Genotypic and phenotypic correlation and path coefficient analysis for yield and yield-related traits in advanced bread wheat (Triticum aestivum L.) lines

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Abstract: Information on the mutual association of traits is important for effective selection in plant-breeding program. Forty-nine advanced bread wheat lines were evaluated in western Amhara region with triple lattice design at two locations in 2018 main rainy season to evaluate the association of yield and yield-related traits and determine the direct and indirect effects of yield-related traits on grain yield. The result of analysis of variance showed significant differences among the tested genotypes for the majority of characters under study for both locations. This indicates the presence of high variability among the tested bread wheat lines. Grain yield had significant positive correlation with days to maturity, grain-filling period, plant height, kernels spike$^{-1}$, hectoliter weight, thousand seed weight, biomass yield, and harvest index at both genotypic and phenotypic levels including spike length at phenotypic levels at Adet and with plant height, thousand seed weight, biomass yield and harvest index at Debre Tabor both at genotypic and phenotypic levels. Days to maturity and grain-filling period also showed significant positive phenotypic correlation with grain yield at Debre Tabor. This indicates that selection based on these traits could be more effective to maximize grain yield. Path analysis showed that biomass yield and harvest index had the highest positive genotypic...
and phenotypic direct effect on grain yield at both locations. This implies the true relationship between these traits and grain yield; therefore, due attention should be given on such traits during selection for further improvement.

**Subjects:** Agriculture & Environmental Sciences; Botany; Plant & Animal Ecology; Natural History – Evolution and general biology

**Keywords:** Bread wheat; correlation; genotypic; path coefficient; phenotypic; traits

1. **Introduction**

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide that has been produced many thousands years ago, which is believed to be one of the first grains domesticated by humans since the Neolithic period ∼10,000 years B.C. To date, wheat counts as one of the most important cereal grains, feeding the increasing world population (Feldmann, 2001). It ranks first in area coverage and second in total production after maize and provides more nourishment than any other food crops (FAOSTAT, 2019). Ethiopia is the largest wheat-producing country in Sub-Saharan Africa, with annual production of about 4.83 million tons of grain on 1.72 million hectares of land which accounted for 13.38% of total land allotted to cereals in 2017 cropping season with national average productivity of 2.8 t/ha (FAOSTAT, 2019). Whereas the world average productivity was 3.54 t/ha with total production of about 773.5 million tons. Wheat is one of the major staple and strategic food security crops in Ethiopia and it has been selected as one of the target crops in the strategic goal of attaining national food self-sufficiency, income generation, poverty alleviation and achieving socio-economic growth of Ethiopia (Mulatu & Dechassa, 2015). It is mainly grown in the central and south eastern highlands during the main rainy (Tefera & Tefera, 2012; White et al., 2001).

Grain yield is a complex quantitative trait that is influenced by a number of yield contributing characters (Xie, 2015). Development of improved cultivar with capability of producing better yield under various agro-climatic conditions depends upon the amount of genotypic variability present in a population for the traits (Ahmad et al., 2018). Genotypic and phenotypic correlations are of value to indicate the degree of which various morpho-physiological characters are associated with economic productivity. A correlation coefficient is useful in quantifying the magnitude and direction of components influence in the determination of main characters. However, it did not provide the relative importance of direct and indirect effects of such components (Da Silva et al., 2009). These may be determined through path analysis, with the unfolding of correlation coefficient for analyzed traits, indirect and indirect effect, providing greater reliability in interpretations of cause and effect between the studied traits. Some researchers indicated the positive correlation between grain yield and yield component traits in wheat such as harvest index (Ghaderi et al., 2009), biological yield (Ghaderi et al., 2009; Kandić et al., 2009), plant height (Leilah & Al-Khateeb, 2005), grains per spike (A. J. Khan et al., 2010) and thousand kernels weight (Leilah & Al-Khateeb, 2005). Ahmad et al. (2018) also reported that grain yield plant$^{-1}$ possessed highly significant positive associations with biological yield plant$^{-1}$, number of spikelets spike$^{-1}$ and spike length at both genotypic as well as phenotypic levels. But selections based on simple correlation coefficients without considering interactions among yield and yield components may mislead the breeders to reach their main breeding purposes (Del Moral et al., 2003; Majumder et al., 2008). Path analysis can be used to calculate the quantitative impact on grain yield through direct and indirect effects caused by one or the other component traits (Ahmed et al., 2003; Rajput, 2019). It provides an effective means of partitioning correlation coefficients into direct and indirect effects and illuminates the relationship in a more meaningful way (Majumder et al., 2008). Path analysis thus permits a critical examination of specific factors that produce a given correlation and can be successfully employed in formulating an effective selection strategy (Larik, 1979). So far some studies on trait associations of bread wheat have been done in Ethiopia in general and in western Amhara region in particular; there is a gap in generating scientific information on trait association in bread wheat spatially and temporarily. Due to these problems this research project was initiated using different advanced bread wheat lines.
introduced from CIMMYT to assess the relationship between yield and yield components and to
determine the direct and indirect effects of different yield-related traits on grain yield of bread wheat.

2. Materials and methods

2.1. Description of the study area
This experiment was conducted at two experimental sites of Adet agricultural research center,
namely Adet and Debre Tabor. Table 1 shows a brief description of the two locations or trial sites.

2.2. Experimental materials and design
The experimental materials consisted of 46 bread wheat advanced lines introduced from CIMMYT and
three released varieties were grown in triple lattice design at Adet and Debre Tabor stations, which are
the trial sites of Adet agricultural research center during the main rainy season. The experiment was
conducted in 2018 with a plot size of 2.5 m (row length) × 0.8 m (width, i.e. 4 rows plot−1 with 40 cm
row spacing). 1.5 m spacing between blocks and between replications were used. A seed rate of 150 kg
ha−1 for both locations and the recommended fertilizer rate (92/46 kg ha−1 N/P2O5 for Adet and 138/
46 kg ha−1 N/P2O5 for Debre Tabor) for each district was applied and other agronomic management
practices were done as required. Different phenological and agronomic traits recorded were days to
50% heading, days to physiological maturity, grain-filling period, plant height (cm), spike length (cm),
number of spikelets spike−1, number of kernels spike−1, grain yield (kg ha−1), hectaroliter weight (kg hl−1),
thousand seed weight (g), biomass yield (kg ha−1), and harvest index (%). The collected data were
subjected to analysis of variance (ANOVA) following proc lattice and proc GLM procedure of SAS 9.4
version software (SAS, 2013). Error variance for the two locations was not homogeneous
as it was checked by F-test method. Since F-test was applied as there are two error variances rather
than Bartlett's test which is used when there are more than two error variances (Gomez & Gomez,
1984). So due to this case, the analysis were done separately for the individual location.

Phenotypic and genotypic correlations were estimated using the standard procedure suggested
by Miller et al. (1958) and Kashiani and Saleh (2010) from the corresponding variance and
covariance components with SAS 9.4 version software (SAS, 2013). Path coefficient analysis was
performed for traits that had significant correlations with grain yield both at genotypic and
phenotypic levels in order to know the direct and indirect effect of yield component traits on
grain yield using the general formula of Dewey and Lu (1959) by considering grain yield per
hectare as dependent variable.

3. Results and discussion

3.1. Analysis of variance
Mean squares of characters under study from ANOVA for the tested materials at Adet and Debre
Tabor are presented in Tables 2 and 3, respectively. The result at Adet revealed that there were
highly significant differences (p ≤ 0.01) among the genotypes for days to 50% heading, days
to maturity, grain-filling period, plant height, spike length, number of spikelets spike−1, number
of kernels spike−1, grain yield (kg ha−1), hectaroliter weight (kg hl−1), thousand seed weight (g), biomass yield (kg ha−1), and harvest index (%). The collected data were
subjected to analysis of variance (ANOVA) following proc lattice and proc GLM procedure of SAS 9.4
version software (SAS, 2013). Error variance for the two locations was not homogeneous
as it was checked by F-test method. Since F-test was applied as there are two error variances rather
than Bartlett's test which is used when there are more than two error variances (Gomez & Gomez,
1984). So due to this case, the analysis were done separately for the individual location.

ANOVA at Debre Tabor showed highly significant differences (p ≤ 0.01) for days to heading, days
to maturity, grain-filling period, and thousand seed weight. Significant differences (p ≤ 0.05) were
observed for plant height, number of spikelets spike−1, and grain yield (kg ha−1), whereas spike
length, number of kernels spike−1, biomass, and harvest index were found non-significant differ-
ences among the tested genotypes (Table 2). Similar results were reported by Kotal et al. (2010), Fikre et al. (2015), and Arya et al. (2017) in their previous studies on bread wheat.
| Location       | Altitude | Geographical location | Soil type | Weather data | Rain fall (mm) | Temperature (°C) |
|----------------|----------|-----------------------|-----------|--------------|----------------|-----------------|
|                |          |                       |           | Min.         | Max.          | Min. | Max.    |
|                |          |                       |           | 2017         | 2018          | 2017 | 2018    |
| Adet           | 2240     | 110 16’N 37029’E      | Nitosol   | 10.81        | 25.55         |      |         |
| Debre Tabor    | 2591     | 11051’N 380 01’E      | Luvisol   | 9.5          | 22.5          |      |         |

Source: National Meteorological Agency Bahir Dare Branch (2018).
durum wheat genotypes. Similarly, Dutamo et al. (2015) reported non-significant difference for biomass yield among the tested bread wheat genotypes. Coefficient of variation (CV) for the traits grain yield, biomass yield, and harvest index were little bit higher. These might be due to erratic rainfall during the growing period.

### 3.2. Association of characters

Estimates of genotypic and phenotypic correlation coefficients were calculated among all characters under study for both locations (Tables 4 and 5). In this study, at both locations, genotypic correlation coefficients were found to be higher in magnitude than that of phenotypic correlation coefficients for most of the traits under study, which clearly indicated the presence of inherent association among various characters. Many earlier research findings also reported lesser magnitude of phenotypic

| Table 2. Mean square of 12 characters from analysis of variance at Adet |
|--------------------------|-------------------|-------------------------------|----------|-----------------------------|
| Character                | Replication (df = 2) | Genotype (df = 48) | Entra-block error (df = 78) | CV       | Efficiency relative to RCBD |
| Days to 50% heading      | 2.1                | 26.56**             | 0.83                        | 1.52     | 105.13                       |
| Days to maturity         | 3.49               | 23.22**             | 1.88                        | 1.26     | 107.16                       |
| Grain-filling period     | 1.06               | 8.61**              | 1.44                        | 2.46     | 101.13                       |
| Plant height (cm)        | 3.07               | 63.95**             | 12.36                       | 4.31     | 98.15                        |
| Spike length (cm)        | 3.23               | 1.03**              | 0.22                        | 6.2      | 97.59                        |
| Spikelets spike\(^{-1}\) | 23.34              | 4.76**              | 1.11                        | 6.6      | 109.15                       |
| Kernels spike\(^{-1}\)  | 88.69              | 66.39**             | 24.89                       | 10.17    | 101.31                       |
| Grain yield (kg ha\(^{-1}\)) | 2386696           | 891665**           | 439705                      | 14.06    | 94.03                        |
| Hectoliter weight        | 4.54               | 17.11**             | 4.61                        | 3.01     | 109.98                       |
| Thousand seed weight (g) | 10.55              | 27.23**             | 4.01                        | 5.71     | 100.4                        |
| Biomass yield (kg ha\(^{-1}\)) | 16183673          | 5983277\(\text{ns}\) | 412855                      | 12.26    | 98.34                        |
| Harvest index            | 8.93               | 27.55*              | 17.62                       | 12.62    | 891.16                       |

Notes: df, Degree of freedom; CV, coefficient of variation.

| Table 3. Mean square of 11 characters from analysis of variance at Debre Tabor |
|--------------------------|-------------------|-------------------------------|----------|-----------------------------|
| Character                | Replication (df = 2) | Genotype (df = 48) | Entra-block error (df = 78) | CV       | Efficiency relative to RCBD |
| Days to 50% heading      | 7.64               | 15.79**             | 1.09                        | 1.6      | 100.7                        |
| Days to maturity         | 17.29              | 17.52**             | 2.84                        | 1.41     | 102.53                       |
| Grain-filling period     | 47.37              | 43.57*              | 27.4                        | 8.06     | 90.24                        |
| Plant height (cm)        | 47.87              | 9.29**              | 3.38                        | 3.42     | 105.00                       |
| Spike length (cm)        | 0.73               | 1.76\(\text{ns}\)  | 1.63                        | 16.73    | 94.91                        |
| Spikelets spike\(^{-1}\) | 6.45               | 4.24*               | 2.45                        | 9.34     | 97.6                         |
| Kernels spike\(^{-1}\)  | 92.61              | 94.46\(\text{ns}\) | 81.35                       | 17.81    | 97.88                        |
| Grain yield (kg ha\(^{-1}\)) | 2965767           | 508371.14*         | 282621                      | 23.78    | 102.77                       |
| Thousand seed weight (g) | 140.93             | 19**               | 7.45                        | 9.54     | 100.4                        |
| Biomass yield (kg ha\(^{-1}\)) | 32904762          | 3271825.4\(\text{ns}\) | 2360195                     | 23.28    | 101.39                       |
| Harvest index            | 235.59             | 57.9\(\text{ns}\)  | 52.91                       | 20.99    | 107.94                       |

Notes: df, Degree of freedom; CV, coefficient of variation; hectoliter weight here was missed, this is because of insufficient amount of seed to measure this parameter.

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correlation coefficients than the genotypic correlation coefficients (Dabi et al., 2016; Kotal et al., 2010; Mohammad et al., 2005) that revealed the presence of inherent genetic relationships among various characters and the phenotypic expression of these traits were less influenced by the environment.

3.3. Correlation between yield and yield-related traits
The result of Adet (Table 4) revealed that grain yield had significant positive correlation with days to maturity, grain-filling period, plant height, number of kernels spike−1, hectoliter weight, thousand seed weight, biomass yield, and harvest index at both genotypic and phenotypic levels and significant positive correlation with spike length only at phenotypic level. Dabi et al. (2016) reported that plant height, thousand kernels weight, biomass yield, hec-toliter weight and harvest index showed significant positive correlation with grain yield both at genotypic and phenotypic level. Likewise, Khalig et al. (2004) also reported that grain yield had significant positive correlation with plant height, spike length, number of spikelets spike−1, kernels spike−1, and thousand seed weight both at genotypic and phenotypic levels. The findings of Dutamo et al. (2015) and Mecha et al. (2017) also showed that grain-filling period, spike length, number of spikelets spike−1, kernels spike−1, thousand seed weight, biomass, hec-toliter weight, and harvest index had positive correlation with grain yield at both genotypic and phenotypic levels. These reports are in accordance with the present study, which implies that selection based on days to maturity, grain-filling period, plant height, number of kernels spike−1, hec-toliter weight, thousand seed weight, biomass yield, and harvest index could be more efficient to maximize grain yield of wheat. Non-significant positive correlation of grain yield was observed with days to heading, spike length, and number of spikelets spike−1 at genotypic level and with days to heading and number of spikelets spike−1 at phenotypic level, which indicates that an increase in days to 50% heading, spike length, and number of spikelets spike−1 will not have significant change in grain yield. Similarly, Dabi et al. (2016) also reported that those days to 50% heading, days to maturity, grain-filling period, spike length, and number of spikelets spike−1 showed non-significant positive correlation with grain yield.

In the case of Debre Tabor, the result (Table 5) showed that grain yield had significant positive correlation with plant height, thousand seed weight, biomass yield, and harvest index at both genotypic and phenotypic levels. Days to maturity and grain-filling period also had significant positive correlation with grain yield at phenotypic level. Ayer et al. (2017) reported that plant height, thousand seed weight, biomass yield, and harvest index showed positive significant correlation with grain yield in their simple correlation analysis in advanced wheat genotypes. Mohsin et al. (2009) also reported that grain yield had positive phenotypic correlation with plant height, biomass yield, spike length, spikelets spike−1, kernels spike−1, thousand grain weight, and thousand seed weight. Similarly, Mecha et al. (2017) also reported that grain yield had positive significant correlation with plant height, hec-toliter weight, thousand seed weight, biomass yield, and harvest index both at genotypic and phenotypic levels, which are in line with the result of the present study. Non-significant positive correlations were observed between grain yield with spike length and number of kernels spike−1 at both genotypic and phenotypic level. Days to maturity and grain-filling period also showed non-significant positive correlation with grain yield at genotypic level. On the other hand, grain yield showed non-significant negative correlation with days to heading and number of spikelets pike−1 both at genotypic and phenotypic levels. This finding is in agreement with the earlier findings of Mohammad et al. (2005) and Dutamo et al. (2015). Similarly, Mecha et al. (2017) reported that days to 50% heading showed non-significant negative correlation with grain yield at both genotypic and phenotypic levels. Furthermore, Aycicek and Yildirim (2006) reported that grain yield showed significant negative correlation with days to 50% heading. Negative correlations indicate inverse relationship between earliness characters, number of spikelets pike−1 and grain yield that is desirable if stresses such as terminal heat and drought stress are expected.

3.4. Correlation among yield-related traits
At Adet, days to 50% heading had significant positive correlation with days to maturity, plant height, number of spikelets spike−1, number of kernels spike−1 and biomass yield at genotypic level.
### Table 4. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of 12 characters for the tested bread wheat genotypes at Adet in 2018 cropping season

| Characters | DH  | DM  | GFP  | PH (cm) | SL (cm) | SPPS | KPS  | GY (kg ha\(^{-1}\)) | HLW (kg hl\(^{-1}\)) | TSW (g) | BMY (kg ha\(^{-1}\)) | HI (%) |
|------------|-----|-----|------|---------|--------|------|------|----------------------|-----------------------|---------|----------------------|--------|
| DH         | 1   | 0.80** | −0.43** | 0.40** | 0.23** | 0.33* | 0.29* | 0.04 ns               | −0.28 ns              | 0.44**  | −0.37**              |        |
| DM         | 0.77** | 1   | 0.19 ns | 0.50** | 0.21 ns | 0.34* | 0.28 ns | 0.32*                | 0.04 ns               | 0.37**  | −1.5 ns              |        |
| GFP        | −0.38** | 0.29** | 1     | 0.10 ns | −0.04 ns | −0.02 ns | −0.06 ns | 0.42**              | 0.45**                | 0.53**  | 0.13 ns              | 0.39 ns |
| PH (cm)    | 0.36** | 0.44** | 0.10 ns | 1       | 0.40** | 0.47** | 0.48** | 0.52**              | 0.40**                | 0.04 ns  | 0.62**              | 0.03 ns |
| SL (cm)    | 0.21*  | 0.19*  | −0.04 ns | 0.38** | 1      | 0.71** | 0.49** | 0.25 ns             | 0.25 ns               | 0.09 ns  | 0.29**              | 0.01 ns |
| SPPS       | 0.25** | 0.23** | −0.03 ns | 0.43** | 0.53** | 1     | 0.56** | 0.26 ns             | 0.22 ns               | −0.02 ns | 0.39**              | −0.07 ns|
| KPS        | 0.23** | 0.19*  | −0.09 ns | 0.45** | 0.52** | 0.58** | 1     | 0.30*               | 0.18 ns               | −0.21 ns | 0.32*              | 0.04 ns |
| GY (kg ha\(^{-1}\)) | 0.09 ns | 0.29** | 0.29** | 0.43** | 0.23** | 0.14 ns | 0.23** | 1                   | 0.65**               | 0.41**  | 0.62**              | 0.65** |
| HLW (kg hl\(^{-1}\)) | 0.20*  | 0.44** | 0.34** | 0.33** | 0.16 ns | 0.11 ns | 0.12 ns | 0.57**             | 1                    | 0.40**  | 0.56**              | 0.27 ns |
| TSW        | −0.24** | 0.06 ns | 0.45** | 0.02 ns | −0.03 ns | −0.03 ns | −0.22 ns | 0.30**            | 0.36**              | 1                   | 0.11 ns  | 0.44**              |        |
| BMY (kg ha\(^{-1}\)) | 0.34** | 0.42** | 0.11 ns | 0.41** | 0.29** | 0.19* | 0.17* | 0.63**             | 0.41**               | 0.06 ns  | 1                   | −0.19 ns|
| HI (%)     | −0.25** | −0.09 ns | 0.24** | 0.07 ns | −0.05 ns | −0.04 ns | 0.08 ns | 0.55**             | 0.26**               | 0.31**  | −0.30**             | 1       |

Notes: DH, days to 50% heading; DM, days to maturity; GFP, grain-filling period; PH, plant height; SL, spike length; SPPS, number of spikelets spike\(^{-1}\); KPS, number of kernels spike\(^{-1}\); GY, grain yield; HLW, hectoliter weight; TSW, thousand seed weight; BMY, biomass yield; HI, harvest index.
Table 5. Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for 11 characters for the tested genotypes at Debre Tabor in 2018 cropping season

| Characters | DH  | DM  | GFP  | PH (cm) | SL (cm) | SPPS | KPS  | GY (kg ha\(^{-1}\)) | TSW (g) | BMY (kg ha\(^{-1}\)) | HI (%) |
|------------|-----|-----|------|---------|---------|------|------|----------------------|---------|----------------------|--------|
| DH         | 1   | 0.73** | -0.33* | 0.41** | 0.24 ns | 0.54** | 0.24 ns | -0.04 ns | 0.15 ns | 0.22 ns | -0.24 ns |
| DM         | 0.59** | 1   | 0.41** | 0.31* | 0.23 ns | 0.46** | 0.22 ns | 0.07 ns | 0.31* | 0.19 ns | -0.07 ns |
| GFP        | -0.35** | 0.55** | 1   | -0.12 ns | 0.00 | -0.09 ns | -0.02 ns | 0.15 ns | 0.23 ns | -0.03 ns | 0.23 ns |
| PH (cm)    | 0.29** | 0.31** | 0.06 ns | 1 | 0.26 ns | 0.39 ** | 0.62** | 0.56** | 0.24 ns | 0.54** | 0.17 ns |
| SL (cm)    | 0.16* | 0.21* | 0.07 ns | 0.39** | 1 | 0.54** | 0.14 ns | 0.15 ns | 0.12 ns | 0.06 ns | 0.16 ns |
| SPPS       | 0.38** | 0.31** | -0.04 ns | 0.38** | 0.42** | 1 | 0.24 ns | -0.07 ns | -0.09 ns | 0.10 ns | -0.18 ns |
| KPS        | 0.15 ns | 0.18* | 0.05 ns | 0.50** | 0.23** | 0.21* | 1 | 0.21 ns | 0.13 ns | 0.17 ns | 0.09 ns |
| GY (kg ha\(^{-1}\)) | -0.12 ns | 0.18* | 0.32** | 0.46** | 0.15 ns | -0.04 ns | 0.16 ns | 1 | 0.50** | 0.65** | 0.55** |
| TSW (g)    | 0.03 ns | 0.36** | 0.39 ** | 0.30** | 0.19* | -0.03 ns | 0.14 ns | 0.63** | 1 | 0.10 ns | 0.57** |
| BMY (kg ha\(^{-1}\)) | 0.12 ns | 0.21** | 0.13 ns | 0.44** | 0.17* | 0.19* | 0.18* | 0.57** | 0.29** | 1 | -0.25 ns |
| HI (%)     | -0.21* | 0.03 ns | 0.25** | 0.13 ns | 0.03 ns | -0.20* | -0.03 ns | 0.51** | 0.45** | -0.37** | 1 |

Notes: DH, days to 50% heading; DM, days to maturity; GFP, grain-filling period; PH, plant height; SL, spike length; SPPS, number of spikelets spike\(^{-1}\); KPS, number of kernels spike\(^{-1}\); GY, grain yield; TSW, thousand seed weight; BMY, biomass yield; HI, harvest index.

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This implied that increasing days to 50% heading would increase days to maturity, plant height, number of spikelets spike⁻¹, number of kernels spike⁻¹, and biomass yield at the expense of grain-filling period, thousand seed weight, and harvest index. Days to 50% heading showed non-significant positive genotypic correlation with spike length and hectoliter weight. Whereas it showed negative significant correlation with grain-filling period, thousand seed weight, and harvest index both at genotypic and phenotypic level except thousand seed weight which was not significant at genotypic level. According to the report of Mecha et al. (2017), days to 50% heading had significant negative genotypic and phenotypic correlation with grain-filling period, thousand seed weight, hectoliter weight, and harvest index. Wolde et al. (2016) also reported that days to 50% heading had significant negative correlation with grain-filling period at both genotypic and phenotypic levels which are in agreement with the present study.

Days to maturity showed significant positive correlation with plant height, number of spikelets spike⁻¹, hectoliter weight, and biomass yield. Grain-filling period had significant positive genotypic correlation with hectoliter weight and thousand seed weight. At phenotypic level, significant positive correlation were observed in days to maturity, hectoliter weight, thousand seed weight, and harvest index with grain-filling period which indicates that increase in the gap between heading date and maturity date leads to increase in hectoliter weight, thousand seed weight, and harvest index.

Plant height had significant positive correlation with spike length, spikelets spike⁻¹, kernels spike⁻¹, hectoliter weight and biomass yield both at genotypic and phenotypic levels, which implies that increase in plant height leads to increase in spike length, spikelets spike⁻¹, kernels spike⁻¹, hectoliter weight, and biomass yield. Thousand seed weight showed significant negative phenotypic correlation with number of kernel spike⁻¹ which implies that increase in number of kernels spike⁻¹ will decrease in thousand seed weight. This might be due to nutrient competition kernels may became shriveled and the weight of them may be low.

At Debre Tabor, days to 50% heading had significant positive correlation with days to maturity, plant height, and number of spikelets spike⁻¹ both at genotypic and phenotypic levels and spike length only at phenotypic level. This is similar with the finding of Masood et al. (2005) in their work in titled with phenotypic diversity and trait association in bread wheat (Triticum aestivum L.) landraces. The finding of Mohammad et al. (2005) indicated that Days to 50% heading had negative correlation with harvest index. Days to maturity had significant positive genotypic correlation with grain-filling period, plant height, number of spikelets spike⁻¹, and thousand seed weight. But days to maturity showed non-significant negative genotypic correlation with harvest index, which implies increase or decrease in days to maturity have no significant change in harvest index. At phenotypic level days to maturity showed significant positive correlation with all characters under consideration in this study except harvest index.

Grain-filling period showed significant positive phenotypic correlation with thousand seed weight and harvest index. This indicted that increase in the gap between heading date and physiological maturity leads to increase in thousand seed weight and harvest index. Plant height had positive significant genotypic and phenotypic correlation with number of spikelets spike⁻¹, kernels spike⁻¹, and biomass yield including spike length and thousand seed weight at phenotypic level. Spike length showed significant positive correlation with spikelets spike⁻¹. Masood et al. (2005) reported that spike length was positively and significantly correlated with number of spikelets spike⁻¹ but negatively associated with biological yield and harvest index. Harvest index showed significant negative correlation with biomass yield which is similar with the result of Adet. Harvest index also showed significant negative correlation with number of spikelets spike⁻¹ at phenotypic level.

3.5. Path coefficient analysis

The result of path coefficient analysis of the present study at Adet both at genotypic and phenotypic levels are presented in Tables 6 and 7, respectively. Grain-filling period, plant height,
number of kernels spike$^{-1}$, hectaroliter weight, biomass yield, and harvest index showed positive direct effect on grain yield both at genotypic and phenotypic levels including spike length at phenotypic level. However, the magnitude of grain-filling period, plant height, number of kernels spike$^{-1}$, hectaroliter weight, and spike length were low their indirect effects through biomass yield and harvest index contribute more on grain yield (Tables 6 and 7). Sabit et al. (2017) have been reported that plant height, peduncle length, spike length, days to flowering, grain-filling periods, biological yield, and harvest index had positive direct effect on grain yield per plant at genotypic level in bread wheat which is similar with the present study. Similarly, the report of Mecha et al. (2017) also indicated that days to 50% heading, days to maturity, grain-filling period, spike length, number of spikelets spike$^{-1}$, kernels spike$^{-1}$, thousand seed weight, and biomass yield had positive direct effect on grain yield. Harvest index exerted the highest positive direct effect (0.786) on grain yield followed by biomass yield (0.751) at genotypic level and vice versa at phenotypic level, which were biomass yield (0.853) and harvest index (0.801). Abinasa et al. (2011) and Obasa et al. (2017) reported that harvest index exerted the highest positive direct effect on grain yield followed by biological yield per plot which confirmed the result of this study. Furthermore, the finding of Leilah and Al-Khateeb (2005) and Dutamo et al. (2015) also showed that harvest index and biomass yield was exerted the highest positive direct effect on grain yield. This implies that selection based on these traits may be effective to improve grain yield of bread wheat. Singh and Choudhury (1985) suggested that if the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, the correlation explains the true relationship and the direct selection based on these traits is effective. Days to maturity and thousand seed weight had negative direct effects on grain yield, even though they had positive significant correlation at both genotypic and phenotypic levels, indicated that indirect effects to be the cause of correlation. Thus, the negative direct effect of days to maturity and thousand seed weight were counter balanced by their positive indirect effects through other traits such as grain-filling period, plant height, number of kernel spike$^{-1}$, hectaroliter weight and biomass yield for days to maturity at both genotypic and phenotypic level including spike length at phenotypic level and grain-filling period, hectaroliter weight, biomass yield, and harvest index for thousand seed weight at both genotypic and phenotypic levels including plant height at genotypic level. Similarly Kotal et al. (2010), Dabi et al. (2016), and Sabit et al. (2017) reported that days to maturity and thousand seed weight showed negative direct effect on grain yield of bread wheat genotypes. Other authors, Wolde et al. (2016) also showed that days to maturity had negative direct effect on grain yield in their study which is in agreement with the present study. However, Mecha et al. (2017) reported that both days to maturity and thousand seed weight showed positive direct effect on grain yield. Khan et al. (2013) also reported that thousand seed weight showed the maximum positive direct effect on grain yield with in their study on durum wheat genotypes which contradicted the result of present work. This suggested that the effect of yield-related traits on grain yield may be affected by environment.

Maximum positive indirect effects on grain yield were observed in plant height followed by days to maturity and hectaroliter weight through biomass yield. Relatively, thousand seed weight also showed high positive indirect effect on grain yield via harvest index at genotypic level and days to maturity followed by plant height and hectaroliter weight at phenotypic level. These indicated that considering these traits during selection besides other traits that showed positive direct effect on grain yield may be more effective for further yield improvement of bread wheat. Residual effects 0.079 and 0.110 at genotypic and phenotypic levels, respectively, indicated that characters included in the path analysis explained 92.1% and 89% of the variability in grain yield at genetic and phenotypic levels in their respective orders at Adet location.

Likewise at Debre Tabor site, the estimation of direct and indirect effects of yield-related traits on grain yield was done both at genotypic and phenotypic levels (Tables 8 and 9). Thus, the results revealed that biomass yield and harvest index had high positive direct effect on grain yield similar to the results at Adet. Whereas plant height and thousand seed weight showed negative direct effects on grain yield at genotypic level. However, their negative direct effects were counter balanced by their positive indirect effect on grain yield through biomass yield and harvest index.
Table 6. Estimate of direct (bold face and diagonal) and indirect effects (off diagonal) at genotypic level for bread wheat genotypes tested at Adet

| Character     | DM    | GFP   | PH (cm) | KPS   | HLW (kg h\(^{-1}\)) | TSW (g) | BMY (kg ha\(^{-1}\)) | HI (%) | \(r_g\) |
|---------------|-------|-------|---------|-------|---------------------|---------|----------------------|--------|--------|
| DM            | -0.024 | 0.004 | 0.014   | 0.003 | 0.008               | -0.001  | 0.429                | -0.116 | 0.32*  |
| GFP           | -0.005 | 0.022 | 0.003   | -0.001| 0.006               | -0.013  | 0.098                | 0.304  | 0.42** |
| PH (cm)       | -0.012 | 0.002 | 0.029   | 0.005 | 0.006               | -0.001  | 0.466                | 0.024  | 0.52** |
| KPS           | -0.007 | -0.001| 0.014   | 0.010 | 0.003               | 0.005   | 0.241                | 0.032  | 0.30*  |
| HLW (kg h\(^{-1}\)) | -0.013 | 0.010 | 0.011   | 0.002 | 0.014               | -0.010  | 0.417                | 0.215  | 0.65** |
| TSW (g)       | -0.001 | 0.011 | 0.001   | -0.002| 0.006               | -0.024  | 0.079                | 0.343  | 0.41** |
| BMY (kg ha\(^{-1}\)) | -0.014 | 0.003 | 0.018   | 0.003 | 0.008               | -0.003  | 0.751                | -0.148 | 0.62** |
| HI (%)        | 0.004  | 0.008 | 0.001   | 0.000 | 0.004               | -0.010  | -0.142               | 0.786  | 0.65** |
| Residual effect | 0.079 |       |         |       |                     |         |                      |        |        |

Notes: DM, days to maturity; GFP, grain-filling period; PH, plant height; KPS, number of kernels spike\(^{-1}\); HLW, hectoliter weight; TSW, thousand seed weight; BMY, biomass yield; HI, harvest index; \(r_g\), genetic correlation.
Table 7. Estimate of direct effect (bold face and diagonal) and indirect effects (off diagonal) at phenotypic level for bread wheat genotypes tested at Adet

| Character | DM | GFP | PH (cm) | SL (cm) | KPS | HLW (kg hl⁻¹) | TSW (g) | BMY (kg ha⁻¹) | HI (%) | r_p  |
|-----------|----|-----|---------|---------|-----|--------------|---------|---------------|--------|------|
| DM        | -0.010 | 0.003 | 0.005 | 0.004 | 0.000 | 0.005 | 0.000 | 0.358 | -0.076 | 0.29** |
| GFP       | -0.003 | 0.009 | 0.001 | -0.001 | 0.000 | 0.004 | -0.004 | 0.095 | 0.190 | 0.29** |
| PH (cm)   | -0.004 | 0.001 | 0.011 | 0.007 | 0.000 | 0.004 | 0.000 | 0.351 | 0.055 | 0.43** |
| SL (cm)   | -0.002 | 0.000 | 0.004 | 0.020 | 0.000 | 0.002 | 0.000 | 0.247 | -0.043 | 0.23** |
| KPS       | -0.002 | -0.001 | 0.005 | 0.010 | 0.000 | 0.001 | 0.002 | 0.147 | 0.067 | 0.23** |
| HLW (kg hl⁻¹) | -0.004 | 0.003 | 0.004 | 0.003 | 0.000 | 0.011 | -0.003 | 0.347 | 0.209 | 0.57** |
| TSW (g)   | -0.001 | 0.004 | 0.000 | 0.000 | 0.000 | 0.004 | -0.008 | 0.053 | 0.252 | 0.30** |
| BMY (kg ha⁻¹) | -0.004 | 0.001 | 0.005 | 0.006 | 0.000 | 0.004 | 0.000 | 0.853 | -0.238 | 0.63** |
| HI (%)    | 0.001 | 0.002 | 0.001 | -0.001 | 0.000 | 0.003 | -0.002 | -0.253 | 0.801 | 0.55** |

Residual value: 0.110

Notes: DM, days to maturity; GFP, grain-filling period; PH, plant height; SL, spike length; KPS, number of kernels spike⁻¹; GY, grain yield; HLW, hectoliter weight; TSW, thousand seed weight; BMY, biomass yield; HI, harvest index; r_p, phenotypic correlation.
Negative direct effect of days to maturity and thousand seed weight on grain yield were reported by Kotal et al. (2010). Other authors, Mitsiwa (2013) and Ayer et al. (2017) also reported that plant height showed negative direct effect on grain yield which is in agreement with the present study. At phenotypic level, biomass yield and harvest index had high positive direct effect on grain yield as well. Grain-filling period and thousand seed weight had low positive direct effect on grain yield but they had good contribution on grain yield by their positive indirect effect via biomass yield and harvest index. Days to maturity and plant height had negative direct effect on grain yield but their negative direct effect were compensated by their indirect effect through grain-filling period, thousand seed weight, biomass yield and harvest index. Besides the high positive direct effects biomass yield and harvest index are important traits for indirect selection of grain yield. As the result, focusing on these traits during selection is critical for further yield improvement of bread wheat. At Debre Tabor location, the residual effects (0.203 and 0.259) at genotypic and phenotypic levels, respectively, indicated that characters included in the path analysis explained 79.7.02% and 74.1% of the variability in grain yield at genetic and phenotypic levels in the respective orders. The remaining variability occurred in grain yield were caused by unknown factors.

In general from, the results of correlation and path analysis obtained biomass yield and harvest index showed significant positive correlation with maximum positive direct effect on grain yield in the studied locations. Therefore, direct selection on the bases of these traits could be effective for grain yield improvement of bread wheat for the studied locations. But both harvest index and biomass yield showed negative indirect effect on grain yield via each other both at genotypic and phenotypic levels in the studied locations. Therefore, their negative indirect effects through each other need to be handled wisely. Furthermore, biomass yield is an important trait for indirect selection of grain yield. Harvest index is also slightly important trait for indirect selection of grain yield. From the result of one year with two locations it is suggested that different yield-related traits of the same genotypes do not
have similar effects on grain yield in different environments. But since it is just one year and two locations results, it should be repeated for extra years to confirm these results.

4. Conclusion and recommendation

Scientific information about the relationship of yield and yield-related traits are very important for successful breeding strategies. 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 under study, which clearly indicates the presence of inherent association among various characters. Grain yield had significant positive correlation with days to maturity, grain-filling period, plant height, kernels spike⁻¹, hectoliter weight, thousand seed weight, biomass yield, and harvest index both at genotypic and phenotypic level including spike length at phenotypic level at Adet. While in case of Debre Tabor, it showed significant positive correlation with plant height, thousand seed weight, biomass yield and harvest index both at genotypic and phenotypic levels including days to maturity and grain-filling period at phenotypic level. Biomass yield and harvest index had the highest positive genotypic and phenotypic direct effect on grain yield at both locations. These results indicate the true relationship between these traits and grain yield. Consequently, these traits should be considered as important selection criteria in bread wheat breeding program for higher grain yield at both locations.

Maximum positive indirect effects on grain yield were observed in plant height, days to maturity and hectoliter weight through biomass yield and thousand seed weight via harvest index at Adet both at genotypic and phenotypic levels. In case of Debre Tabor, maximum positive indirect effect were observed by plant height via biomass and thousand seed weight via harvest index both at genotypic and phenotypic levels. Strong correlation and positive direct effects of plant height and hecoliter weight with grain yield on the one hand and strong correlation with insignificant negative direct effect of thousand seed weight with grain yield at Adet indicated that selection of these genotypes with high plant height, hectoliter weight and moderate thousand grain weight should be emphasized while selection for improving grain yield. Whereas strong correlation of plant height and thousand seed weight with grain yield on the one hand and low negative direct effect with grain yield in the other way indicated that selection of these genotypes with moderate plant height and thousand seed weight should be focused during selection for improving grain yield at Debre Tabor. Therefore, selection based on high biological yield and harvest index together with the above indicated traits is recommended for further grain yield improvement of bread wheat if selection will be done for individual location.

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