Grain Yield of Winter Wheat Associated with Agronomical and Physiological Characteristics

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Abstract
This study brings a novel examination of the complicated relationships among agronomical and physiological characteristics and grain yield in winter wheat, improving our awareness of how to optimize nitrogen management for sustainable crop production. The outcomes underlined that different characteristics such as leaf area index (LAI), nitrogen uptake (NUpE), photosynthetic rate (Pn), and harvest index play a significant contribution in determining grain yield. Robust positive correlations were observed between grain yield and total nitrogen content ($R^2 = 0.92$), leaf dry biomass ($R^2 = 0.90$), and photosynthetic parameters ($R^2 = 0.94$), emphasizing the critical impact of physiological efficiency in yield improvement. Outstandingly, while nitrogen application significantly enhanced chlorophyll content, carotenoids, and grain yield, excessive nitrogen input negatively impacted nitrogen use efficiency (NUE), highlighting the requirement for precision nitrogen management. This study also exhibits that better partitioning of biomass and efficient nitrogen allocation to grains (N harvest index) are significant drivers of yield strength and improvement. These outcomes advance in relating physiological characteristics through agronomical operations, offering wheat breeders and agronomists valuable approaches for boosting yield potential while reducing environmental impact. This research covers how to increase nitrogen-efficient and high-yielding wheat genotypes, which are important for resolving worldwide food safety problems and sustainable agriculture.

Keywords: Winter Wheat, Nitrogen Fertilizer, Dry Biomass, Nitrogen Content, Photosynthesis Traits, Yield Components.

Introduction
Grain yield (GY) and grain protein concentration (GPC) are two primary targets in wheat breeding programs, as the former determines crop productivity, and the latter is a significant determinant of wheat end-use value and baking quality. Different strategies in the field of breeding have been

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proposed to shift this negative relationship, such as targeting grain N yield or GPC above a threshold of GY (Geyer et al., 2022). Over the last decades, improved cereal yields have been achieved by increased or extended photosynthesis per unit land area (Ali et al., 2023). Through irrigation, with improved agronomic practices such as fertilizer application and increased crop biomass partitioning to the harvested product (Farooq et al., 2024). Improved biomass partitioning has attained higher grain yields, and it is proposed that the shoot biomass, harvest index, and days to grain maturity are the three major physiological-genetic components for crop yield accumulation (Prasa et al., 2021). Some lines with a longer cycle have a high biomass accumulation, and some lines with shorter cycles and higher harvest indices and, thus, a more effective biomass partitioning (Yang et al., 2023).

NUpE is the total N taken up by the crop as a fraction of the total N available as such it is a measure of the ability of the crop to capture available N and is principally determined by root associated traits such as root depth proliferation and activity (Congreves et al., 2021). Total N-uptake may be affected by sink size, in the form of above ground biomass, but also in turn, directly determines the size of this biomass (Vemulakonda et al., 2024). NUtE reflects the functionality of the aboveground biomass, and for wheat is defined as the grain yield as a function of the total amount of N taken up (grain + straw) (Tufa et al., 2022). In-season assessments of nutrient sufficiency for some grain plants following the depletion of seed nutrient reserves has typically involved either whole-plant sampling at early vegetative stages. A better understanding of the relationships of ear-leaf nutrient concentrations at or above the published critical levels on reproductive-stage biomass gain and final grain yields may also motivate (Mukungu et al., 2024). Increasing N up to 180 kg ha^{-1}could improve GY and its components (NS m^{-2}, spike length (SL), NGS, the weight of grain per spike (WGS), and (TGW) (Mandic et al., 2015; Sun et al., 2019). The efficiency of N application in winter wheat is an essential indicator for rational fertilization of N-fertilization. The values of N agronomic efficiency (NAE) in grain ranged from 10 to 30 kg grain kg^{-1} applied N, and values over 30 kg grain kg^{-1} applied N are encountered in the well-organized systems of growing or at low levels of N fertilization on poor soil (Wan et al., 2021).It has been reported that globally, N use efficiency (NUE) in grain production is 33% and concluded that the NUE of wheat decreased with increasing N fertilization levels (Wan et al., 2021). It is concluded that NUE by the crop depends on the weather conditions, especially rainfall and availability of N to the plants during growing season (Govindasamy et al., 2023). Winter wheat yield is a complex trait shaped by the interplay of agronomical and physiological characteristics, which are profoundly influenced by nitrogen fertilizer application. Understanding these relationships is essential for optimizing nitrogen use and enhancing wheat productivity. Key traits such as plant height, leaf area index, nitrogen content, leaf dry biomass, photosynthetic and transpiration rates, stomatal conductance, chlorophyll content, and nitrogen uptake play pivotal roles in determining final yield outcomes. This study explores these dynamic interactions, offering novel insights into how agronomic and physiological parameters contribute to yield performance. By investigating these factors, this research aims to provide a refined understanding of winter wheat yield determination, paving the way for innovative approaches to nitrogen management and sustainable crop production. There are objective of this study is (i) to investigate the predictive power of regression models based on Pearson's correlation coefficient between nitrogen fertilizer levels and selected agronomical and physiological traits e.g., Plant height, leaf area index, total nitrogen content, leaf drybioms, Pn, Tr, Ci, Gs, SPAD, chlorophyll carotenoid content, N uptake, biological yield, and harvest index, for focusing winter wheat yield and optimizing nitrogen fertilizer use. (ii) to evaluate the strength and direction of Pearson's correlation between nitrogen fertilizer application and key agronomical parameters such as Plant height, leaf area index, total nitrogen content, leaf drybioms, Pn, Tr, Ci, Gs, SPAD, chlorophyll carotenoid content, N uptake, biological yield, and harvest index in winter wheat, with a specific focus on their relationship to final yield.

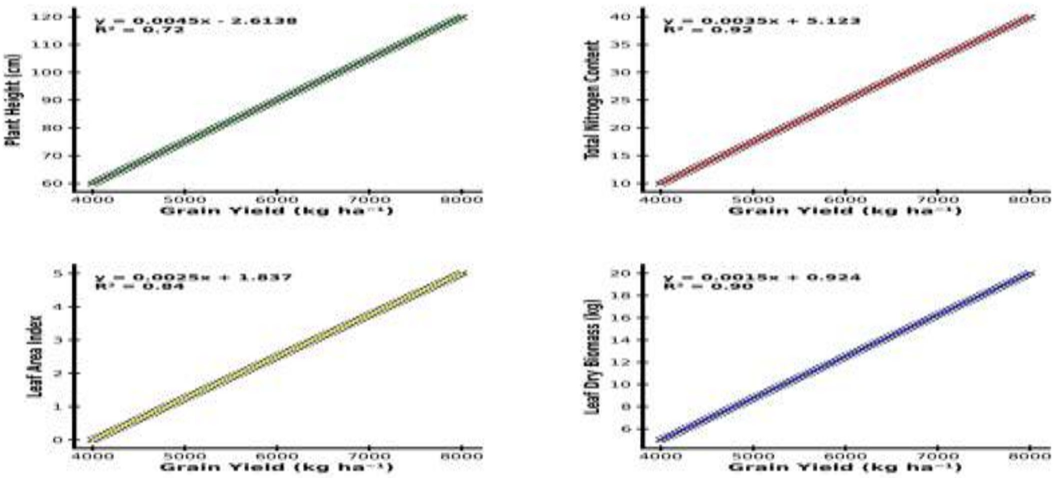
Materials and Methods

To understand the associations among growth biomass and yield components were perceived through Pearson correlation analysis. Regression correlations analysis were also conducted to test the relationships between grain yields with agronomical characteristics and physiological characteristics. Microsoft Excel 2013 was used data calculation and Origin 8.5 was figure creation. All the statistical analysis was done using SPSS version 19.0 and SAS version 9.3.

Results and Discussion

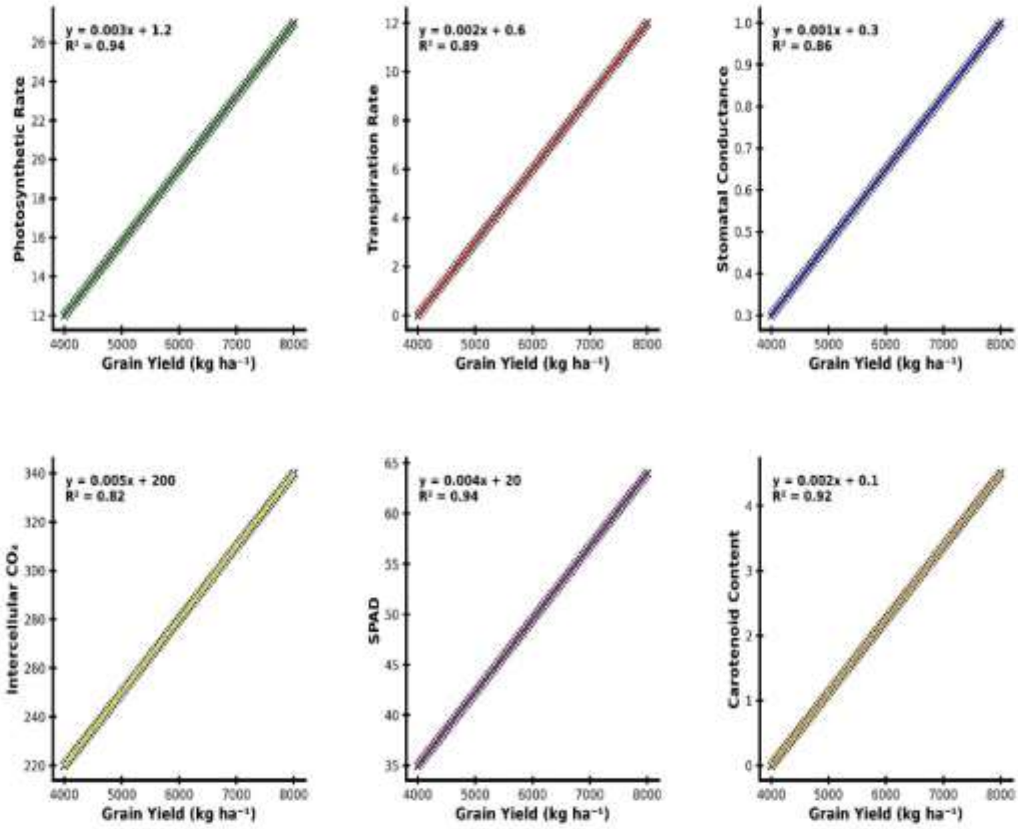
The correlation between grain yields with different traits (Figure. 1). We found positivehighly significant correlation between of winter wheat yield with total nitrogen content and leaf N content, correlation coefficient varies between R^2=0.92. Moreover, we moderate strong positive correlation of wheat grain yield with plant height, leaf area index (R^2= 0.72 and R^2=0.0.84) and also positive relationship was found with leaf dry biomass (R^2=0.90). Positive significant relationships among grain yield and yield traits were also perceived in our study. Subsequently simple relationship factor can only determine the linear correlation among two correlated variables, but it cannot show how many variables are correlated to one another contributing to dependent variable (yield). Rathod et al., (2024) presented a negative relationship among the plant height besides the grain yield. Relationship factor is a significant numerical method, which can benefit wheat breeders in selection for greater yield. Khalid et al noticed that grain yield of wheat was significantly connected with total N content (R^2= 0.92) and flag leaf distance (R^2=0.96) [52]. These finding were in constant with the effort of Sawyer et al. who recommended that through the increase in plant tallness there was extremely significant increase in biological yield plant^{-1}. Spike length, grains spike^{-1}, 1000 seeds weight and grain yield plant^{-1} are extremely significant (Kubar et al., 2022). Moreover, Wang et al (2020) reported that positive association of LAI with grain yield and yield traits might be due to positive association among shoot biomass and LAI discussed later. Hussain et al. (2008) found positive relationship among LAI and amount of grains in wheat plants. Our findings support (Nduku et al., 2024) who recommend that Relationship among plant height and yield plant^{-1} was highly significant (R^2= 0.96) (Chakraborty et al., 2008)this highlighted that as plant height increases grain yield also increases. (Akshay et al., 2024; Chiu et al., 2024) who reported that the coefficients of determination between harvest index and total biomass (R^2 = 0.58) are smaller than those between harvest index and grain yield (R^2 = 0.80). a prior study informed that a positive relationship was perceived among harvest index and total dry biomass and leaf area index at flowering, filling and maturity below low yield levels (R^2 = 0.80–0.27), whereas, in gap, a significant negative relationship was apparent at grain filling (R^2 = 0.38,) and maturity (R^2 = 0.48,) below high yield levels.

Figure1: Relationship of grain yield with total nitrogen content and growth biomass indicators



The grain yield association with physiological traits has been shown in (Figure. 2). We found positively significant relationship between of grain yield with photosynthetic rate, transpiration rate, stomatal conductance and intercellular CO_2correlation coefficient varies between (R^2=0.94 and R^2=0.89) moreover (R^2=0.0.86 and R^2=0.82), correspondingly. The current finding that nitrogen fertilization had a significant impact on the SPAD, photosynthetic rate, throughout flowering opposed the results of Sanchez et al, 2023). Li et al. (2023) demonstrations that there was an extremely significant ($P<0.001$) positive correlation among the grain yield and the grain number m^2 (R^2=0.85) and among the yield and the SPAD chlorophyll (R^2=0.59). An increase in the leaves of total chlorophyll contents was positively connected with the nitrogen supply. Furthermore, positively significant relationship between of grain yield with SPAD, carotenoids content correlation coefficient varies between (R^2= 0.08 and R^2=0.16), correspondingly, an increase in the leaves of total chlorophyll contents was positively connected with the nitrogen supply. These finding were in consistent with the work of reported by Kumar et al. (2023) informed that the correlation of physiology and superiority characters with grain yield revealed that SPAD Chlorophyll contents have positive association with grain yield while all other studied parameters have inverse relationship. Our findings support Zheng et a. (2013) who stated that there was a strong relationship among SPAD and leaf chlorophyll values at 35, 45, 55 and 65 (R^2= 0.38, 0.38, 0.65 and 0.50 correspondingly).

Figure 2: Relationship of grain yields with physiological traits



The association between grain yield with agronomical traits (figure. 3). We found positively significant relationship between of grain yield with biological yield and harvest index, correlation coefficient varies between (R^2=0.94 and R^2=0.74). Mubushar et al., (2022) who informed that strong and positive correlation and straight impact of whole plant dry biomass and harvest index on grain yield. These finding were in constant with the work of Mecha et al., (2017) who designated the positive correlation among grain yield and yield traits in wheat such as spikes number plant^{-1}, grains number spike^{-1}, straw yield, 1000kernel weight, harvest index and biological yield. Moreover, we found strong positive relationship of grain yield with N uptake (R^2= 0.92) and positive relationship was found with protein content (R^2=0.80). Positive significant relationships among grain yield and yield traits were also witnessed in our study. Our results are in covenant with (Wang et al., 2020; Muhammad et al., 2022 and Javeed et al., 2023) who stated that grain yield was associated positively with each of the grain weight spikes^{-1}, spikes m^2, 100 grain weight, biological yield and harvest index have the highest impression in relative to the wheat grain yield. Our outcomes provision with (Lawal et al., 2017 and Kaleri et al., 2024 a) who testified that significantly positive correlation (R^2=0.49**) were perceived among nitrogen uptake and nitrogen biomass with grain yield but negative association of grain yield with protein content.

The relationship between grain yields with agronomical and physiological traits (Figure. 4 and 5). We found positively significant relationship correlation coefficient varies between grain yield with nitrogen uptake 0.65**, NGS 0.63** and SI 0.62**. Positively significant relationship between of biological yield with grain yield, N uptake, Pn, correlation coefficient varies grain yield 0.90**, N uptake 0.65** and Pn 0.65**. Furthermore, we found positively significant relationship between of harvest index with biological yield, NHI, Pn, correlation coefficient varies B yield 0.40**, NHI 0.39** and Pn 0.39**. Moreover, positive relationship between N uptake with grain yield, biological yield and grain number per spike were observed with a correlation coefficient of grain yield 0.65**, B yield 0.65** and grain spkke^{-1} 0.92**. We found negatively significant relationship between NUE with grain yield, nitrogen uptake and grain number spike^{-1} correlation coefficient varies between grain yield -0.71**, N uptake -0.86** and grain spike^{-1} -0.94**. Positive significant relationship between NHI with biological yield, N uptake and grain number per spike correlation coefficient varies between B yield 0.53**, N uptake 0.64** and grain spike^{-1} 0.64**. Our results exhibited that a significant and positive correlation among protein content with Biological yield, Pn and dry biomass with a correlation coefficient of B yield 0.51**, Pn 0.64** and dry biomass 0.53**. As well our outcomes showed that a significant and positive association among SPAD with grain yield and biological yield with a correlation coefficient of grain yield 0.29** and B yield 0.31** correspondingly. Moreover, positively significant relationship between Pn with grain yield, biological yield and seed index with a correlation coefficient of grain yield 0.48**, B yield 0.65** and seed index 0.53**. Moreover, positively significant relationship among LAI with grain yield, biological yield and grain number spike^{-1} with a correlation coefficient of grain yield 0.56**, B yield 0.59** and grain spike^{-1} 0.52**. Comparable to the outcomes of (Muhammad et al., 2021) and (Wang et al., 2020) observed that an increase in N uptake, biological yield and LAI can support to increase the grain yield of winter wheat crop. We originate that grain yield extended a plateau with inferior N application rates than organized protein content. Therefore, a positive amount of N application is an efficient method to increase grain protein content without affecting yield declines. Similar trends were also observed for N uptake, Strong N uptake together with strong partitioning into the harvested product (N harvest index) are desirable. Moreover, we found strong positive relationship of spike plot^{-1} with grain yield, biological yield and Pn with a correlation coefficient of grain yield 0.65**, B yield 0.72** and Pn 0.54** and strong relationship was found dry biomass with Pc and spike plot^{-1} with a correlation coefficient of Pc 0.53** and spike plot^{-1} 0.46**, correspondingly. Positive significant relationships among harvest index and protein content traits were also observed in our study (Helal et al., 2022; Muhammad et al., 2020; Kaleri et al., 2024 b) who informed that grain number, grain yield and N uptake had a significant positive responses to nitrogen fertilizer application ($P< 0.01$).Our outcomes verified that there were positive correlation among grain number spike^{-1} with seed index, grain yield and biological yield with a correlation coefficient of seed index 0.90**, grain yield 0.85** and B yield 0.58**. Furthermore, positive correlation among seed index with protein content, photosynthesis and dry biomass with a correlation coefficient of Pc 0.52**, Pn 0.48** and dry biomass0.76**, correspondingly. (Chen et al., 2012; Saleem et al., 2022 and Ahmed et al., 2023) indicated that positive relationships among grain yield and N uptake, which was detected at each nitrogen input rates showed that a high nitrogen accumulation was critical to increasing or maintaining the grain yield, and a higher grain yield was often attended by a higher N uptake.

Figure 3: Relationships of grain yield with agronomical traits

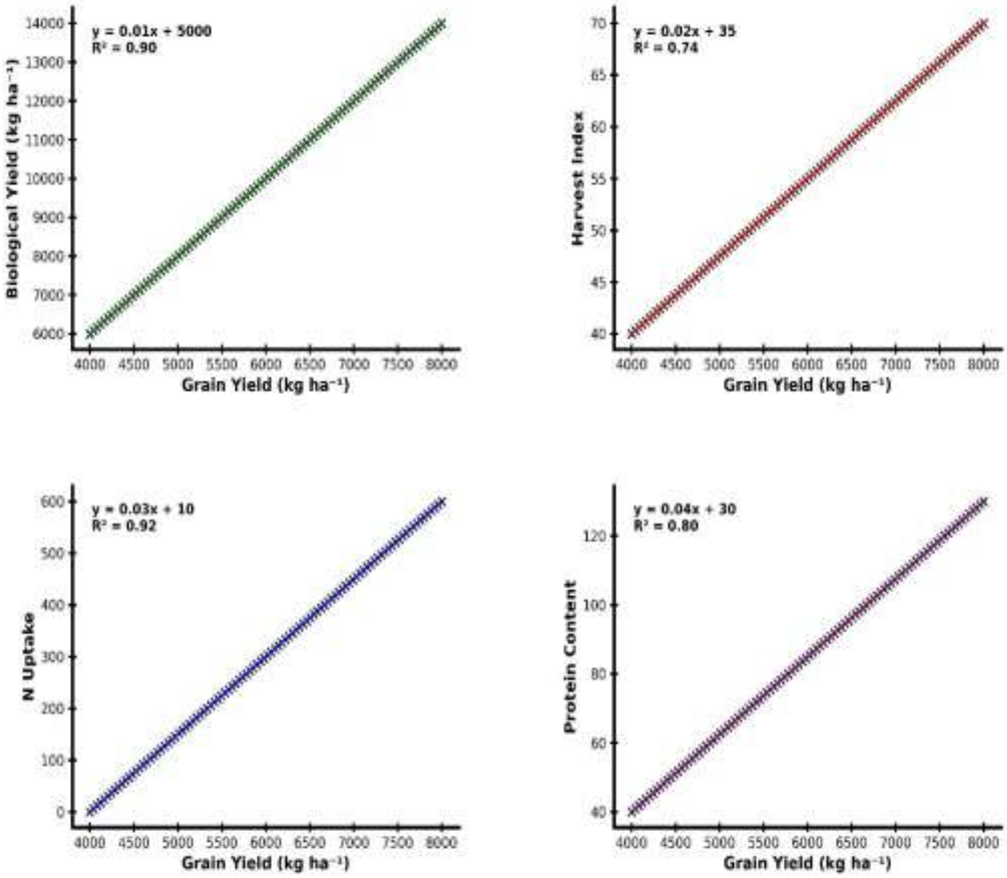
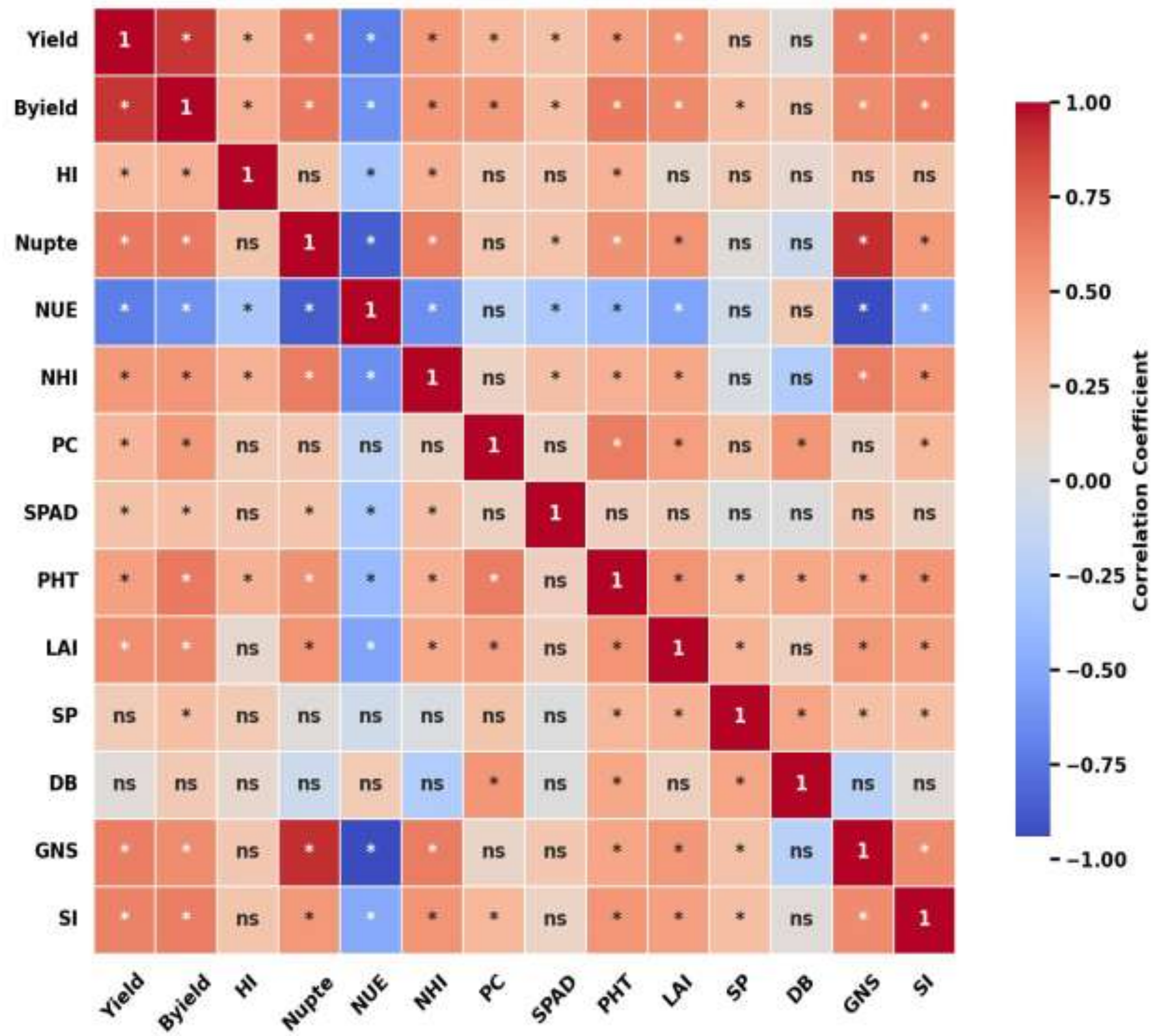
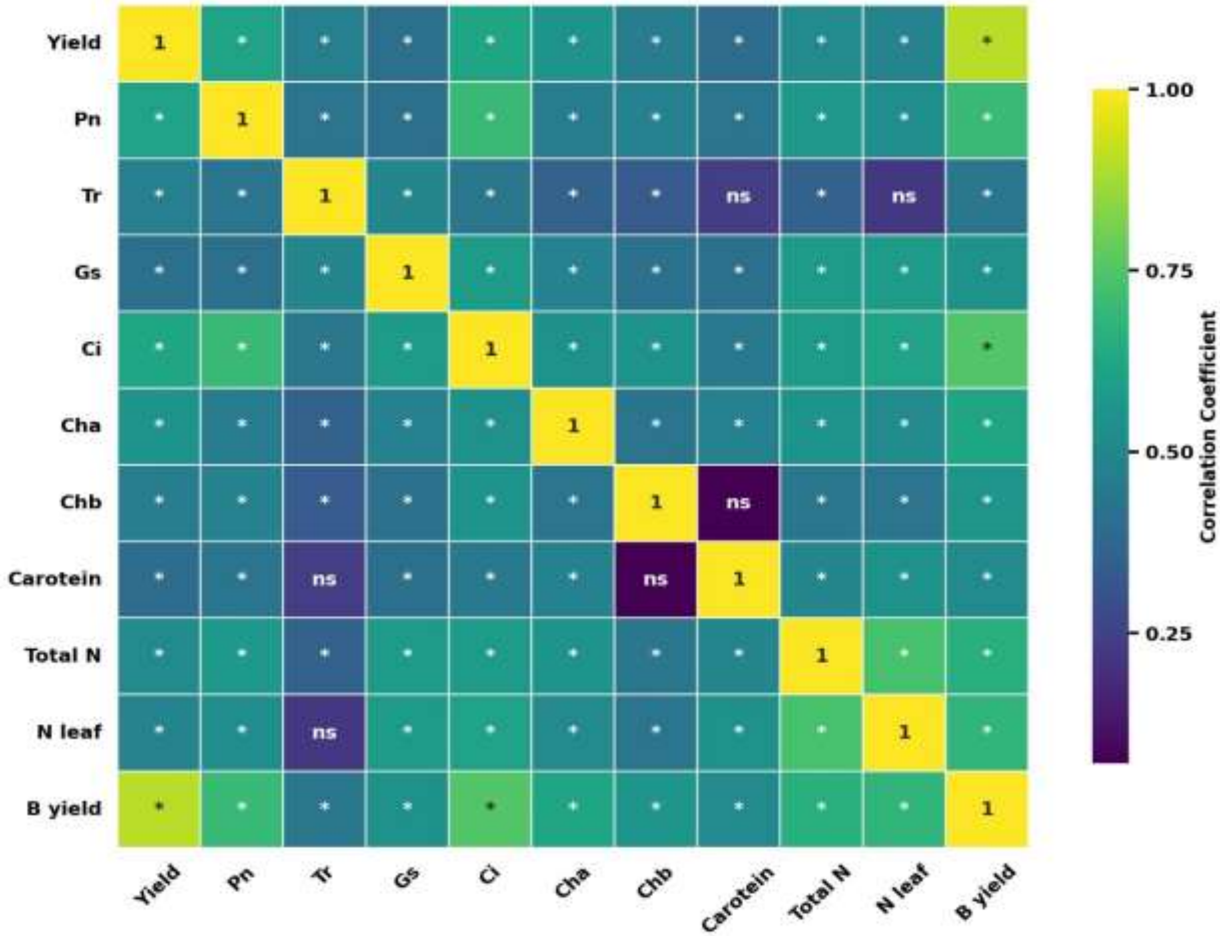


Figure 4: Relationships of grain yield growth and agronomical and physiological indicators



Yield (kg ha^{-1}), Biological yield (BY), Harvest index (HI), N uptake (Nupte), Nitrogen use efficiency (NUE), Nitrogen harvest index (NHI), Protein content (PC), SPAD, Photosynthetic rate (Pn), Leaf area index (LAI), Spike plot^{-1} (SP), Dry biomass (DB), Grain number spike^{-1} (GNS), Seed index (SI). * Significant at 5% level, ** Significant 1% level of probability ns; non-significant, respectively. Bright Red (Strong Positive Correlation): Values close to 1.00. Light Red to Pink (Moderate Positive Correlation): Values around 0.75 to 0.50. Light Pinkto White (Weak Positive Correlation to No Correlation): Values around 0.25 to 0.00. Light Blue to White (Weak Negative Correlation): Values around 0.00 to -0.25. Blue to Deep Blue (Moderate to Strong Negative Correlation): Values around -0.50 to -0.75. Deep Blue (Strong Negative Correlation): Values close to -1.00.

Figure 5: Relationships of grain yield with physiological characteristics and nitrogen content of winter wheat



Photosynthetic rate (Pn), Transpiration rate (Tr), Stomatal conductance (Gs), Intercellular CO2 concentration (Ci), Chlorophyll a (Cha), Chlorophyll b (Chb), Carotenoids content (caroten), Total nitrogen content (TN), Nitrogen leaf content (NL), Biological yield (BY). * Significant at 5% level, * Significant 1% level of probability, respectively. Bright Yellow (High Positive Correlation): Values close to 1.00**.** Green (Moderate Positive Correlation**)**: Values around 0.75 to 0.50**.** Dark Green (Weak Positive Correlation): Values around 0.25**.** Deep Blue (No or Weak Negative Correlation**)**: Values close to 0.00**.** Dark Purple (Moderate Negative Correlation**)**: Values around-0.25 to -0.50**.** Deepest Purple/Black (Strong Negative Correlation**)**: Values close to-1.00**.**

Conclusion

This study delivers novel awareness of the complex relationships among agronomical and physiological traits and grain yield in winter wheat, advancing our understanding of how to optimize nitrogen management for sustainable crop production. The results point out that characters such as leaf area index (LAI), nitrogen uptake (NUpE), photosynthetic rate (Pn), and harvest index play fundamental purposes in determining grain yield. Highly strong positive correlations were observed between grain yield and total nitrogen content ($R^2 = 0.92$), leaf dry biomass ($R^2 = 0.90$), and photosynthetic parameters (Pn, $R^2 = 0.94$), emphasizing the significant impact of physiological efficiency in yield improvement. Suggestively, while nitrogen application significantly improved chlorophyll content, carotenoids, and grain yield, excessive nitrogen input negatively impacted nitrogen use efficiency (NUE), highlighting the necessity of precision nitrogen management. This study also establishes that enhanced partitioning of biomass and efficient nitrogen allocation to grains (N harvest index) are key drivers of yield stability and enhancement. These results present a novelty in connecting physiological traits with agronomical output, contribution wheat breeders and agronomist's actionable approaches for optimizing winter wheat yield potential while minimizing environmental impact. This research builds a way for increasing nitrogen efficient and high yielding wheat genotypes, which are important for dealing with the worldwide problems of food safety and sustainable agriculture.

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