium (K ppm) and soil nitrogen percentage (N %) as pre-sowing and post-sowing of treatments to compare the leaching and uptake of nutrients by the plants. The soil parameters data were recorded from 0 to 15 cm and 15 to 30 cm for each treatment before and after harvesting.
The recorded data were then subjected to analysis of variance and other post hoc analyses (14). To compare the performance of the wheat genotype for each trait under a given nitrogen dosage bar plots were drawn using Microsoft Excel and OriginPro packages.

Table 1: Soil analysis report for key soil parameters (Pre- and Post-Harvest)

SOIL ANALYSIS (Pre-Sowing)								
Treatments	Soil Parameters	EC (dS m^{-1})	pH	OM%	P (ppm)	N (%)	K (ppm)	Texture
	Depth (0 - 15) cm	1.1	8.5	0.76	13.3	0.0383	82	Loam
	Depth (15-30) cm	0.9	8.5	0.72	14.7	0.0364	80	-
SOIL ANALYSIS (Post Harvest)								
Treatments	Soil Parameters	EC (dS m^{-1})	pH	OM%	P (ppm)	N (%)	K (ppm)	Texture
1	Depth (0 - 15) cm	1.16	8.53	0.82	12.34	0.043	67	Loam
	Depth (15-30) cm	0.96	8.52	0.78	13.67	0.038	65	-
2	Depth (0 - 15) cm	1.21	8.56	0.79	12.89	0.042	69	
	Depth (15-30) cm	0.99	8.53	0.76	13.98	0.039	63	
3	Depth (0 - 15) cm	1.18	8.48	0.72	13.37	0.038	78	

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	Depth (15-30) cm	0.93	8.51	0.71	14.78	0.037	82	
4	Depth (0 - 15) cm	1.16	8.46	0.66	13.48	0.034	89	
	Depth (15-30) cm	0.93	8.52	0.62	14.79	0.032	86	
5	Depth (0 - 15) cm	1.18	8.46	0.56	14.34	0.029	97	
	Depth (15-30) cm	0.94	8.51	0.52	15.78	0.028	89	

The results obtained from the analysis of variance depicted the presence of significant genetic variations among treatments based on the morpho-agronomical and physiological parameters including flag leaf area, relative water content, thousand-grain weight, grains per spike, net photosynthetic rate, stomatal conductance, biological yield and grain yield (Table 2). The results also unveiled that all the study traits showed highly significant variations among nitrogen treatments. However, the variations in biological yield among treatments were significant at 5% only. Similar results were also reported by (15, 16,17,) who showed that data regarding grain yield and related traits vary significantly under a different set of treatments of nitrogen dosages.

Table 2: Mean Square (MS) of key plant traits in Akbar-2019 under varying amounts of nitrogen

SOV	Df	FLA	RWC	TGW	GPS	Pn	C	GY	BY
Replication	2	0.14	0.86	0.22	0.42	4.32	1757.00	124300000	0.39
Treatments	4	3.94^{**}	6.54^{**}	4.72^{**}	3.82^{**}	5.25^{**}	3608.74^{**}	120800000^{**}	0.43^{*}
Error	8	0.71	1.26	0.44	0.41	1.11	533.99	12320000	0.13

The data obtained showed that the highest flag leaf area was observed in treatment-1 (31.0 cm^2) of nitrogen dosage where 160 kg per hectare in nitrogen was applied followed by treatment-2 (29.5 cm^2), where 145 kg per hectare was used while the lowest flag leaf area in wheat variety Akbar -2019 was observed in treatment-5 (27.9 cm^2) where minimum nitrogen application was made (103 kg per hectare) (Figure 1a). This shows that the amount of nitrogen applied has a direct relationship with the growth and development of weed plants as higher nitrogen increases the rate of plant growth and has a direct impact on biomass accumulation assimilated partitioning and biological yield. Similarly, the thousand-grain weight was observed highest under treatment-1 where wheat variety Akbar-2019 gave 46.5 g weight per 1000 grains of wheat followed by treatment-2 where 45.8-gram weight was obtained while the lowest thousand-grain weight was observed in treatment-5 (44 g) where minimal nitrogen was applied (Figure 1b). This suggests that higher nitrogen dosage has a significant impact on grain filling rate, source-sink relationship, and accumulation of carbohydrates in the endospermic part of grains in cereals (18,19).

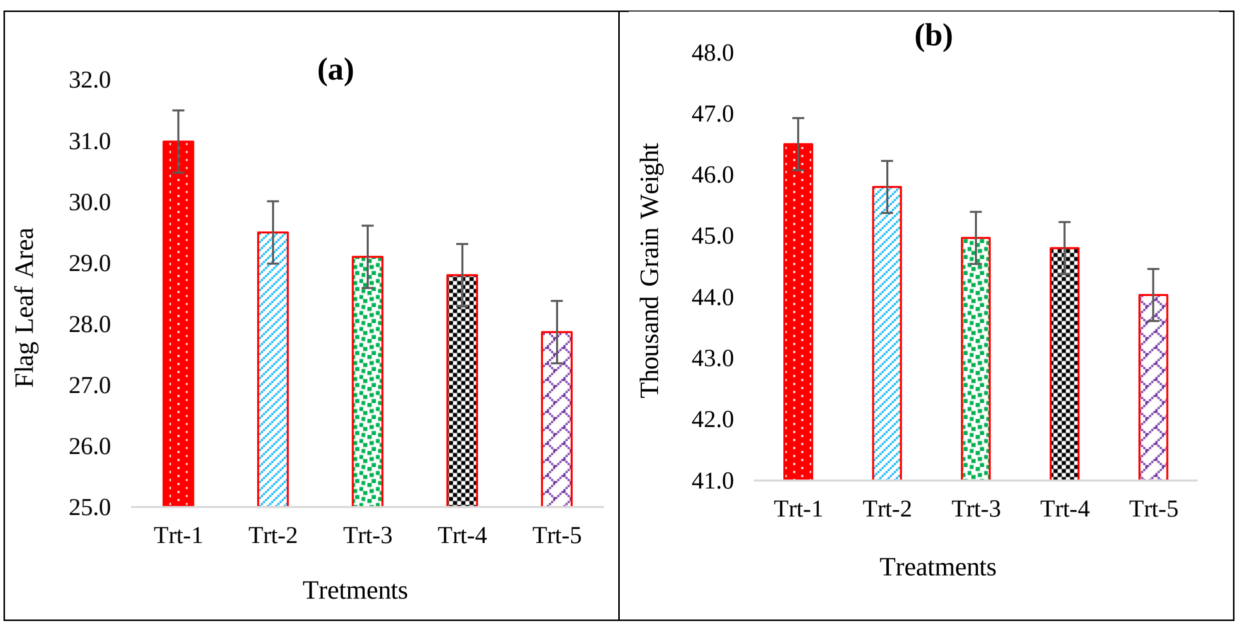

FIGURE 1 | Performance of wheat variety Akbar-2019 under different nitrogen dosages based on (a) Flag Leaf Area (b) Thousand Grain Weight

The same trend was also been observed for the number of grains per spike where the highest number of grains per spike was observed and treatment-1 (55.82) followed by treatment-2 (55.53) and treatment-3 (55.10) while the lowest number of grains per spike in Akbar-2019 was observed under treatment-5 (53.83) (Figure 2c). This is the

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same trend as for flag leaf area and thousand-grain weight where nitrogen was supposed to play a crucial role in the growth and development of the plant, accumulation of carbohydrates in seed, source-sink relationship, maintenance and assimilate partitioning which resulted in the larger flag leaf area, higher thousand-grain weight and number of grains per spike in higher nitrogen dosage (20,21).

Relative water contents also showed highly significant variation among treatments, where treatment-1 retained higher relative water contents (69.67) followed by treatment-2 (68.13) and treatment-4 (67.17) while the lowest relative water contents were depicted in treatment-5 (66.57) (Figure 2d).

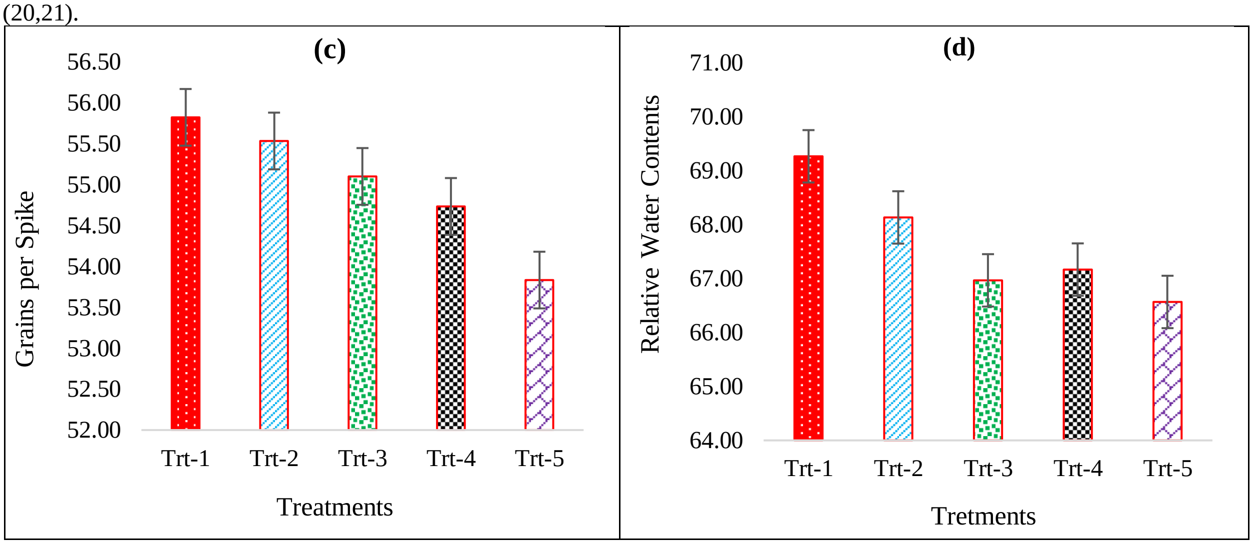

FIGURE 2 | Performance of wheat variety Akbar-2019 under different nitrogen dosages based on (c) Grains per Spike (d) Relative Water Contents

Similar to relative water contents, nut photosynthetic rate showed similar patterns among studied nitrogen treatments where the highest net photosynthetic rate was observed in treatment-1 (32.47) followed by treatment-2 (31.23) and treatment-4 (30.70) and the lowest net photosynthetic rate was seen in treatment 5 (29.20) (Figure 3e). This might be due to the fact that under higher nitrogen availability plant chlorophyll contents increase which stands to increase the photosynthetic process of plants to develop their food from nutrients in the presence of sunlight through a complex biological process (21, 22, 23). A similar pattern was observed for stomatal conductance, where the highest stomatal conductance was observed for treatment-1 (457.0) followed by treatment-2 (427.0) and treatment-3 (401.7) while the lowest stomatal conductance was observed in treatment-5 (369.9) followed by treatment-4 (384.4) (Figure 3f). This pattern shows that the higher the gas is exchanged through leaves; the higher will be the photosynthetic activity which will strengthen the source that ultimately converts its food assimilate to sink; hence, grain yield of a particular variety or genotype will be improved (24, 25, 26).

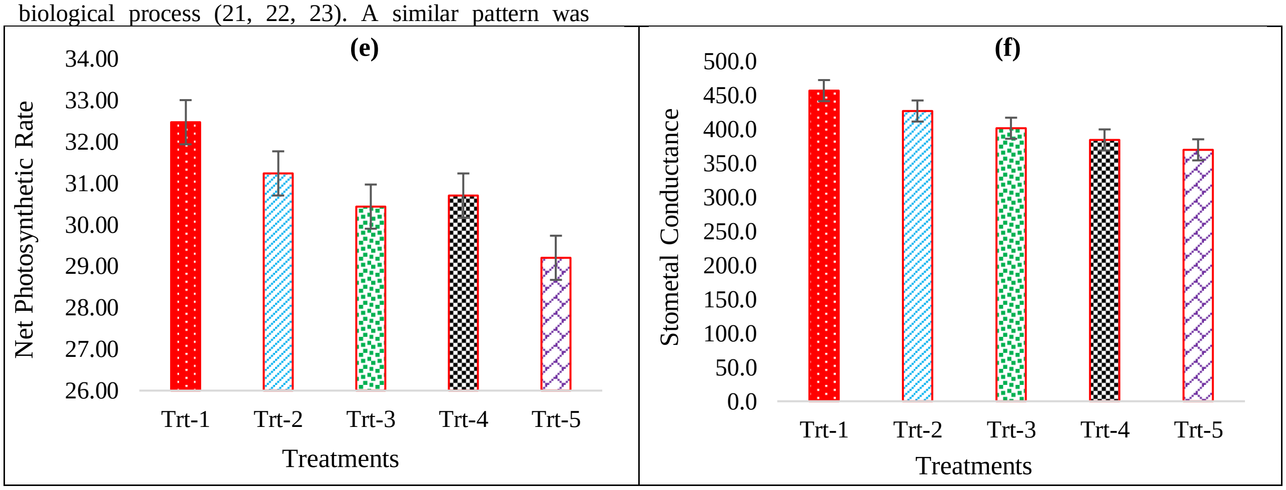

FIGURE 3 | Performance of wheat variety Akbar-2019 under different nitrogen dosages based on (e) Net Photosynthetic Rate (f) Stomatal Conductance

There are several studies which show that the biological yield of wheat plants has a direct relationship with grain yield for any variety 27). The studies also showed that the higher the biomass of a variety, the higher will be the food

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resources developed through photosynthesis processes, which strengthen the sink and ultimately increase the grain yield. In the current study, biological yield per plot was taken and it showed a slightly changed pattern from the previously studied yield-associated traits. The results revealed that treatment-1 produced the highest biological yield per plot (13.18) followed by treatment-5 (12.67) and treatment-2 (12.37) while the lowest biological yield was observed in treatment-4 (12.28) followed by treatment-3 (12.33) (Figure 4g).

The ultimate goal of any wheat improvement program is to increase its grain yield sustainable way. In the current study, we examine the impact of varying amounts of nitrogen on grain yield and its associated parameters. The results revealed that the highest grain yield was produced under treatment-1 followed by treatment-2 and treatment-3 while the lowest grain yield was given by treatment-5 followed by treatment-4 (Figure 4h). As described earlier, grain yield is a complex, multigenic parameter, whose performance depends on its associated traits and surrounding environment. The grain yields associated traits like flag leaf area, thousand-grain weight, grains per spike, relative water contents, net photosynthetic rate, stomatal conductance, and biological yield showed a similar behaviour that was associated with higher nitrogen demands (28-32).

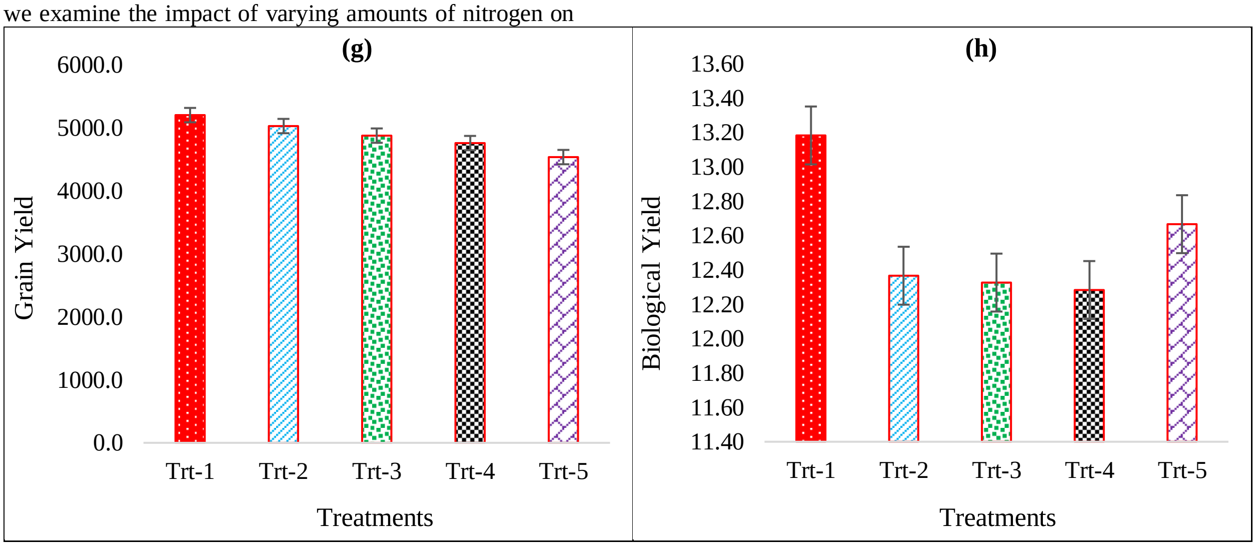

FIGURE 4 | Performance of wheat variety Akbar-2019 under different nitrogen dosages based on (g) Biological Yield (h) Grain Yield

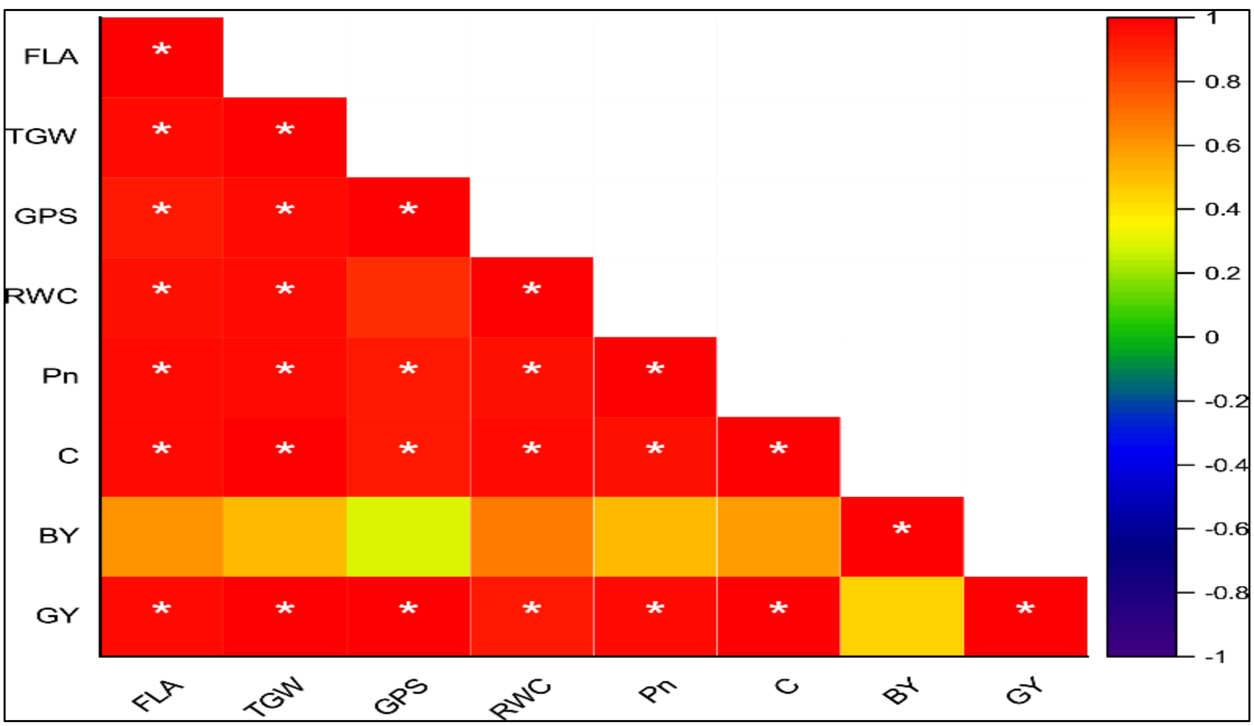

FIGURE 5: Correlation coefficients between studied plant traits in wheat variety Akbar-2019 under varying amounts of nitrogen dosages (* shows the significant relationship)

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The correlation coefficient analysis was carried out to find out the magnitude and direction of correlation between different studied traits in wheat under varying amounts of nitrogen application (Figure 5). The results revealed that grain yield had a very strong and positive correlation with flag leaf area, thousand-grain weight, grains per spike, relative water contents, net photosynthetic rate, and stomatal conductance while the relationship between grain yield and biological yield was although positive yet non-significant. All the study traits had positive and strong correlations with other yield-associated traits under study except biological yield for which the relationship was positive but non-significant. This indicates that selection based on individual grain yield will not be the best option due to its polygenic nature and higher dependency on surrounding environmental conditions. However, the selection based on associated traits must be carried out for more comprehensive results. The findings of this study were in complete line with the previous findings of other researchers who showed that flag leaf area, thousand-grain weight, grains for the spike, relative water contents, net photosynthetic rate and stomatal conductance had a significant association with grain yield in wheat under different nitrogen dosages (32-37).

Conclusion

The current study was designed to evaluate the performance of wheat under different levels of nitrogen keeping the phosphorus and potassium levels constant. The results indicated that highly significant variations were present among different treatments based on the studied traits including flag leaf area, thousand-grain weight, grains per spike, relative water contents, stomatal conductance, net photosynthetic rate, biological yield and grain yield. A similar pattern was observed for all the traits under study where higher nitrogen application responded towards the higher grain heel and associated traits. The results were also confirmed through correlation coefficient analysis, which unveiled the presence of a highly significant and positive correlation of grain yield with flag leaf area, thousand-grain weight, grains per spike, relative water contents, stomatal conductance and net photosynthetic rate. The correlation between grain yield and biological yield was also found positive yet non-significant. Similar was the case with other parameters where biological yield had a positive but non-significant correlation with these traits. The results obtained through this research indicated that higher nitrogen application is needed to obtain maximum yield in wheat crops to a certain level under semi-arid conditions of the Punjab Province.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate
Approved by the department Concerned.
Consent for publication
Approved
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Not applicable

Conflict of interest

The authors declared the absence of a conflict of interest.

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