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Studies of Genotypic, Phenotypic and Path Coefficient Analysis for Yield and Yield Contributing Traits in Wheat (Triticum Aestivum L.)

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ABSTRACT

The experiment conducted during 2022-23 and 2023-24 *Rabi* seasons at three locations with objective to identify the genotypic and phenotypic correlations and path analysis among yield-related traits in wheat. Line x tester mating design was used to generate forty five F_1s hybrids by the cross of fifteen lines with three testers. Randomized Complete Block Design (RCBD) with three replications was used during 2024 *Rabi* season at three locations. Observations were recorded on sixteen quantitative and qualitative parameters viz.; Days to 50% Heading (DH) and Days to Maturity (DM) (377.96), indicating that earlier heading leads to earlier maturity. DH also correlated highly with Grain Filling Period (GFP) (502.97), Plant Height (PH) (205.34), and Flag Leaf Area (FLA) (346.47). PH was significantly correlated with yield-related traits like Grain Weight per Spike (GWS) (170.02) and Grain Yield per Plant (GYP) (164.59), highlighting their importance in productivity. In phenotypic correlations, DH showed a strong negative correlation with GFP (-521.03), PH (-215.10), and GYP (-191.67), suggesting that later heading plants have longer grain filling periods and lower yield. GFP had the most significant negative correlations with PH (-379.75) and GYP (-337.96). Pearson correlation analysis found that GWS had strong positive correlations with 1000-Grain Weight (TGW) (0.761) and Biological Yield (BY) (0.6895). Path coefficient analysis revealed Plant Height (PH) as the most influential trait (0.804 total contribution), followed by Number of Grains per Spike (0.712) and 1000-Grain Weight (0.658). Thus, study identified traits that correlated directly or indirectly to grain yield in wheat.

Key words: Trait, Phenotype, Genotype, Path Analysis, Wheat and Yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) belong to family poaceae and second most important staple food crop next to rice and contributed immensely to the world's economy and human nutrition [1, 2]. Wheat is an allohexaploid species consisting of 21 chromosome pairs, organized into three subgenomes; A, B, and D, with AABBDD genome composition and chromosome number of 2n = 6x = 42 [3, 4]. It was developed through natural hybridization between Emmer wheat (AABB) (*Triticum dicoccon*) and Goat grass (DD) (*Aegilops tauschii*) commonly called hard grass [5]. Wheat is a self-pollinating plant with three anthers connected to the base by slender filaments, enclosed within bract-like structures called the lemma and palea [6, 7]. The optimal tSSSemperatures is 20-25^{0}C for germination, 16-20^{0}C for tillering, and 20-23^{0}C for grain formation [8, 9].

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According to [10] correlation analysis plays a critical role in plant breeding, as it helps breeders understand the relationships between different traits and how they influence one another. Particularly those focused on improving yield or other desirable traits, understanding these relationships is key for making informed decisions about which traits to select for improvement. Correlation analysis measures the degree to which two or more traits are related. If there is a strong positive correlation between traits like number of grain per spike and grain yield per plant, selecting for number of grain per spike could naturally result in higher yields [11]. According to [12] reported that conversely, a negative correlation might indicate that improving one trait could potentially lead to a decrease in another, helping breeders make trade-off decisions when improving multiple traits simultaneously.

According to [13] one of the major advantages of correlation analysis in breeding is its ability to guide the selection of traits for improvement in multi-trait breeding programs. This enables breeders to focus their efforts on the traits with the most significant impact, potentially speeding up the breeding process.

According to [14], path coefficient analysis is a more effective tool for understanding and predicting plant yield. Path coefficient analysis is a powerful tool for understanding the direct and indirect effects of various interrelated components that contribute to complex traits. It allows for a deeper understanding of how different variables influence one another, especially when dealing with traits that are influenced by multiple factors. Specifically, path coefficient analysis helps to measure the direct effect of one variable on another, providing valuable insights into how each component contributes to the overall trait.

In path coefficient analysis, the total correlation between a predictor variable and a response variable is broken down into its direct and indirect effects. The direct effect represents the standardized partial regression coefficient of the predictor variable, showing how much it directly influences the response variable. The indirect effect, on the other hand, is calculated by multiplying the correlation coefficient between two predictor variables with the relevant path coefficient in the path diagram [15].

According to [16] path analysis allows researchers to identify not just the direct relationships but also the more complex indirect influences that might affect the outcome. The primary goal of path coefficient analysis in the context of sugarcane yield is to determine which traits are most important for selection in breeding programs aimed at improving yield. By identifying these key traits, the research can help guide efforts to enhance sugarcane productivity, which is particularly significant for boosting agricultural economies in Africa. The information derived from path analysis aids in selecting the most influential traits to target for improvement, ultimately contributing to the economic development of regions dependent on sugarcane cultivation [17].

Scenario of wheat in India and Nigeria

Data from Ministry of Agriculture and Farmers Welfare, Government of India and Federal Ministry of Agriculture and Rural Development of Nigeria, reveals a significant difference in wheat productivity per hectare between India's and Nigeria's top wheat-producing states. In India, states like Punjab and Haryana achieve much higher productivity, with yields ranging from 4.8–5.2 tons/ha and 4.5–4.9 tons/ha, respectively. Other Indian states, like Western Uttar Pradesh and Gujarat, also produce more than 3 tons/ha [18]. While Nigeria's leading wheat-producing states, such as Borno and Kano, have considerably lower productivity, with yields ranging from 1–1.2 tons/ha [19].

Table 1: Area, Production and Productivity of Wheat

	World	**India**	**Nigeria**
Area	228 million ha	31.8 million ha	0.07 million ha
Total production	797 million t	110 million t.	0.08 million t.
Productivity	3.5 t/ha	4.7 (varies by region) t/ha	1.2 t /ha

Source: [20]

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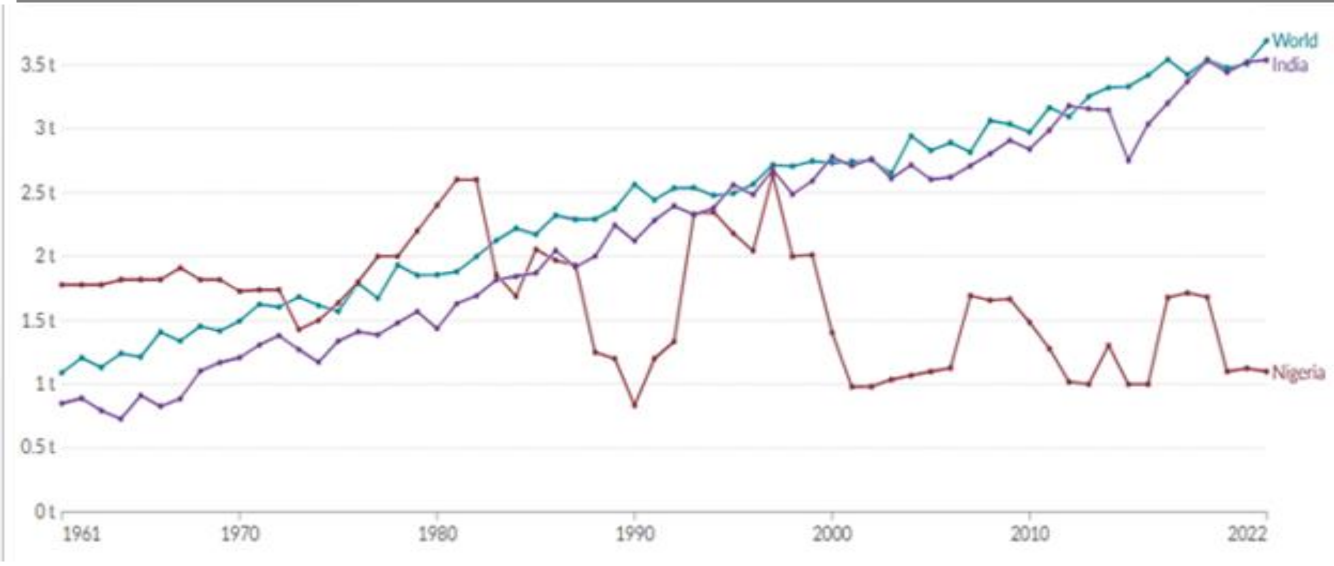

Fig. 1 Wheat production record based on yield/ha (y=yield & x=production period) from 1961 to 2022 [20]

The significance of the study, helps in understanding the intricate relationships between various yield-contributing traits, which is crucial for improving wheat productivity, especially under varying environmental conditions. By pinpointing the most influential traits for yield, the study provides valuable information for breeders to develop high-yielding wheat varieties with enhanced agronomic traits. The findings can contribute to the development of more efficient breeding strategies, ultimately leading to increased food security through improved wheat production. Objective of the study is to identify the genotypic and phenotypic correlations and path analysis among yield-related traits in wheat.

MATERIAL AND METHODS

The present investigation entitled Studies on interrelationship for unlocking the potential of yield and yield contributing traits in wheat (*Triticum aestivum* L.) was conducted at three locations viz.; (i) Lovely Professional University, Phagwara Punjab India (ii) Kebbi State University of Science and Technology Aliero (KSUSTA), Kebbi State Nigeria and (iii) Lake Chad Research Institute, Borno State Nigeria during the Rabi seasons of 2022-23 and 2023-24. The edaphic and climatic conditions under which present study was carried along with techniques applied and materials used have been described in this chapter.

Eexperimental materials comprises sixty seven genotypes of wheat (fifteen line, three testers, four checks and forty five F_1's) and forty five hybrids (F_1's) that were derived by the cross of fifteen lines (females) with three testers (males) to workout stability analyses for yield and yield components. The planting material used were fifteen lines, three testers and four checks (Table 2). Other materials includes; Breeders kit; SPAD (Soil Plant Analysis Development) handheld meter, meter rule, electric balance (Compax- Cx-600), seed counting machine, digestion apparatus, sodium hydroxide, hydrochloric acid etc.

Table 2 List of parents and four checks used in the experiment

Sr. No.	Genotype	Source of genotypes	Status of genotypes
1	BHU 25	Banaras Hindu University (BHU)	Released Variety
2	WB-02	Private Sector (West Bengal)	Released Variety
3	BHU 31	Banaras Hindu University (BHU)	Released Variety
4	HD 3721	ICAR-IIWBR	Released Variety
5	PBW 725	Punjab Agricultural University (PAU)	Released Variety
6	CRD GEHNU1	ICAR-IIWBR/Collaborator Institute	Released Variety
7	PBW 550	Punjab Agricultural University (PAU)	Released Variety
8	PBW 677	Punjab Agricultural University (PAU)	Released Variety
9	PBW 822	Punjab Agricultural University (PAU)	Released Variety

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10	HD 3117	ICAR-IIWBR	Released Variety
11	DBW 173	ICAR-IIWBR	Released Variety
12	HD 3086	ICAR-IIWBR	Released Variety
13	DBW 222	ICAR-IIWBR	Released Variety
14	CSW 18	ICAR-IIWBR	Released Variety
15	PBW 757	Punjab Agricultural University (PAU)	Released Variety
16	PBW ZN1 (tester1)	Punjab Agricultural University (PAU)	Released Variety
17	PBW 343 (tester2)	Punjab Agricultural University (PAU)	Released Variety
18	HD 3326(tester3)	ICAR-IIWBR	Released Variety
19	HD 2967 (check1)	ICAR-IIWBR	Released Variety
20	DBW 187 (check2)	ICAR-IIWBR	Released Variety
21	Norman (check3)	CIMMYT/ICAR Collaborations	Released Variety
22	Borlaug-100(check4)	CIMMYT/ICAR Collaborations	Released Variety

Experimental Site

The present investigation was conducted at three locations viz.; (i) Lovely Professional University, Phagwara Punjab India (ii) Kebbi State University of Science and Technology Aliero (KSUSTA), Kebbi State Nigeria and (iii) Lake Chad Research Institute, Borno State Nigeria during the *Rabi* seasons of 2022-23 and 2023-24. The edaphic and climatic conditions under which present study viz.; location one was teaching and research farm, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara Punjab India, located between latitude 31.2245° N and longitude 75.7711° E on an altitude of about 243 m above the sea level with annual rainfall of 527.1 mm [18]. Location two was teaching and research farm of Kebbi State University of Science and Technology Aliero, Kebbi State (KSUSTA), Nigeria, located in the Sudan Savanna agro-ecological zone of Nigeria between latitude 13^0 08 N and longitude 5^0 15 E on an altitude of about 250 m above sea level with annual rainfall ranges from 1500-1700 mm. While lake chard wheat research Institute, Borno State Nigeria, located between latitude 11.8467° N and longitude 13.1571° E, on an altitude of about 325 m above sea level with annual rainfall ranges from 900-1500 mm [19].

Table 3 Weather report 2023-2024 seasons across three locations

	Borno state Nigeria 2023					**Kebbi state Nigeria 2023**					**Punjab state India**			
Month	High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)		High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)		High Temp (°C)	Low Temp (°C)	R. H. (%)	Rain fall (mm)
Oct.	36	23	15	45		37.4	25.5	36.3	58		32	20	54	14
Nov.	34	18	0	25		37.1	22.4	0	29		27	15	52	30
Dec.	31	15	0	20		34.4	18.1	0	20		21	10	58	25
***Rabi* season 2024**														
Jan.	31	14	0	15		34.7	17.1	0	20		19	8	60	75
Feb.	34	17	0.2	14		37.8	19.8	0.53	18		23	10	57	61
Mar.	38	20	1	17		40.8	23.3	4.9	24		29	15	52	51
Apr.	41	24	3	21		42.3	27	24.2	36		36	21	45	39
May	40	27	13.5	35		41.3	29.8	75.5	49		40	26	38	27
June	37	26	63	50		38.8	28.8	94.9	58		41	29	50	50
July	33	24	115	65		35.4	26.3	170.2	70		36	28	73	211
Aug.	31	23	198	75		32.8	24.4	179.1	79		34	26	67	150
Sept.	33	24	80	68		34.7	24.9	151.1	76		34	24	60	101

Source: Nigerian Meteorological Agency (Nime t) report for the two State

Source: Punjab Agricultural University

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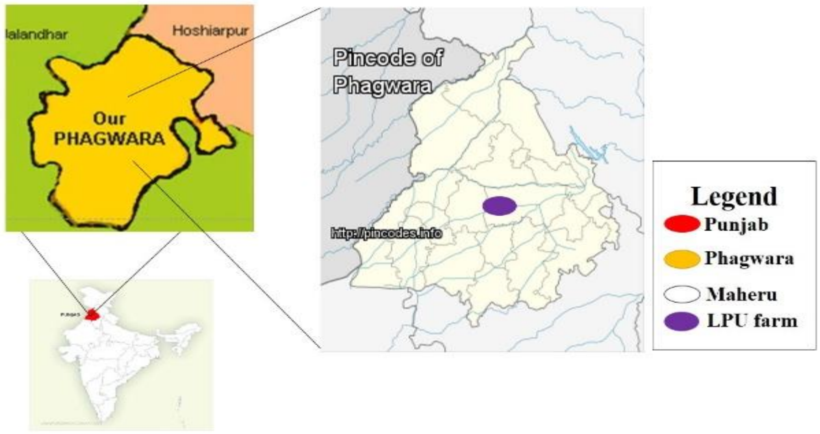

Fig. 2: shows the experimental site in Lovely Professional University, Phagwara (LPU), India (Location I)

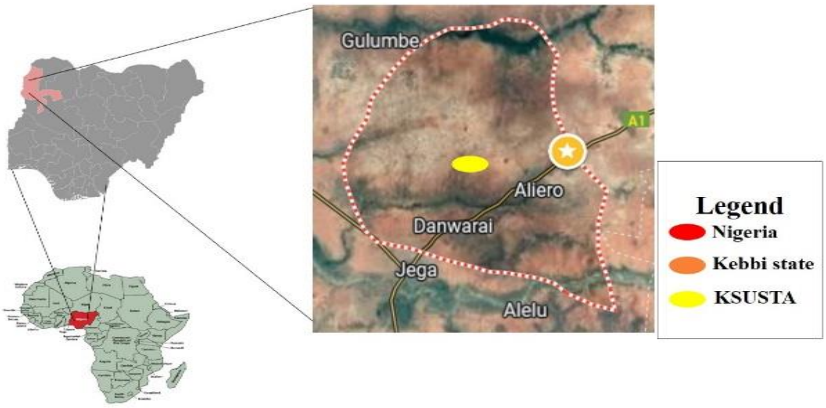

Fig. 3: shows the experimental site in Kebbi State University of Science and Technology Aliero (KSUSTA), Nigeria (Location II)

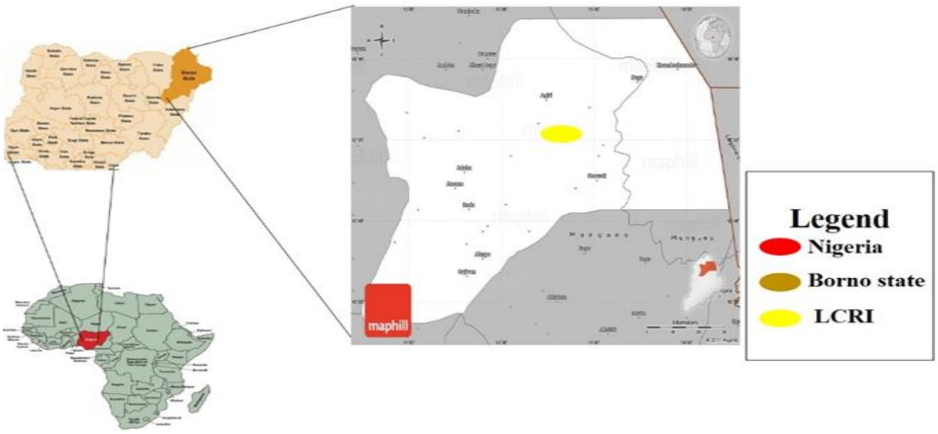

Fig. 4: shows the experimental site Lake Chad Research Institute (LCRI) in Kukawa, Borno State Nigeria (Location III

Statistical Analysis

The simple correlation coefficient between different characters was estimated according to [21] as follows:

Correlation coefficient (r) between characters x and y

$$r_{xy} = \frac{\text{Cov.xy}}{\sqrt{(\text{Var.x X var.y})}}$$

Where,

r_{xy} = Correlation coefficient between characters x and y. Cov. xy= Covariance between characters x and y. Var.x = Variance for x character. Var.y = Variance for y character.

The significance of correlation coefficient was tested by comparing at an appropriate level of significance the significant values of (r) at (n-2) degrees of freedom, where 'n' is number of genotypes.

Path coefficient analysis

Path coefficient analysis was carried out according to [14]. Grain yield per plant was assumed to be dependent variable (effect) which was influenced by the thirteen characters, the independent variables (causes), directly as well as indirectly through other characters. The variation in grain yield per plant unexplained by the thirteen causes was presumed to be contributed by a residual factor (x) which is uncorrelated with other factors. Path-coefficients were estimated by solving the following simultaneous equations indicating the basic relationship between correlation and path coefficient.

The equations used are as follows:

$$r_{iy} = P_{iy} + \sum_{j=1}^{13} r_{ij} P_{jy} \quad \text{For } i = 1, 2,.13.$$

$$r_{iy} = \sum_{j=1}^{13} r_{ij} P_{jy} \quad \text{For } r_{ii} = 1$$

The above equations can be written in the form of matrix: $[A]_{13\times1} = [B]_{13\times1} [C]_{13\times1}$

Where, A is column vector of correlations r_{iy}, B is the correlation matrix of r_{ij}, and C is the column vector of direct effects, P_{iy} Residual factor was calculated as follows:

$$P_{xy} = \sqrt{1 - R^2}$$

Where,

$$R^2 = \sum_j P_{iy} \; r_{iy}$$

The r_{ij}'s i.e. $r_{1.2}$ to $r_{13.14}$ denote correlations between all possible combinations of independent characters and P_{1y} to P_{13y} denote direct effects of various characters on character y.

r_{iy} = Correlation coefficient between i^{th} and y character. P_{iy} = Direct effect of i^{th} character on y.

RESULTS AND DISCUSSION

Genotypic correlations

The genotypic correlations observed across various agronomic traits demonstrate significant relationships that highlight the interconnectedness of key plant characteristics and their influence on growth and yield (Table 4). A strong positive correlation is seen between Days to 50% Heading (DH) and Days to Maturity (DM), with a correlation value of 377.96, indicating that earlier heading typically leads to earlier maturity. This is further supported by the correlations between DH and other growth traits such as Grain Filling Period (GFP) (502.97), Plant Height (PH) (205.34), and Flag Leaf Area (FLA) (346.47), suggesting that earlier heading varieties might exhibit distinct growth patterns as also reported by Sharma *et al.* (2021). Additionally, PH shows significant correlations with traits like GFP (298.57), FLA (209.04), Spike Length (SL) (449.81), and yield-related traits such as Grain Weight per Spike (GWS) (170.02) and Grain Yield per Plant (GYP) (164.59), with values indicating that taller plants generally demonstrate better growth and productivity.

The analysis also highlights the importance of productivity-related traits. For instance, Number of Productive Tillers (NPT) (97.95), Number of Grains per Spike (NGS) (101.10), and Grain Weight per Spike (GWS) (170.02) all show strong positive correlations with GYP (164.59), underlining their key role in determining overall grain yield. Furthermore, Biological Yield (BY) (208.68) and Harvest Index (HI) (243.64) are also positively correlated with GYP, indicating that both the total biomass and grain production efficiency are crucial factors for improving yield. Particularly, HI displays a robust correlation with multiple grain-related traits, with values of 243.64 for HI and 227.25 for GYP, reinforcing its importance as an indicator of yield efficiency (Table 4). Similar results were revealed by [22]

Traits like Chlorophyll Content (CLC) (601.27), which shows a strong correlation with GFP (881.91), SL (786.03), and NGS (173.88), suggest that plants with higher chlorophyll content may perform better in photosynthesis, leading to improved grain development. The correlation between CLC and Protein Content (PC) (217.25) emphasizes the link between photosynthetic efficiency and grain quality as reported by [23]. Additionally, Flag Leaf Area (FLA) (346.47), which is a key determinant of photosynthetic capacity, is positively correlated with traits like SL (455.27) and NGS (134.23), further demonstrating its role in promoting plant health and productivity (Table 4).

In terms of quality, Protein Content (PC) (217.25) (Table 4) correlates positively with GYP (164.59), GWS (170.02), and 1000-Grain Weight (TGW) (131.09), indicating that improving protein content may be aligned with increasing yield. These findings collectively suggest that various growth and yield traits are strongly interrelated, and selection for key characteristics such as plant height, chlorophyll content, and harvest index could significantly enhance both yield and grain quality. In summary, the genotypic correlations in this dataset emphasize the complex genetic relationships that govern plant growth and productivity, the results agree with research conducted by [23]. The strong interdependence between traits like heading time (346.46), maturity (377.96), photosynthetic capacity (CLC 601.27), and yield (GYP 164.59) highlights the importance of a multifaceted approach in plant breeding.

Phenotypic correlations

The phenotypic correlation analysis provides insightful relationships between various agronomic traits, revealing the interconnectedness of plant growth and yield characteristics. In this dataset (Table 5), significant negative correlations were observed between Days to 50% Heading (DH) and other key traits such as Chlorophyll Content (CLC), Grain Filling Period (GFP), Plant Height (PH), and Number of Spikelets per Spike (NSS), Spike Length (SL), Flag Leaf Area (FLA), and Grain Yield per Plant (GYP). For instance, DH showed a strong negative correlation with GFP (-521.03), indicating that later heading plants tend to have a longer grain filling period. Additionally, the negative correlation between DH and GYP (-191.67) suggests that later heading varieties might be associated with lower grain yield per plant commemorated with results reported by [24].

Plant Height (PH) also demonstrated significant negative correlations with various traits such as CLC (-215.10), GFP (-150.10), NGS (-196.50), GWS (-142.49), and GYP (-138.87), which highlights that shorter plants may have improved photosynthetic efficiency and higher grain production. A similar negative trend is observed for Days to Maturity (DM), where significant correlations with GYP (-133.30) and other yield-related traits such as 1000-Grain Weight (TGW) (-121.04) suggest that shorter maturity durations might lead to better overall productivity [25, 26].

The Grain Filling Period (GFP) showed the most pronounced negative correlations with other traits (Table 5), including DM (-361.85), PH (-379.75), SL (-796.45), and GYP (-337.96). This reinforces the idea that longer grain filling periods tend to negatively impact plant height and yield-related traits, as longer periods of filling might not always correlate with optimal grain development similar results obtained by [26]. Number of Productive Tillers (NPT) exhibited negative correlations with several traits like PH (-116.05), GWS (-57.42), and GYP (-75.06), which suggests that fewer productive tillers could be linked to better grain weight and overall yield, perhaps due to better resource allocation to fewer tillers. Number of Grains per Spike (NGS) and Grain

Weight per Spike (GWS) also showed negative correlations with GYP (-71.19 for NGS and -126.72 for GWS), which further supports the idea that an increase in these parameters might not always lead to a proportional increase in grain yield.

A strong negative correlation was observed between Chlorophyll Content (CLC) and most other traits such as GFP (-379.75), PH (-215.10), SL (-328.67), and GYP (-138.87), suggesting that chlorophyll content, which is indicative of photosynthetic efficiency, plays a complex role in grain development [27]. Higher chlorophyll content seems to have an inverse relationship with traits related to size and weight, possibly due to the distribution of energy in the plant's various growth processes (Table 5).

Furthermore, Biological Yield (BY) and Harvest Index (HI) displayed negative correlations with GYP (-160.11 and -161.84, respectively), indicating that while biological yield and harvest index are important for determining overall plant productivity, their relationship with grain yield per plant is complex, and an increase in one may not always correlate with increased grain yield. In terms of Protein Content (PC), there were negative correlations with both grain yield traits and other growth parameters, with the most notable being GYP (-123.09). This suggests that higher protein content may sometimes be associated with reduced grain yield per plant. In summary form, the negative correlations between various agronomic traits, including growth parameters, yield components, and grain quality traits, highlight the complex nature of plant development. Selection for one trait, such as shorter days to heading or increased chlorophyll content, could potentially have trade-offs with other traits like grain filling period or grain yield [28].

Pearson correlation

The correlation analysis of various agronomic traits provides valuable insights into the relationships between key plant characteristics and their impact on yield and quality (Table 6). Days to 50% Heading showed a weak positive correlation with Plant Height (0.2362), indicating that later heading varieties tend to be taller. However, it had a negative correlation with Grain Filling Period (-0.3806), suggesting that shorter grain filling periods tend to occur with earlier heading, as reported by [28]. Plant Height exhibited a positive correlation with Flag Leaf Area (0.5126), Number of Grains per Spike (0.6339), and Grain Weight per Spike (0.5017), indicating that taller plants tend to have larger leaf areas, more grains per spike, and heavier grains. It had weaker correlations with Chlorophyll Content (-0.0084) and Protein Content (0.6585), suggesting a minimal association with chlorophyll but a strong positive relationship with protein content.

Days to Maturity exhibited a negative correlation with Grain Yield per Plant (-0.1792) and Biological Yield (-0.224), indicating that longer maturity periods slightly reduce yield. Grain Filling Period had weak positive correlations with Number of Productive Tillers (0.2923) and Number of Spikelets per Spike (0.1533), but negative correlations with Spike Length (-0.0919) and Grain Weight per Spike (-0.0596), suggesting that longer grain filling periods may reduce tillering and spikelet formation [30].

Number of productive tillers was positively correlated with both Grain Yield per Plant (0.7125) and Grain Weight per Spike (0.6927), highlighting the importance of tillers in contributing to overall grain production. Similarly, Flag Leaf Area had strong positive correlations with Grain Weight per Spike (0.5342) and 1000-Grain Weight (0.4738), demonstrating the role of leaf area in enhancing grain development and weight. Chlorophyll Content showed weak negative correlations with Grain Yield per Plant (-0.1642) and Biological Yield (-0.1381), suggesting that higher chlorophyll content could slightly reduce yield.

Grain Weight per Spike was strongly correlated with 1000-Grain Weight (0.761), Biological Yield (0.6895), and Harvest Index (0.603), confirming its key role in determining yield. Additionally, 1000-Grain Weight was positively correlated with Biological Yield (0.6511) and Harvest Index (0.6563), suggesting that heavier grains contribute to better biomass production and seed allocation. Biological Yield itself showed significant positive correlations with both Harvest Index (0.752) and Protein Content (0.5339), underlining the importance of total plant biomass in achieving higher yield and quality (Table 6).

Finally, Harvest Index demonstrated a positive correlation with Grain Yield per Plant (0.5589), reflecting that efficient biomass allocation to seeds enhances yield. Similarly, Protein Content was positively correlated with

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both Grain Yield per Plant (0.6557) and Harvest Index (0.635), suggesting that high protein content in grains is linked to higher overall yield and better resource allocation, similar results observed by [31]. In summary, the correlations indicate that traits such as Plant Height (0.2362), Number of Productive Tillers (0.7125), and Grain Weight per Spike (0.6927) are crucial for improving yield, while Harvest Index (0.752) and Biological Yield (0.6895) play significant roles in maximizing productivity and seed quality.

Path coefficient analysis

The path coefficient analysis provides insightful information regarding the direct (in blue color) and indirect effects of various traits on grain yield and quality (in orange color). Plant height exhibited the highest total contribution of (in ash color) with a significant direct contribution, highlighting its dominant role in influencing yield and other agronomic traits (Figure 5). Days to 50% heading and Grain yield per plant also showed reasonable total contributions. The positive direct contribution for both traits indicates their influence on yield, although their indirect effects are not as strong.

Number of grains per spike had a notable total contribution, with a direct high contribution, emphasizing the potential role that grain number plays in yield determination. This trait's strong direct effect suggests it is a critical target for improvement in breeding programs aimed at enhancing productivity. Similarly, 1000-grain weight and Grain weight per spike showed high total contributions, with direct contributions, reinforcing the importance of these traits in determining overall yield [32]. The Flag leaf area had a total contribution, with a dominant direct effect. This suggests that larger leaf areas directly contribute to higher productivity by improving photosynthesis and biomass production. No. of productive tillers also demonstrated a positive total contribution with a strong direct effect, indicating that increased tillering has a moderate but significant impact on overall yield (Figure 5).

On the other hand, Grain filling period showed a very low total contribution, with both direct and indirect contributions being minimal. This suggests that while it might influence yield in certain contexts, it has a negligible impact in this particular analysis. Similarly, Chlorophyll content showed a negative direct effect and a small total contribution of indicating that higher chlorophyll content may not necessarily lead to improved yield in this context (Figure 5).

Traits like Protein content and Biological yield also displayed relatively high total contributions, driven by both direct and indirect contributions. Protein content, in particular, had a strong direct contribution, suggesting that improving protein content could directly enhance grain quality and yield potential. Biological yield, with a direct contribution, underlines the importance of overall plant biomass in achieving higher yield. In summary, the path coefficient analysis highlights key traits that influence yield and quality, with Plant height, Grain number, and 1000-grain weight emerging as the most influential factors due to their high direct contributions, the findings were similar to [32]. Traits like Flag leaf area and No. of productive tillers also play essential roles, while Grain filling period and Chlorophyll content contribute less significantly. Understanding the direct and indirect relationships among these traits provides valuable guidance for improving crop breeding strategies aimed at optimizing both yield and grain quality (Figure 5).

Table 4: Showing genotypic correlation for combine locations among 16 characters in wheat

Trait	DH	CLC	GFP	DM	FLA	PH	NSS	SL	PC	NPT	NGS	GWS	TGW	BY	HI	GYP
DH	346.44**	205.3429**	377.9615**	502.9663**	97.9481**	486.9273**	449.8096**	346.4725**	601.2696**	101.1007**	170.0154**	131.0888**	208.6751**	243.6425**	217.2465**	164.5933**
CLC	205.3429**	125.4343**	224.9244**	298.5745**	59.5578**	289.1941**	270.2725**	209.0376**	357.6003**	62.9697**	103.7315**	80.7206**	127.0129**	147.9318**	132.1218**	100.8678**
GFP	377.9615**	224.9244**	421.2625**	556.8614**	104.6688**	537.4224**	493.8553**	380.5754**	665.3845**	109.0579**	185.6646**	142.7904**	228.9235**	268.2094**	237.8756**	179.9002**
DM	502.9663**	298.5745**	556.8614**	739.3455**	140.3268**	711.9595**	656.5963**	506.0962**	881.9099**	146.2800**	247.0685**	190.4005**	304.4100**	355.5594**	316.5443**	239.2344**

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FLA	97.9481**	59.5578**	104.6688**	140.3268**	31.0504**	137.0454**	128.0617**	98.9801**	168.3138**	29.8985**	49.4735**	38.2163**	60.3371**	69.9086**	62.4850**	47.8014**
PH	486.9273**	289.1941**	537.4224**	711.9595**	137.0454**	693.5994**	636.1130**	489.5217**	853.5150**	141.6512**	239.5376**	184.4298**	294.5165**	343.9537**	306.7365**	231.8176**
NSS	449.8096**	270.2725**	493.8553**	656.5963**	128.0617**	636.1130**	590.3445**	455.2724**	786.0262**	134.2272**	224.3532**	173.8041**	275.4424**	321.0656**	286.7421**	217.3536**
SL	346.4725**	209.0376**	380.5754**	506.0962**	98.9801**	489.5217**	455.2724**	351.7978**	605.7218**	104.1652**	173.3999**	134.4892**	212.8197**	247.8499**	221.4000**	168.1229**
PC	601.2696**	357.6003**	665.3845**	881.9099**	168.3138**	853.5150**	786.0262**	605.7218**	1063.6618**	173.8790**	294.7859**	226.4551**	363.3256**	424.9074**	378.4065**	286.0074**
NPT	101.1007**	62.9697**	109.0579**	146.2800**	29.8985**	141.6512**	134.2272**	104.1652**	173.8790**	33.0440**	52.5998**	41.5617**	64.1286**	74.4734**	66.7145**	51.3058**
NGS	170.0154**	103.7315**	185.6646**	247.0685**	49.4735**	239.5376**	224.3532**	173.3999**	294.7859**	52.5998**	86.8848**	67.6601**	105.9782**	123.1444**	109.8951**	83.6512**
GWS	131.0888**	80.7206**	142.7904**	190.4005**	38.2163**	184.4298**	173.8041**	134.4892**	226.4551**	41.5617**	67.6601**	53.1144**	82.5620**	95.8508**	85.7625**	65.3621**
TGW	208.6751**	127.0129**	228.9235**	304.4100**	60.3371**	294.5165**	275.4424**	212.8197**	363.3256**	64.1286**	105.9782**	82.5620**	129.7249**	150.6089**	134.6701**	102.3556**
BY	243.6425**	147.9318**	268.2094**	355.5594**	69.9086**	343.9537**	321.0656**	247.8499**	424.9074**	74.4734**	123.1444**	95.8508**	150.6089**	175.6101**	156.7700**	119.4069**
HI	217.2465**	132.1218**	237.8756**	316.5443**	62.4850**	306.7365**	286.7421**	221.4000**	378.4065**	66.7145**	109.8951**	85.7625**	134.6701**	156.7700**	140.4556**	106.8267**
GYP	164.5933**	100.8678**	179.9002**	239.2344**	47.8014**	231.8176**	217.3536**	168.1229**	286.0074**	51.3058**	83.6512**	65.3621**	102.3556**	119.4069**	106.8267**	81.8585**

Table 5: Showing phenotypic correlations for combine locations among 16 characters in wheat

	DH	CLC	GFP	DM	FLA	PH	NSS	SL	PC	NPT	NGS	GWS	TGW	BY	HI	GYP
DH	-293.9464**	-215.1008**	-206.5501**	-521.0252**	-116.0452**	-389.6787**	-452.036**	-374.8998**	-523.3177**	-111.1968**	-196.5006**	-146.8594**	-247.9691**	-250.4953**	-245.2492**	-191.6705**
CLC	-215.1008**	-155.2992**	-150.0958**	-379.7542**	-84.2444**	-283.8907**	-328.6703**	-272.4659**	-380.8067**	-80.0828**	-142.4945**	-106.3107**	-179.9353**	-181.6453**	-177.767**	-138.8733**
GFP	-206.5501**	-150.0958**	-140.1249**	-361.8466**	-81.186**	-272.0292**	-314.5835**	-261.0585**	-363.1563**	-77.2288**	-136.7401**	-101.7498**	-172.7425**	-174.8007**	-170.9017**	-133.3023**
DM	-521.0252**	-379.7542**	-361.8466**	-916.2674**	-205.247**	-687.2432**	-796.449**	-660.9443**	-921.2859**	-196.2655**	-346.5316**	-258.5711**	-437.3397**	-441.9915**	-432.5344**	-337.9567**
FLA	-116.0452**	-84.2444**	-81.186**	-205.247**	-44.7344**	-153.3169**	-177.565**	-147.1979**	-205.9587**	-43.3944**	-76.9176**	-57.4177**	-97.1892**	-98.2547**	-96.1595**	-75.0623**
PH	-389.6787**	-283.8907**	-272.0292**	-687.2432**	-153.3169**	-512.3682**	-596.3019**	-494.8351**	-689.5227**	-146.7589**	-259.3719**	-193.7694**	-327.127**	-330.2488**	-323.3974**	-252.9874**
NSS	-452.036**	-328.6703**	-314.5835**	-796.449**	-177.565**	-596.3019**	-689.583**	-572.8967**	-799.3565**	-169.4574**	-299.9141**	-223.6574**	-378.6901**	-382.7345**	-374.4313**	-292.5545**
SL	-374.8	-272.4	-261.0	-660.9	-147.1	-494.8	-572.8	-474.4	-663.3	-140.3	-248.692**	-185.4	-314.0	-317.3	-310.5	-242.4

	998**	659**	585**	443**	979**	351**	967**	033**	912**	487**		723**	032**	352**	541**	774**
PC	-523.3177**	-380.8067**	-363.1563**	-921.2859**	-205.9587**	-689.5227**	-799.3565**	-663.3912**	-922.1895**	-196.7106**	-347.8099**	-259.7209**	-438.9873**	-443.4506**	-433.9853**	-339.2698**
NPT	-111.1968**	-80.0828**	-77.2288**	-196.2655**	-43.3944**	-146.7589**	-169.4574**	-140.3487**	-196.7106**	-40.4564**	-73.0311**	-54.3365**	-92.4727**	-93.4497**	-91.3961**	-71.19**
NGS	-196.5006**	-142.4945**	-136.7401**	-346.5316**	-76.9176**	-259.3719**	-299.9141**	-248.692**	-347.8099**	-73.0311**	-129.43**	-96.6849**	-164.072**	-165.9809**	-162.3575**	-126.7249**
GWS	-146.8594**	-106.3107**	-101.7498**	-258.5711**	-57.4177**	-193.7694**	-223.6574**	-185.4723**	-259.7209**	-54.3365**	-96.6849**	-71.4159**	-122.3149**	-123.8743**	-121.0412**	-94.2711**
TGW	-247.9691**	-179.9353**	-172.7425**	-437.3397**	-97.1892**	-327.127**	-378.6901**	-314.0032**	-438.9873**	-92.4727**	-164.072**	-122.3149**	-207.1005**	-209.5516**	-204.9984**	-160.1115**
BY	-250.4953**	-181.6453**	-174.8007**	-441.9915**	-98.2547**	-330.2488**	-382.7345**	-317.3352**	-443.4506**	-93.4497**	-165.9809**	-123.8743**	-209.5516**	-211.0725**	-207.1586**	-161.843**
HI	-245.2492**	-177.767**	-170.9017**	-432.5344**	-96.1595**	-323.3974**	-374.4313**	-310.5541**	-433.9853**	-91.3961**	-162.3575**	-121.0412**	-204.9984**	-207.1586**	-202.2754**	-158.262**
GYP	-191.6705**	-138.8733**	-133.3023**	-337.9567**	-75.0623**	-252.9874**	-292.5545**	-242.4774**	-339.2698**	-71.19**	-126.7249**	-94.2711**	-160.1115**	-161.843**	-158.262**	-123.0857**

Table 6: Showing Pearson coefficient correlations for combine locations among 16 characters in wheat

	DH coef	CLC coef	GFP coef	DM coef	FLA coef	PH coef	NSS coef	SL coef	PC coef	NPT coef	NGS coef	GWS coef	TGW coef	BY coef	HI coef	GYP coef
DH																
CLC	0.2362															
GFP	-0.3806	-0.1843														
DM	0.1533	-0.1442	0.1141													
FLA	0.2923	0.4252	-0.1581	-0.0919												
PH	0.2952	0.1506	-0.3673	0.0129	0.1701											
NSS	0.1923	0.4178	-0.161	0.0811	0.3302	0.0862										
SL	0.2659	0.5126	-0.1586	0.0269	0.3802	0.0327	0.429									
PC	-0.1245	-0.0084	0.0487	-0.1306	-0.0685	-0.017	-0.036	-0.126								
NPT	0.0705	0.6339	0.0479	-0.1653	0.3203	0.0051	0.4072	0.539	0.0499							
NGS	0.1546	0.5017	-0.0462	-0.0596	0.4092	0.0014	0.4718	0.5342	0.1221	0.6927						
GWS	-0.0154	0.3808	0.1204	-0.0061	0.281	-0.1136	0.4425	0.4738	-0.117	0.6181	0.6563					
TGW	0.2329	0.6121	-0.1382	-0.0313	0.4546	0.1672	0.5424	0.6359	0.1381	0.6895	0.761	0.6511				

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BY	0.2502	0.6502	-0.224	-0.0578	0.3711	0.3329	0.4627	0.5309	0.0247	0.5878	0.5267	0.3725	0.6689		
HI	0.1767	0.6585	-0.1792	-0.0929	0.3661	0.1789	0.4962	0.5358	0.0873	0.6641	0.61	0.5339	0.752	0.635	
GYP	0.1265	0.5725	-0.0151	-0.0688	0.3721	-0.0034	0.4429	0.5711	0.1642	0.7125	0.603	0.6584	0.6729	0.5589	0.6557

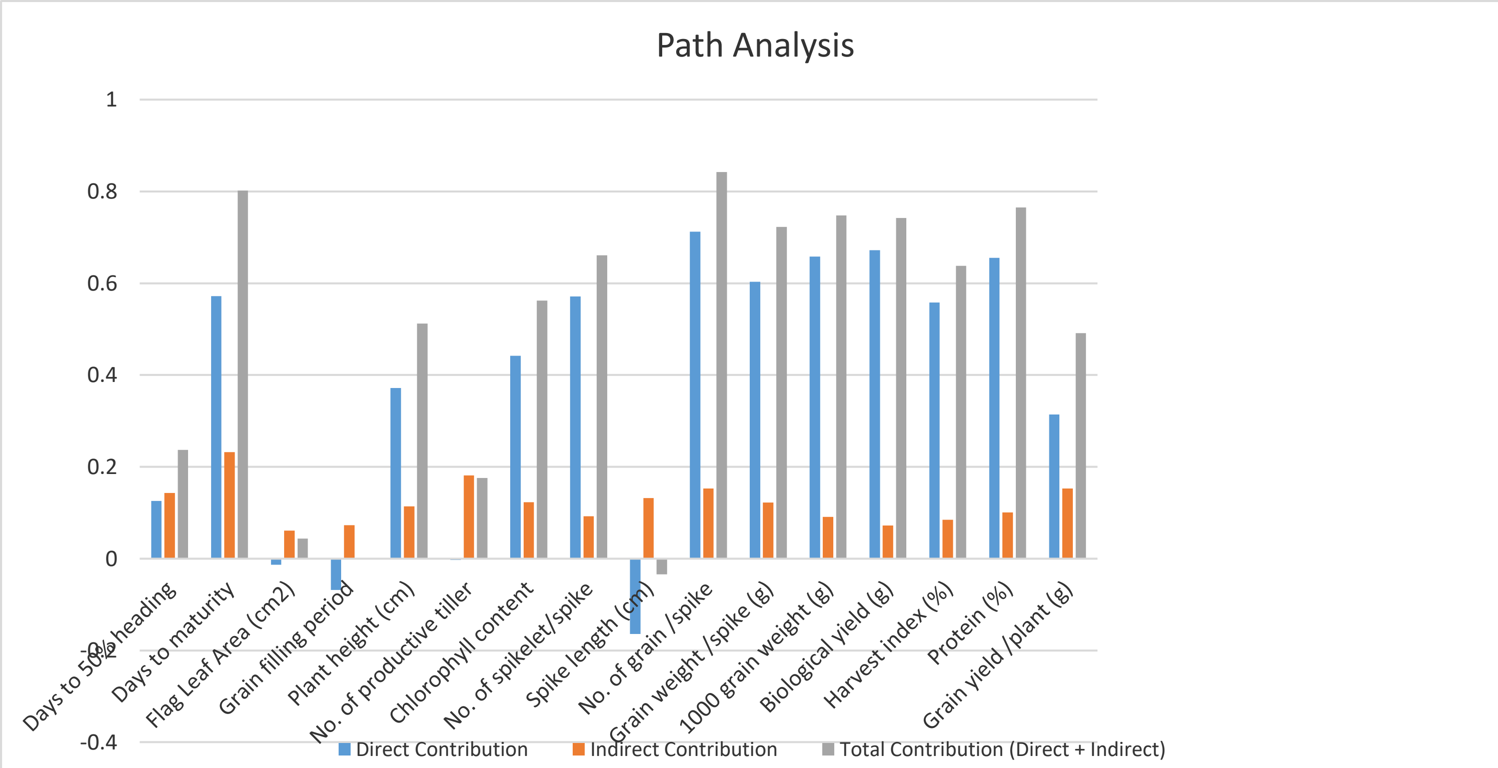

Figure 5: Showing path coefficient (direct and indirect effects) for combine locations among 16 characters in wheat

CONCLUSION

In conclusion, the analyses reveal that plant height, grain number, 1000-grain weight, and harvest index are the most influential traits for improving crop yield. Plant height and grain number directly impact productivity, while harvest index enhances yield efficiency. Chlorophyll content and flag leaf area are important for photosynthesis and grain development, though their effects can be complex. Protein content positively correlates with yield and quality, but its impact on yield is nuanced. Breeding strategies should focus on traits like plant height, grain number, and harvest index, balancing trade-offs between traits like grain filling period and days to heading. A holistic approach targeting these key traits will help optimize both yield and grain quality.

Authors' Contributions

All authors contributed to the study conception and design. TSB contributed to the formal analysis of the experiment, and writing-original draft of the manuscript. IS methodology. SPS comprehensively edited, critically reviewed the manuscript, supervised the project and gave final approval of the version to be published and BSH field layout and seed supply. All authors have read and agreed to publish version of the manuscript.

Declaration

The authors declare no conflict of interest

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