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Estimation of Genetic and Phenotypic Correlation Coefficients and Path Analysis of Yield and Yield Contributing Traits of Bread Wheat (*Triticum aestivum* L.) Genotypes

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Abstract: Thirty bread wheat genotypes were tested to assess the association among yield and yield contributing traits and determining the direct and indirect effect of the traits on the grain yield. The genotypes were grown in alpha-lattice design at Tongo sub-center of Assosa Agricultural Research Center and Kulumsa Agricultural Research Center in 2015. Grain yield showed significant ($p \leq 0.01$) positive phenotypic correlations with thousand kernels weight, above ground biomass, harvest index, hectoliter weight and plant height at each location except for kernels per spike at Tongo and days to maturity at Kulumsa. Similarly, grain yield showed significant ($p \leq 0.01$) positive genotypic correlations with 1000 kernel weight, above ground biomass, harvest index,, hectoliter weight and plant height at Tongo and only with above ground biomass and harvest index at Kulumsa. Likewise, significant ($p \leq 0.01$) positive and negative phenotypic and genotypic correlations between the yield components were observed at each location. As per the path analysis above ground biomass and harvest index showed high positive phenotypic direct effect on grain yield at each location whereas low positive phenotypic direct effect observed for characters plant height and number of kernel per spike at Tongo and hectoliter weight at Kulumsa. Similarly, at genotypic level above ground biomass and harvest index showed highly significant direct effect on the grain yield at each location. Generally, it has been observed the presence of relationships in the tested traits of the genotypes studied. Hence, Selection and hybridization on those genotypes based on the trait with high positive correlation coefficient and direct effect on grain yield can be recommended for farther yield improvement of bread wheat at respective location.

Keywords: Association, Direct and Indirect Effect, Traits

1. Introduction

Wheat is an important cereal crop which is cultivated worldwide and was one of the first crops to be domesticated some 10000 years ago. World wheat production is based almost entirely on two modern species: common or hexaploid bread wheat (*Triticum aestivum* L, 2n=6x=42, AABBDD) and durum or tetraploid wheat (*T. turgidum* subsp. durum, 2n=4x=28, AABB). Unlike rice and maize, which prefer tropical environment, wheat is extensively grown in temperate regions occupying 17% of all crop acreage worldwide. It is the staple food for 40% of the world's population [11, 19]. Currently it is also becoming most important cereals grown on a large scale [8], because of its significance as cash crop, high level of production per unit area, its major role in supplying the dietary requirements of the society. Wheat is the second only to rice which provides 21% of the total food calories and 20% of the protein for more than 4.5 billion people in 94 developing countries [4]. Food consumption of wheat is projected at 488 million tonnes, 1.3 percent higher than in the 2014 season, keeping the average per capital level steady at 67.6 kg [7]. Global wheat grain production must increase 2% annually to meet the requirement of consistently increasing world population (around 9 billion) till 2050 [22].

Wheat is an important staple food crop and the third highest source of grain-based calories behind corn and sorghum in Ethiopia. It accounts for a little more than 20 percent of the total calorie supply. 60 percent of production is used for household consumption, 20 percent is sold to the market, while the balance is used for seed, in-kind wages, animal feed and other uses. Wheat bran from commercial wheat millers is used as one of the ingredients in commercially-produced, compound animal feed [10]. It grows on 1.6 million hectares of production area with a total production of 3.8 million metric tons and ranks fourth in both area and production among cereal crops in different regions of Ethiopia [5]. Ethiopian wheat production self-sufficiency is only 75 percent and the remaining 25 percent of wheat imported commercially and through food aid and shares of total cereal consumption is increased by 20% in resent year, making it the second most consumed cereal in Ethiopia after corn [26]. Therefore, to meet the self-sufficiency, growing demand of manufacturing industries and reduce the importing, increasing the yield potential would be the solution in the long-run. Farther more increasing wheat production is important to the economic stability and food security of Ethiopia.

Grain yield and its quality are the principal characters of a cereal crop [20]. They are complex quantitative characters, which are influenced by a number of yield contributing characters. Hence, the selection for desirable genotypes should not only be based on yield alone, and the other yield components should also be considered. Direct selection for yield is often misleading in wheat because wheat yield is polygenically controlled. For effective utilization of the genetic stock in crop improvement, information of mutual association between yield and yield components is necessary. It is therefore, necessary to know the correlation of various component characters with yield and among themselves. The correlation coefficients between yield and yield components usually show a complex chain of interacting relationship. Path coefficient analysis partitions the components of correlation coefficient into direct and indirect effects and illuminates the relationship in a more meaningful way [13]. However, no character association studies have been conducted at Benishangul Gumze Regional State. Therefore, such information is essential for identification of association among traits for further bread wheat improvement particularly, in the region and generally in the country. Therefore, the current study was carried out to estimate the magnitude of correlation between grain yield and yield contributing characters, and to partition the correlation coefficients of yield with its related traits into direct and indirect effects through path analysis.

2. Materials and Methods

Table 1. *The bread wheat genotypes to be studied were listed below.*

Entry	Name	Pedigree/Genotypes
1	Hidasse	ETBW5795(check 1)
2	ETBW 6861	WAXWING*2/HEILO
3	ETBW 8506	AGUILAL/FLAG-3
4	ETBW 8507	DURRA-4
5	ETBW 7120	QAFZAH-23/SOMAMA-3
6	ETBW 8508	REYNA-8
7	ETBW 7213	CHAM4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB
8	ETBW 8509	REYNA-29
9	ETBW 7038	ATTILA/3*BCN//BAV92/3/TILHI/5/BAV92/3/PRL/SARA//TSI/VEE#5/4/CROC_1/AE.SQUARROSA (224)//2*OPATA
10	ETBW 8510	HIJLEEJ-1
11	ETBW 7058	ROLF07//TAM200/TUI/6/WBLL1/4/HD2281/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/TACUPETO F2001
12	ETBW 8511	BOW #1/FENGKANG 15/3/HYS//DRC*2/7C
13	ETBW 7147	CROC-1/AE.SQUARROSA(224)// OPATA/3/QAFZAH-21/4/SOMAMA-3
14	ETBW 8512	BABAX/LR42//BABAX*2/3/KURUKU/4/KINGBIRD #1
15	ETBW 7871	PAURAQ/4/PFAU/SERI.1B//AMAD/3/WAXWING
16	ETBW 8513	MUTUS//WBLL1*2/BRAMBLING/3/WBLL1*2/BRAMBLING
17	ETBW 6940	UTIQUE 96/FLAG-1
18	ETBW 8514	TUKURU//BAV92/RAYON/3/WBLL1*2/BRAMBLING/4/WBLL1*2/BRAMBLING
19	ETBW 7368	D. 56455
20	ETBW 8515	BECARD/3/PASTOR//MUNIA/ALTAR 84
21	ETBW 7364	ACSAD1115
22	ETBW 8516	KACHU/KIRITATI
23	ETBW 7194	VAN'S'/3/CNDR'S'/ANA//CNDR'S'/MUS'S'/4/TEVEE-5
24	ETBW 8517	FRNCLN*2/TECUE #1
25	ETBW 7101	KAMB2/PANDION
26	ETBW 8518	SUP152/AKURI//SUP152
27	ETBW 7872	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
28	ETBW 8519	ATTILA/3*BCN*2//BAV92/3/KIRITATI/WBLL1/4/DANPHE
29	ETBW 6937	AGUILAL/FLAG-3
30	Danda'a	DANPHE#1(check 2)

The experimental material comprised of thirty bread wheat genotypes. Trials were planted in July 04, 2015 at Kulumsa Agricultural research center and August 18, 2015 at Tongo, sub-center of Assosa Agricultural Research Center. [14] reported Alpha lattice Design provided smaller standard errors of differences, coefficients of variation and error mean squares as compared to RCBD providing efficiency in comparing different entries/lines. Therefore this design should be employed while conducting field research trials on different crops when number of varieties in the experiments is large. Therefore in the current study, thirty genotypes were grown in Alpha-Lattice Design with three replications. Each experimental unit consisted six rows of 2.5 m length with 20 cm spacing between rows. Data were collected from the central four rows for the parameters days to heading, days to maturity, grain filling period, grain yield, 1000 kernel weight, above ground biomass yield, harvest index, hectoliter weight and from randomly sampled plants for the characters; tillers per pant, plant height, kernel per spike, spikelet per spike, spike length and spikes per plant. 1.5 m alleys were left between reps. Non-experimental variables such as seed and fertilizer rates were used as recommended for the specific testing sites. Hence, 73/69kgha^{-1} N/P_2O_5 were used for Kulumsa and 60/69kgha^{-1} N/P_2O_5 for Tongo. A seed rate of 125kgha^{-1} was used at both locations.

2.1. Statistical Data Analysis

Correlation studies

The character associations represented by correlation coefficient between different pairs of characters at the genotypic and phenotypic levels were calculated from the genotypic, phenotypic and environmental covariance.

Covariance simply indicates whether two related characters tend to vary together i.e. variation occurring simultaneously in two variables or characters is referred to as covariance. The analysis of covariance between all possible pairs followed the same form as the variance analysis. Mean product expectation of the covariance analysis is analogous to the mean square expectation of the analysis of variances. Thus, estimate of genotypic and phenotypic covariance component between two traits ($\sigma g\,1.2$, $\sigma p1.2$) were derived in the same fashion as those for the corresponding variance components. These covariance components were substituted in the following formula to calculate the genotypic and phenotypic correlation as described by [24].

$$\text{Genotypic r} = \frac{\text{Cov}_{g12}}{\sqrt{(\sigma^2 g_1).\sigma^2 g_2}}$$

Where, Cov_{g12} is the genotypic covariance between two traits, $\sigma^2 g_1$ is the genotypic variance of the first trait, and $\sigma^2 g_2$ is the genotypic variance of the second trait; and

$$\text{Phenotypic r} = \frac{\text{Cov}_{p12}}{\sqrt{(\sigma^2 p_1).\sigma^2 p_2}}$$

Where, Cov_{p12} is the phenotypic covariance of the progeny means between the two traits, and $\sigma^2 p_1$ and $\sigma^2 p_2$ are the phenotypic variance for each trait.

The calculated phenotypic correlation values were tested for its significance using t-test:

$$t = \frac{r_p}{SE(r_p)}$$

Where, r_p = Phenotypic correlation; SE (r_p) = Standard error of phenotypic correlation was obtained using in the following procedure [24]:

$$SE(r_p) = \sqrt{\frac{(1 - r_p^2)}{(n-2)}}$$

Where, n is the number of genotypes tested, r_p is phenotypic correlation coefficient.

The coefficients of correlations at genotypic levels were tested for their significance using the formula described by Robertson (1959) as indicated below:

$$t = \frac{r_{gxy}}{\text{SEr}_{gxy}}$$

The calculated "t" value was compared with the tabulated "t" value at (n-2) degree of freedom at 5% level of significance. Where, n = number of genotypes

$$SEr_{gxy} = \sqrt{\frac{(1 - r_{gxy}^2)}{(2H_x.H_y)}}$$

Where, H_x = Heritability of trait x
H_y = Heritability of trait y

2.2. Path Coefficient Analysis

Path coefficient analysis were performed using the phenotypic and genotypic correlation coefficients to know the direct and indirect effect of yield components on grain yield using the general formula of [6] by considering grain yield per hectare as dependent variable. The path coefficients were obtained by solving the following simultaneous equations, which express the basic relationship between correlation and path coefficient.

$$rij = pij + \sum rik.pkj$$

Where, r_{ij} = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficient.

p_{ij} components of direct effects of the independent character (i) on the dependent variable (j) as measured by the genotypic path coefficient; and $\Sigma\, rik.pkj$ =summation of components of indirect effects of a given independent character (i)on a given dependent character (j) via all other independent character (k)

The residual effect, which determines how best the causal factors account for the variability of the dependent factor, was calculated using the following formula.

$$1 = p2r + \Sigma piy.riy$$

Where, P^2r is the residual factor, P_{iy} is the direct effect of yield by i^{th} trait, and r^{iy} is the correlation of yield with the i^{th} trait.

3. Results and Discussion

3.1. Association of Characters

Estimates of genotypic and phenotypic correlation coefficients between each pair of characters were studied for studied locations (Table 2 and 4). In most cases, the phenotypic correlation coefficients were less in magnitude than the genotypic correlation coefficients that revealed the presence of inherent genetic relationships among various characters and less dependent on environment. In this study, at both locations genotypic correlation coefficients were found to be higher in magnitude than that of phenotypic correlation coefficients in most of the traits, which clearly indicated the presence of inherent association among various characters.

3.2. Correlation of Yield with Yield Related Traits

The results at Tongo indicated that at phenotypic level there was significant correlation between thousand kernel weight (r=0.50), above ground biomass (r=0.69), harvest index(r=0.85), hectoliter weight (r=0.58), plant height (r=0.47) and kernels per spike (r=0.25) with grain yield (Table 2). [27] reported significant positive phenotypic correlations of above ground biomass, kernels per spike and plant height with grain yield. The same outer reported non-significant correlation of thousand kernel weight and harvest index with grain yield which contradicted with this finding. [20] also reported positive correlations of grain yield with above ground biomass, harvest index, kernel per spike, which in agreement with this study for those traits. [9] reported high biomass is an especially valuable trait to raise yield potential of bread wheat, because HI is approaching the limit of approximately 0.64, and there has been no significant progress since the early 1990s (0.50−0.55). Recent yield improvement has showed an association with increased biomass [23]. Among the studied character harvest index is the most important physiological trait. Similar association in winter wheat was also reported by [13] in spring wheat indicating improvement of these characters can increase the grain yield of wheat. Grain yield showed non-significant positive phenotypic correlations with the rest of the character.

Days to heading showed significant positive correlation with days to maturity (r= 0.88), above ground biomass (r=0.48), plant height (r=0.39), spikelet's per spike(r=0.64), kernels per spike (r=0.30) spike length (r=0.62) and negative significant correlation with grain filling period (r=-0.59), 1000 kernel weight (r=-0.45), harvest index (r=-0.36) and hectoliter weight (r=-22). The result is in agreement with [3] for the association of days to heading with days to maturity and grains filling period. Days to maturity showed negative significant correlation with 1000 kernels weight (r=-0.32), harvest index (r=- 0.34), tiller per plant and positive significant correlation with plant height (r=0.38), number of kernels per spike (r=0.30) and number of spikelets per spike (r=0.73). Grains filling period showed signs of significant positive and negative correlation with 1000 kernel weight and spike length, respectively. 1000 kernel weight showed significant positive correlation with harvest index (0.62), hectoliter weight (r=0.59), tiller per plant (r=0.23), number of spike per plant and negative correlation with spikelets per spike and spike length. Plant height exhibited highly significant positive association with spikelets per spike, kernels per spike and spike length. [27] reported significant positive phenotypic association of plant height with spike length, biological yield, tillers per m^2 and grains. Spike length and kernel per spike showed highly positive correlation with each other which is in accordance with the finding of [27].

At the genotypic level, grain yield showed highly positive significant correlation with thousand kernel weight (r=0.53), above ground biomass (r=0.67), harvest index (r=0. 0.88) and hectoliter weight (r=0.64) and significant association with the plant height (Table 2). [27] reported significant positive genotypic correlations of above ground biomass, kernels per spike and plant height with grain yield.

Days to heading showed significant positive correlation with days to maturity (r= 0.92), above ground biomass (r=0.61), plant height (r = 0.47), spikelet's per spike(r=0.74), spike length (r=0.67) and negative significant correlation with grain filling period (r=-0.64), 1000 kernel weight (r= -0.54) and harvest index (r = -0.43). There was highly significant positive correlation between grain filling period and 1000 kernel weight both at genotypic and phenotypic level. 1000 kernel weight showed highly significant positive correlation with harvest index (r = 0.66) and hectoliter weight(r = 0.59). Plant height showed highly significant positive coloration with above ground biomass, spikelet per spike, kernel per spike and spike length. The result is in line with the finding of [27] for above ground biomass and spike length. On the other hand, this finding contradicted with [2, 20] who reported weak above ground biomass association with plant height, indicating that more biomass can be achieved in short plants, which is essential for lodging resistance. Spikelet per spike showed positive highly significant association with kernel per spike and spike length at genotypic level.

At Tongo Environmental correlations were computed to estimate the association of two traits due to environmental effects (Table 3). Grain yield had positive and significant environmental correlation with days to maturity (r= 0.34), 1000 kernel weight (r=0.43), harvest index (r=0.80), hectoliter weight (r=0.48), plant height (r=0.49), spikelets per spike (r=0.33) and above ground biomass yield (r=0.75). It showed non-significant environmental correlation with rest of the character. Plant height had highly significant positive environmental correlation with 1000 kernel weight, harvest index, hectoliter weight, above ground biomass yield, spikelets per spike, kernels per spike, spike length and non-significant environmental correlation with rest of the character. Grain filling period showed negative environmental correlation with days to heading.

Table 2. *Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of the 14 quantitative traits of bread wheat genotypes at Tongo 2015/16 cropping season.*

Traits	HD	MD	GFP	GY	TKW	AGB	HI	HW	TPP	PH	SPS	KPS	SL	SPP
HD	1	0.92**	-0.64**	-0.03	-0.54**	0.61**	-0.43*	-0.31	-0.22	0.47**	0.74**	0.35	0.67**	-0.28
MD	0.88**	1	-0.29	-0.05	-0.43*	0.60**	-0.45*	-0.36	-0.15	0.44*	0.79**	0.29	0.67**	-0.20
GFP	-0.59**	-0.15	1	-0.02	0.49**	-0.31	0.17	0.05	0.26	-0.29	-0.25	-0.29	-0.33	0.30
GY	-0.02	0.02	0.06	1	0.53**	0.67**	0.88**	0.64**	0.05	0.46*	0.03	0.26	0.10	0.09
TKW	-0.45**	-0.32**	0.41**	0.50**	1	0.06	0.66**	0.59**	0.33	0.05	-0.37*	-0.33	-0.30	0.36*
AGB	0.48**	0.51**	-0.15	0.69**	0.10	1	0.24	0.30	-0.05	0.66**	0.51**	0.42*	0.53**	-0.09
HI	-0.36**	-0.34**	0.19	0.85**	0.62**	0.23*	1	0.66**	0.09	0.16	-0.29	0.07	-0.23	0.16
HW	-0.22*	-0.25*	0.05	0.58**	0.59**	0.29**	0.60**	1	-0.06	0.14	-0.12	0.01	-0.04	-0.02
TPP	-0.098	-0.08	0.07	0.03	0.23*	-0.06	0.07	0.05	1	-0.003	-0.34	-0.27	-0.37*	0.95**
PH	0.39**	0.38**	-0.17	0.47**	0.13	0.58**	0.22*	0.26*	0.008	1	0.48**	0.51**	0.63**	-0.04
SPS	0.64**	0.73**	-0.09	0.10	-0.24*	0.45**	-0.17	-0.06	-0.20	0.42**	1	0.51**	0.81**	-0.39*
KPS	0.30**	0.30**	-0.13	0.25*	-0.19	0.33**	0.10	0.07	-0.16	0.50**	0.51**	1	0.50**	-0.25
SL	0.62**	0.50**	-0.27*	0.06	-0.25*	0.37**	-0.18	0.03	-0.08	0.56**	0.67**	0.47**	1	-0.40*
SPP	-0.15	-0.13	0.09	0.07	0.26*	-0.06	0.12	0.06	0.94**	-0.03	-0.24*	-0.17	-0.12	1

Note, ** and * indicates highly significant at 1% and significant at 5% probability levels, respectively. DH: days to heading, DM: days to maturity, GFP: grain filling period, GY: grain yield, TKW: 1000 kernel weight, AGB: above ground biomass ($kgha^{-1}$), HI: harvest index, HW: hectoliter weight, TPP: tillers per plant, PH: plant height (cm), SPS: spikelets per spike, KPS: kernels per spike, SL: spike length, SPP, spikes per plant.

Table 3. *Environmental correlation coefficients of the 14 quantitative traits of bread wheat genotypes at Tongo 2015/16 cropping season.*

Traits	HD	MD	GFP	GY	TKW	AGB	HI	HW	TPP	PH	SPS	KPS	SL	SPP
HD	1													
MD	0.44**	1												
GFP	-0.61**	0.44**	1											
GY	0.06	0.34**	0.24	1										
TKW	-0.03	0.23	0.23	0.43**	1									
AGB	0.18	0.35**	0.12	0.75**	0.19	1								
HI	-0.07	0.21	0.25*	0.80**	0.49**	0.22	1							
HW	0.04	0.09	0.04	0.48**	0.59**	0.27*	0.49**	1						
TPP	0.24	0.08	-0.16	0.02	0.10	-0.07	0.04	0.20	1					
PH	0.07	0.19	0.09	0.49**	0.34**	0.44**	0.37**	0.48**	0.02	1				
SPS	0.04	0.41**	0.32*	0.33*	0.21	0.32*	0.24	0.09	0.02	0.27*	1			
KPS	0.11	0.36**	0.21	0.21	0.19	0.16	0.21	0.19	0.0004	0.46**	0.50**	1		
SL	0.29*	0.20	-0.11	-0.03	-0.09	-0.03	-0.003	0.21	0.45**	0.35**	0.12	0.38**	1	
SPP	0.23	0.03	-0.20	0.05	0.09	-0.04	0.06	0.17	0.93**	-0.01	0.03	-0.05	0.43**	1

Note, ** and * indicates highly significant at 1% and significant at 5% probability levels, respectively. DH: days to heading, DM: days to maturity, GFP: grain filling period, GY: grain yield, TKW: 1000 kernel weight, AGB: above ground biomass ($kgha^{-1}$), HI: harvest index, HW: hectoliter weight, TPP: tillers per plant, PH: plant height (cm), SPS: spikelets per spike, KPS: kernels per spike, SL: spike length, SPP, spikes per plant.

For the experiment done at Kulumsa, there was significant correlation between few traits and grain yield at both phenotypic and genotypic level (Table 4). At phenotypic level, grain yield showed highly significant and positive correlation with days to maturity (r = 0.27), above ground biomass (r = 0.54) and harvest index (r = 0.49). [1] reported biomass yield (r= 0.8) had positive and high correlation with grain yield. [18] also reported highly significant positive phenotypic correlation of grain yield with above ground biomass and harvest index which support this finding. In the present study grain yield showed significant positive correlation with hectoliter weight and plant height. This indicated that selection based on these characters could be more efficient to maximize grain yield of wheat. The grain yield showed non-significant association with the rest of the character.

Days to heading showed significant positive correlation with days to maturity, above ground biomass, plant height, and spikelet's per spike and spike length at both genotypic and phenotypic level. However its association with grain filling period, 1000 kernel weight, harvest index and hectoliter weight were negative, this implied that increasing the days to heading would increase days to maturity, above ground biomass, plant height, spikelet's per spike and spike length as the expense of grain filling period, 1000 kernel weight, harvest index and hectoliter weight. This association is similar at each location (Tongo and Kulumsa) with the diffidence of correlation coefficient value. [3, 17] reported highly significant association of days to heading with days to maturity and spikelet per spike.

Days to maturity showed positive significant correlation with 1000 kernel weight and above ground biomass at phenotypic level. It also showed significant correlation with above ground biomass at genotypic level. This probably indicated that longer phonological period could result in large biomass accumulation with the maximum contribution to 1000 kernel weight and grain yield. Grain filling period showed highly significant and positive correlation with hectoliter weight and 1000 kernel weight at both genotypic and phenotypic level suggesting that longer interval between days to heading and days to maturity had high contribution for increments of hectoliter weight and 1000 kernel weight.

Harvest index had significant negative correlation with above ground biomass and significant positive correlation with 1000 kernel weight at both genotypic and phenotypic level. [16] reported Biomass per plant showed positive and highly significant correlation coefficients with grain yield per plant and negative association with harvest index on his experiment in titled with estimation of genetic and phenotypic correlation coefficients among grain yield and its components in bread wheat. [1, 27] also reported negative association of above ground biomass and harvest index. This indicates that increments in the above ground biomass reduce the harvest index ratio. Hectoliter weight showed highly significant and positive correlation with 1000 kernel weight and harvest index at both phenotypic and genotypic level.

Plant height showed significant positive correlation with above ground biomass at both genotypic and phenotypic level and significant negative correlation with 1000 kernel weight, harvest index and hectoliter weight at phenotypic level. This was clearly indicate that larger above ground biomass is the result of increment in plant height. Similarly, [18] reported a positive significant association of plant height and biomass yield (r=0.34). The same author indicates positive association of 1000 kernel weight with plant height which contradicted with this study. Number of kernel per spike exhibited highly significant and positive correlation with tiller per plant and spikelet per spike and significant negative correlation with 1000 kernel weight which has often been seen in wheat. Similar report was indicated by [20], 1000 kernel weight was consistently negatively associated with grains per spike.

Spike length revealed significant positive association with plant height, spikelet per spike and kernel per spike and significant negative correlation with1000 kernel weight at phenotypic level. [18] reported positive and significant correlation of peduncle length with plant height and kernels per spike, suggesting the genotypes with longer peduncle length may also be longer in plant height with more number of kernels per spike. It also showed significant positive correlation at genotypic level with plant height and spikelet per spike. Tiller per plant and spike per plant had highly significant and positive association at both genotypic level and phenotypic level indicating increasing number of tillers per plant could be result in high number of spike per plant. Indicating a key function of tillering is to establish final spike number per plant [20].

Table 4. *Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of the 14 quantitative traits of bread wheat genotypes at Kulumsa Centre 2015/16 cropping season.*

Traits	HD	MD	GFP	GY	TKW	AGB	HI	HW	TPP	PH	SPS	KPS	SL	SPP
HD	1	0.69**	-0.59**	0.06	-0.76**	0.49**	-0.44*	-0.57**	0.01	0.59**	0.34	0.18	0.40*	-0.02
MD	0.55**	1	0.17	0.26	-0.36	0.49**	-0.22	-0.19	-0.05	0.54	0.14	0.18	0.29	-0.003
GFP	-0.56**	0.31**	1	0.21	0.63**	-0.13	0.35	0.56**	-0.07	-0.21	-0.30	-0.05	-0.21	0.02
GY	0.03	0.27**	0.17	1	0.20	0.56**	0.48**	0.24	0.06	0.19	-0.18	0.10	0.02	0.17
TKW	-0.67**	-0.26*	0.51**	0.17	1	-0.27	0.48**	0.54**	0.08	-0.35	-0.59**	-0.24	-0.30	0.15
AGB	0.40**	0.37**	-0.08	0.54**	-0.16	1	-0.44*	-0.35	0.21	0.53**	0.14	0.25	0.19	0.25
HI	-0.36**	-0.08	0.25*	0.49**	0.34**	-0.46**	1	0.61**	-0.13	-0.35	-0.37*	-0.16	-0.14	-0.03
HW	-0.48**	-0.09	0.40**	0.26*	0.45**	-0.20	0.47**	1	-0.27	-0.36	-0.22	-0.0097	-0.16	-0.06
TPP	-0.0064	-0.04	-0.05	0.07	0.004	0.06	0.025	-0.13	1	-0.002	-0.31	0.21	0.07	0.93**
PH	0.55**	0.43	-0.18	0.23*	-0.28**	0.48**	-0.24*	-0.31**	-0.003	1	0.34	0.15	0.49**	0.08
SPS	0.28**	0.12	-0.24*	-0.06	-0.49**	0.14	-0.22*	-0.16	-0.10	0.28**	1	0.37*	0.40*	-0.30
KPS	0.16	0.13	-0.08	0.12	-0.22*	0.18	-0.07	-0.02	0.26*	0.12	0.39**	1	0.35	0.29
SL	0.35**	0.19	-0.20	0.11	-0.30**	0.13	0.005	-0.14	0.20	0.42**	0.43**	0.45**	1	0.07
SPP	-0.013	-0.02	-0.02	0.15	0.04	0.11	0.06	-0.03	0.93**	0.08	-0.10	0.32**	0.24*	1

Note, ** and * indicates highly significant at 1% and significant at 5% probability levels, respectively. DH: days to heading, DM: days to maturity, GFP: grain filling period, GY: grain yield, TKW: 1000 kernel weight, AGB: above ground biomass (kgha^{-1}), HI: harvest index, HW: hectoliter weight, TPP: tillers per plant, PH: plant height (cm), SPS: spikelets per spike, KPS: kernels per spike, SL: spike length, SPP, spikes per plant.

Table 5. *Environmental correlation coefficients of the 14 quantitative traits of bread wheat genotypes at Kulumsa 2015/16 cropping season.*

Traits	HD	MD	GFP	GY	TKW	AGB	HI	HW	TPP	PH	SPS	KPS	SL	SPP
HD	1													
MD	-0.12	1												
GFP	-0.54**	0.65**	1											
GY	-0.12	0.31*	0.08	1										
TKW	-0.09	0.12	0.11	0.10	1									
AGB	0.003	0.06	0.06	0.46**	0.22	1								
HI	-0.13	0.26*	0.04	0.52**	-0.08	-0.50**	1							
HW	-0.13	0.18	-0.003	0.29*	0.12	0.18	0.15	1						
TPP	-0.08	-0.04	-0.01	0.10	-0.20	-0.21	0.28*	0.09	1					
PH	0.35**	0.06	-0.08	0.36**	0.06	0.31*	0.09	-0.16	-0.006	1				
SPS	-0.02	0.03	-0.06	0.30*	-0.09	0.12	0.17	-0.003	0.34**	0.05	1			
KPS	0.15	0.04	-0.14	0.17	-0.20	0.05	0.08	-0.03	0.32*	0.04	0.46**	1		
SL	0.27*	-0.03	-0.18	0.30*	-0.35**	-0.002	0.28*	-0.11	0.41**	0.26*	0.52**	0.62**	1	
SPP	0.004	-0.07	-0.09	0.13	-0.25	-0.15	0.24	0.03	0.92**	0.09	0.32*	0.37**	0.50*	1

Note, ** and * indicates highly significant at 1% and significant at 5% probability levels, respectively. DH: days to heading, DM: days to maturity, GFP: grain filling period, GY: grain yield, TKW: 1000 kernel weight, AGB: above ground biomass (kgha^{-1}), HI: harvest index, HW: hectoliter weight, TPP: tillers per plant, PH: plant height (cm), SPS: spikelets per spike, KPS: kernels per spike, SL: spike length, SPP, spikes per plant.

Environmental correlations were computed to estimate the magnitude of environmental effects on a pair of characters (Table 5). Grain yield had positive and significant environmental correlation with days to heading (r= 0.31), harvest index (r=0.52) hectoliter weight (r=0.29), plant height (r=0.36) spikelets per spike (r=0.30) and above ground biomass yield (r=0.46). It showed no significant environmental correlation with rest of the character. Tillers per plant had highly significant positive environmental correlation with spikelets per spike, kernels per spike, spike length, spikes per plant and harvest index. No significant environmental correlation with rest of the character. Grain filling period showed negative environmental correlation with days to heading.

3.3. Path Coefficient Analysis

Phenotypic and genotypic correlations were analyzed by path coefficient analysis technique, to identify the important yield attributes by estimating the direct effects of traits contributing to grain yield and separating the direct from the indirect effects through other related traits by partitioning the correlation coefficient and finding out the relative importance of different characters as selection criteria. In most cases, the magnitudes of the phenotypic direct and indirect effects were slightly greater than the genotypic effects. Due to complexity, grain yield can be divided into a number of relatively simpler components either numerically or physiologically [25]. Numerical components include grain number per unit land area and individual grain weight; the former has four sub-components, i.e. plants per unit land area, spikes per plant, spikelets per spike and grains per spikelet. The other approach is physiological, considering yield as a product of biomass and harvest index. Thus, factors affecting these components would determine final grain yield indirectly. Grain yield is the complex outcome of varies characters, was considered as resultant character. The rest character indicating significant associations with grain yield were considered as causal characters. At both locations the residual effect was not significantly high indicating that almost all traits that influenced grain yield were considered.

3.4. Phenotypic Direct and Indirect Effects of Various Characters on Grain Yield

At Tongo above ground biomass (0.518) and harvest index (0.738) had high direct effect on grain yield indicating the relationship between these traits as good contributors to grain yield (Table 6). These characters could be considered as main components of selection in a breeding program for obtaining higher grain yield. Compromise of significant high positive correlation and considerable direct effects of above ground biomass and harvest index on grain yield justified that the need to identify the nature of relationships between yield and yield related traits by using path analysis. In addition, low positive direct effect was exhibited by plant height and number of kernel per spike and contributed indirectly to the grain yield via above ground biomass and harvest index. [2] reported on positive direct effect and highly significant positive correlation coefficient of number of grains per spike and plant height with grain yield which are in relation with this study. The direct selection for these traits might be slightly effective. Hectoliter weight had positive association with grain yield but, it showed negative direct effect on grain yield indicating its negative direct effect was counterbalanced by its positive indirect effect via above ground biomass, harvest index, pant height and kernel per spike. Similarly, 1000 kernel weight showed positive association with grain yield, but it exhibited negative direct effect on grain yield and considerable indirect effect via harvest index (0.458) and above ground biomass (0.05). [3] reported thousand-grain weight exhibited negative direct effect on grain yield which are in agreement with this study. Selection of for this trait might not be improving grain yield of wheat genotypes. Therefore, the direct selection of this character might be ineffective. But its considerable indirect effects should be considered for selection. This was not in line with the work of [21] who reported 1000 grain weight and spikelet per spike (0.457) had the highest direct effect (0.629) on grain yield, except for spikelet per spike which had the low positively direct effect on grain yield. Similarly, [2] also reported significant direct effect of 1000 kernel weight on the grain yield which contradicted with this study.

At Kulumsa above ground biomass (0.979**)** and harvest index (0.931**)** had direct effect on grain yield (Table 7). This positive phenotypic direct effect of above ground biomass and harvest index on grain yield is in agreement with the result showed at Tongo. This justifies that the presence of relationship between these characters and grain yield as depicted by positive and significant correlations of grain yield with harvest index and above ground biomass yield, there by direct selection through these characters would result reasonable effect on grain yield. The finding is in line with [1, 18] who reported biomass yield and harvest index exerted highest positive direct effect on grain yield. Hectoliter weight showed low positive phenotypic direct effect (0.015) and contributed indirectly to the grain yield via harvest index (0.437). Plant height (-0.0059) and days to maturity (-0.014) were showed negligible negative direct effect to the grain yield. In accordance with [15] who reported negative direct effect of plant height and days to maturity on grain yield. But, it contradicted with the finding of [1] who report positive direct effect for both traits. On the other hand, both plant height (0.47**)** and days to maturity (0.362) showed positive indirect effect via above ground biomass. Generally, consideration should be given to above ground biomass, harvest index and plant height at each location. In addition, number of kernel per spike at Kulumsa and hectoliter weight at Tongo should be considered when selecting the genotype for individual location.

The phenotypic residual values at Tongo (0.138) and at Kulumsa (0.128) were low indicated that the traits which are included in the phenotypic path analysis explained 86.2% and 87.3% of the variation in grain yield, respectively. It is suggested that maximum emphasis should be given on the above characters in selecting wheat with higher yield.

Table 6. *Estimate of direct effect (bold face and diagonal) and indirect effects (off diagonal) at phenotypic level in 30 bread wheat genotypes tested at Tongo (2015/16).*

	TKW	AGB	HI	HW	PH	KPS	rg
TKW	-0.00248	0.051821	0.458147	-0.00889	0.001434	-0.000031	0.50**
AGB	-0.00025	0.518208	0.169958	-0.00437	0.006396	0.0000547	0.69**
HI	-0.00154	0.119188	0.738946	-0.00904	0.002426	0.0000166	0.85**
HW	-0.00147	0.15028	0.443368	-0.01506	0.002867	0.0000116	0.58**
PH	-0.00032	0.300561	0.162568	-0.00392	0.011027	0.0000828	0.47**
KPS	0.000472	0.171009	0.073895	-0.00105	0.005514	0.0001657	0.25*
Residual value		0.1381496					

Note: ** and * indicates highly significant at 1% and significant at 5% probability levels, respectively. rp: correlations with the rain yield, TKW: 1000 kernel weight, AGB: above ground biomass (kgha^{-1}), HI: harvest index, HW: hectoliter weight. PH: plant height (cm) and KPS: kernels per spike.

Table 7. *Estimate of direct effect (bold face and diagonal) and indirect effects (off diagonal) at phenotypic level in 30 bread wheat genotypes tested at Kulumsa (2015/16).*

	MD	AGB	HI	HW	PH	r_p
MD	-0.01392	0.36229	-0.0745	-0.0014	-0.0025	0.27**
AGB	-0.00515	0.97916	-0.4281	-0.0031	-0.0028	0.54**
HI	0.0011136	-0.4504	0.93068	0.00721	0.00141	0.49**
HW	0.0012528	-0.1958	0.43742	0.01533	0.00183	0.26*
PH	-0.005985	0.47	-0.2234	-0.0048	-0.0059	0.23*
Residual value	0.12787					

Note, ** and * indicates not significant, highly significant at 1% and significant at 5% probability levels, respectively. rp; correlations with the rain yield, DM: days to maturity, AGB: above ground biomass (kgha^{-1}), HI: harvest index, HW: and PH: plant height (cm).

3.5. Genotypic Direct and Indirect Effects of Various Characters on Grain Yield

At Tongo the genotypic direct and indirect effect of different characters on grain yield is presented in (Table 8). Harvest index (0.789) followed by above ground biomass (0.485), 1000 kernel weight (0.0118) and plant height (0.02) exerted positive direct effect on grain yield. This result is in line with the finding of [1] for harvest index and above ground biomass. However, hectoliter weight (-0.055) had showed negative direct effect on grain yield. But, its negative direct effect was counterbalanced by its considerable positive indirect effect (0.520) via harvest index. Biomass yield and harvest index which showed positive genotypic correlation with grain yield exerted considerable direct effect on grain yield. 1000 kernel weight showed highly significant positive genotypic correlations and considerable positive indirect effect (0.520) on grain yield via harvest index. [12] reported 1000-grain weight exerted the highest direct positive effect (0.661) on grain yield. Plant height had indirect significant effect via above ground biomass and harvest index in positive direction and its high direct effect on grain yield. Harvest index, above ground biomass, 1000 kernel weight and plant height showed negative indirect effect only through hectoliter weight. Therefore, from the correlation and path coefficient analyses, it can be summarized that more emphasis should be given on harvest index, above ground biomass, 1000 kernel weight and plant height could be useful selection criteria for wheat breeding. But, their negative indirect effects through hectoliter weight need to be handled wisely. Similar result was reported by [12] for plant height and 1000 kernel weight in durum wheat.

At Kulumsa the genotypic direct and indirect effect of selected two characters on grain yield is presented in (Table 9). Only above ground biomass (0.56) and harvest index (0.48) showed highly significant and positive genotypic correlation with grain yield. Therefore, those two characters were subjected to path analysis. Both above ground biomass (0.956) and harvest index (0.901) showed highly significant direct effect on the grain yield indicating selection based on these characters would be effective for enhancing the grain yield of the genotypes. The results indicate the effect of both traits is the same at both locations (Tongo and Kulumsa). Hence, the result suggested that selection of genotypes for high performance of these traits might be effective when the breeding objective is becoming selection of genotypes for higher grain yield. The present result is in close agreement with [1, 18] who reported harvest index and biological yield per plot exerted the highest positive direct effect on grain yield. Both harvest index and above ground biomass yield have negative indirect effect on grain yield via each other. Therefore, their negative indirect effects through each other need to be handled wisely.

The residual effect of the present study were 0.179 at Kulumsa and 0.017 at Tongo indicating that he characters studied contributed 83.1% and 99.98% of the yield, respectively. It is suggested that maximum emphasis should be given on the above characters in selecting wheat with higher yield.

Table 8. *Estimate of direct effect (bold face and diagonal) and indirect effects (off diagonal) at genotypic level in 30 bread wheat genotypes tested at Tongo (2015/16).*

	TKW	AGB	HI	HW	PH	rg
TKW	0.011858	0.029108	0.520867	-0.03287	0.001038	0.53**
AGB	0.000712	0.485129	0.189406	-0.01894	0.013696	0.67**
HI	0.007826	0.116431	0.789193	-0.03677	0.00332	0.88**
HW	0.006996	0.164944	0.520867	-0.05571	0.002905	0.64**
PH	0.000593	0.320185	0.126271	-0.0078	0.020751	0.46*
Residual value		0.0173133				

Note, ** and * indicates not significant, highly significant at 1% and significant at 5% probability levels, respectively. rg; correlations with the rain yield, TKW: 1000 kernel weight, AGB: above ground biomass ($kgha^{-1}$), HI: harvest index, HW: and PH: plant height (cm).

Table 9. *Estimate of direct effect (bold face and diagonal) and indirect effects (off diagonal) at genotypic level in 30 bread wheat genotypes tested at Kulumsa (2015/16).*

	AGB	HI	rg	Residual factors
AGB	0.9563492	-0.3963	0.56**	0.17906
HI	-0.420794	0.90079	0.48**	

Note, ** indicates highly significant at 1% probability levels. rg; correlations with the rain yield, AGB: above ground biomass ($kgha^{-1}$) and HI: harvest index.

4. Summary and Conclusion

Thirty bread wheat genotypes were grown at Tongo and Kulumsa to determine association among grain yield and yield components and estimation of direct and indirect influence of yield components on the grain yield.

Grain yield showed significant (P≤0.01) positive phenotypic correlations with thousand kernels weight, above ground biomass, harvest index, hectoliter weight and plant height at each location except for kernels per spike at Tongo and days to maturity at Kulumsa. Similarly, grain yield showed significant (p≤0.01) positive genotypic correlations with 1000 kernel weight, above ground biomass, harvest index,, hectoliter weight and plant height at Tongo and only with above ground biomass and harvest index at Kulumsa. Likewise, significant (P≤0.01) positive phenotypic correlations were observed between yield components. Harvest index was the most important physiological trait. Hence, positive association indicates improvement of these characters can contribute to increased grain yield of wheat. Thousand kernel weight showed significant positive correlation with harvest index (0.62), hectoliter weight (r=0.59), tiller per plant (r=0.23) number of spike per plant and negative correlation with spikelets per spike and spike length. Plant height exhibited highly significant positive association with spikelets per spike, kernels per spike and spike length. Spike length and kernel per spike showed highly positive correlation with each other. In the cases where there is negative correlation, the improvement in characters will leads to the decline in the respective character.

Path analysis showed positive and negative phenotypic direct effects. Above ground biomass and harvest index showed high and positive phenotypic direct effect on grain yield. However, negative phenotypic direct effects were observed in 1000 kernel weight, plant height and maturity i.e., selection of for these trait might not contribute to improve grain yield. Above ground biomass and harvest index showed highly significant direct effect on the grain yield at each location at genotypic level indicating selection for these traits could be effective for enhancing grain yield.

Generally, Genotypic and phenotypic correlations among characters of crop plants are useful in planning, evaluating and setting selection criteria for the desired characters for selection in breeding program. Therefore, thousand kernel weights, above ground biomass, harvest index, hectoliter weight and plant height showed positive phenotypic and genotypic correlation with the grain yield. The character harvest index and above ground biomass had highly significant direct effect at both genotypic and phenotypic level to grain yield indicating more attention should be given to those character to improve the grain yield of bread wheat. Finally, the presence of variability among the genotypes, heritability and relationships in the tested traits of the genotypes confirmed possibility to increase wheat productivity in target area. Hence, Selection and hybridization on those genotypes based on the traits with high positive correlation coefficient and direct effect on grain yield can be recommended for farther yield improvement of bread wheat at respective location.

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