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Genotypic Variability, Heritability, Genetic Advance and Associations among Characters in Ethiopian Durum Wheat (*Triticum durum* Desf.) Accessions

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Abstract: A field experiment was conducted at Geregera (11^0 45' N latitude and 38^0 45' E longitude) in north Wollo, Ethiopia during the 2003 cropping season with the objectives of estimating genotypic variability, heritability, genetic advance and associations among yield and yield-related characters of durum wheat. Forty four randomly taken Ethiopian durum wheat accessions were evaluated using randomized complete block design in three replications. Analysis of variance showed significant differences ($p < 0.05$) among the durum wheat accessions for all the characters considered. Genotypic coefficients of variation (GCV %) were medium for spike length (12.5%) and kernel yield plant^{-1} (12.3%). Broad sense heritability were high for spike length (89.2%), plant height (87.1%) and thousand kernels weight (80.2%), indicating that these characters were predominantly controlled by genetic factors. Maximum heritability in broad sense coupled with high genetic advance were exhibited for spike length, plant height and thousand kernels weight, implying that phenotypic selection could identify superior genotypes for these traits. Genotypic correlation analysis revealed that grain yield had strong positive associations ($p < 0.01$) with kernel yield plant^{-1} ($r_g = 0.89$), plant height ($r_g= 0.84$), thousand kernels weight ($r_g = 0.82$), biomass yield ($r_g = 0.80$) and number of kernels spike^{-1}($r_g = 0.78$), where biomass yield and harvest index exerted maximum positive direct effects on grain yield. On the other hand, days to heading had a significant negative correlation ($p < 0.01$) with grain yield ($r_g = -0.75$) which exerted maximum negative direct effect on grain yield. Therefore, earliness coupled with high biomass yield could be considered as an indirect selection criterion for durum wheat grain yield improvement in moisture stressed areas.

Keywords: Genetic; Genetic Advance; Harvest Index; Heritability; Variability

1. Introduction

Wheat is one of the most important cereal crops grown in Ethiopia. According to CSA (2005), wheat ranks second both in total production (21.7%) and in area coverage (18.3%) next to maize and *teff,* respectively, among the cereal crops. Durum wheat grows mostly on Vertisols under rainfed conditions. It is locally called *Yekoticha Sinde* (*in Amharic*), which means wheat of heavy black clay soils. Sometimes it is also known as *Yekinche Sinde* (*in Amharic)* in recognition of the hard vitreous grain, which is very suitable for making *Kinche* (hard porridge), a local food, when the grains are cracked and cooked.

Most tetraploid wheat varieties currently grown in Ethiopia are landraces that consist of a large number of different genetic lines. Zohary (1970) observed tremendous variability of durum wheat in Ethiopia; differing in spike forms, spike density, awns and kernel colors (brown, amber and violet) and awn condition (awnless, short awned and long awned varieties). Other distinguishing characteristics include hairy or waxy leaves, hairy or glabrous glumes and presence of pigmentation in glumes, awns and kernels. Agronomically important traits, for instance, early maturing, and rust and drought resistance genes have been reported from Ethiopian durum wheat accessions (Porceddu *et al.,* 1973*).*

Heritability estimates provide an indication of the expected response to selection in a population. Information on the nature and magnitude of heritability in a population is one of the prerequisites for successful breeding programs in selecting genotypes with desirable characters (Amin *et al.,* 1992). Hence, it is essential to divide the observed variability into its heritable and non-heritable components. Heritability estimates and genetic advance should always be considered simultaneously, because high heritability will not always be associated with high genetic advance (Johnson *et al.*, 1955; Amin *et al.*, 1992).

Thus, giving emphasis to easily measurable characters with high heritability and having useful relationship with grain yield is of paramount importance to practice indirect selection for high yield (Falconer and Mackey, 1996). Correlation studies are, therefore, useful in disclosing the magnitude and direction of the relationships between the different characters and grain yield. However, correlation study fails to give an exact picture of the relative importance of direct and indirect effects of the various yield attributes. Thus, in order to get a clear picture of the inter-relationship between grain yield and other characters, direct and indirect effects should be worked out using path coefficient analysis at genotypic level (Dokuyucu and Akkaya, 1999). Getachew *et al.* (1993) reported the effectiveness of indirect selection for grain yield through plant height and thousand kernels weight. In another study by Srivastava *et al.* (1980), the direct effect of kernel yield plant^{-1} on grain yield was found to be positive and high, whereas number of kernels

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spike^{-1} and thousand kernels weight had negative and low direct effects.

To make an effective selection for high grain yield in durum wheat, a thorough understanding on the nature and extent of genetic variability, heritability and genetic advance; as well as the inter-relationships among yield and yield contributing traits are very important. However, such information for moisture-stressed areas in Ethiopia is very limited. Therefore, this study was designed to estimate the degree of genetic variability, heritability, genetic advance and associations among characters in Ethiopian durum wheat accessions.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at the Geregera Research Site of Sirinka Agricultural Research Center (SARC), north Wollo, Ethiopia during the 2003 cropping season. The experimental site is located at 11^0 45' N latitude and 38^0 45' E longitude and at an altitude of 2846 m above sea level. The soil type is generally characterized as having clay texture (60.02%) containing 1.77% organic matter, 0.183% total N and 7.11 mg kg^{-1} of P with pH of 6.6. Rainfall is characterized as uni-modal with erratic distribution and a mean annual rainfall of 1105 mm. Delayed onset (during sowing time), early cessation (during grain filling period), and torrential rainfall followed by long dry spells are the major and common problems of the area.

2.2. Experimental Material

The experimental material consisted of forty four durum wheat accessions (Table 1), which were randomly taken from the indigenous durum wheat germplasm. The accessions were collected by the Debre Zeit Agricultural Research Center from the central highlands and western parts of the country. The experiment comprised seven durum wheat accessions from Kotu (Northern Shewa), 19 from Ambo (Western Shewa), 14 from Bichena (Gojam) and four from Chefe-Donsa (Eastern Shewa). These areas are the major durum wheat growing regions of Ethiopia.

Table 1. List of the durum wheat (*Triticum durum* Desf) accessions and collection areas.

Collection area	Accessions
Kotu	K-I-73, K-I-90, K-I-95, K-I-108, K-I-128, K-II-9 and K-II-126
Ambo	A-I 123, A-I 130, A-I 138, A-I 171, A-I 184, A-II 124, A-II-127, A-II-139, A-II-158, A-III 59, A-III 130, A-III 159, A-III 163, A-III 186, A-IV 9, A-IV 12, A-IV 29, A-IV 52 and A-IV 71
Bichena	B-I 100, B-I 113, B-I 118, B-I 157, B-I 163, B-II 102, B-II 159, B-II 187, B-II 188, B-II 191, B-III 38, B-III 114, B-III 122 and B-III 132
Chefe-Donsa	CD I-49, CD I-76, CD I- 104 and CD I- 131

2.3. Experimental Design and Cultural Practices

The experiment was laid out in a randomized complete block design with three replications. Each accession was planted in a plot size of 2 m^2 (4 rows, each 2.5 m long, with 20 cm distance between rows). A seed rate of 125 kg ha^{-1} was used as per the national seed rate recommendation (Tanner *et al.*, 1991). Nitrogen and phosphorus were applied at the rates of 41 and 46 kg ha^{-1} N and P_2O_5, respectively. Phosphorus as diammonium phosphate (46% P_2O_5 and 18% N) was applied at sowing while N was applied in split (half at sowing and half at full tillering stage) as Urea (46% N) and diammonium phosphate. The trial was hand weeded twice, the first weeding at 20 days after emergence and the second weeding at 45 days after emergence. Data were collected both from plot and plant basis. The data recorded from plot basis were days to heading, days to maturity, grain filling period, thousand kernels weight, biomass yield, grain yield and harvest index. The data recorded from plant basis (from ten randomly taken plants, which were tagged just before heading) were plant height, number of productive tillers plant^{-1}, number of spikelets spike^{-1}, spike length, number of kernels spike^{-1} and kernel yield plant^{-1}.

2.4. Statistical Procedures

2.4.1. Analysis of Variance

To compare the total variability present within the accessions, the mean of ten randomly sampled plants from each plot as well as the data from plot basis were subjected to analysis of variance (ANOVA) using MSTAT-C computer program (MSU, 1988) following randomized complete block design (RCBD) as per Gomez and Gomez (1984). Coefficients of variations (CV) in percent for all the characters were computed as per Gomez and Gomez (1984).

2.4.2. Estimation of Genotypic and Phenotypic Variations and Covariance Components

Phenotypic and genotypic coefficients of variations were estimated according to the method suggested by Burton and de Vane (1953). Environmental, phenotypic and genotypic covariances between two characters were estimated in the same way as of the corresponding variance components.

2.4.3. Estimation of Broad Sense Heritability and Genetic Advance

Broad sense heritability was expressed as the percentage of the ratio of the genotypic variance to the phenotypic variance and was estimated on genotype mean basis as described by Allard (1960). Similarly, genetic advance in absolute unit (GA) and as percent of the mean (GAM), assuming selection of superior 5% of the genotypes was estimated in accordance with the methods illustrated by Johnson *et al.* (1955).

2.4.4. Estimation of Phenotypic and Genotypic Correlations

Phenotypic and genotypic correlation coefficients were estimated using the standard procedure suggested by Miller *et al.* (1958) from the corresponding variance and covariance components. Significance of phenotypic and genotypic correlation coefficients among characters was tested as per Sharma (1998) and Robertson (1959), respectively. Finally, the direct and indirect effects of characters on grain yield were estimated by computing path coefficient analysis as suggested by Wright (1921) and worked out by Dewey and Lu (1959) using phenotypic as well as genotypic correlation coefficients.

3. Results and Discussion

3.1. Analysis of Variance

Analysis of variance showed significant differences ($p < 0.05\%$) for all the characters considered, revealing the presence of adequate variability within the durum wheat accessions (Table 2). The present finding is in agreement with the report of Zohary (1970) who found tremendous variability in Ethiopian durum wheat accessions. Similarly, Getachew (1997) reported highly significant variations for days to heading, days to maturity, grain filling period, plant height, number of tillers plant^{-1}, number of kernels spike^{-1}, number of spikelets spike^{-1}, thousand kernels weight, biomass yield, kernel yield plant^{-1} and harvest index for Ethiopian durum wheat germplasm. Amin *et al.* (1992) also found highly significant variations among durum wheat accessions for grain filling period, number of kernels spike^{-1}, thousand kernels weight, grain yield, biomass yield and harvest index.

Plant height ranged from 73 cm (A-IV 29) to 111 cm (A-III 130) indicating the presence of sufficient variability among the tested accessions. The range of variation for grain yield was also very wide ranging from 2.4 to 4.2 ton ha^{-1} (Table 3) where the highest grain yield was obtained from A-III-130 followed by B-II-187 and B-II-191. Thus, we could succeed in improving durum wheat grain yield from direct selection of the best yielding accessions.

Table 2. Mean square estimates and the corresponding coefficient of variation for 13 quantitative traits in Ethiopian durum wheat accessions.

Characters	Mean square^a		CV
	Accession (43)	Error (86)	(%)
Days to heading (days)	55.6**	13.2	4.8
Days to maturity (days)	89.4**	25.3	3.8
Grain filling period (days)	55.4*	32.7	10.0
Plant height (cm)	230.8**	29.8	6.0
Number of productive tillers plant^{-1}	0.03*	0.02	12.1
Spike length (cm)	1.2**	0.2	7.4
Number of spikelets spike^{-1}	3.1**	0.8	5.6
Number of kernels spike^{-1}	22.9**	7.7	9.9
Grain yield plant^{-1} (g)	0.09**	0.03	16.7
Biomass yield (ton ha^{-1})	394.0**	183.2	15.5
Thousand kernels weight (g)	42.1**	8.3	7.4
Harvest index (%)	15.2*	5.5	6.4
Grain yield (ton ha^{-1})	525.5**	278.1	16.5

^{a} *Figures in parenthesis are degrees of freedom; * = Significant at $p < 0.05$; ** = Significant at $p < 0.01$; CV = Coefficients of variation*

3.2. Estimates of Variance Components

Phenotypic coefficient of variability (PCV %) values ranged from 4.1% for days to maturity to 15.6% for kernel yield plant^{-1}, while genotypic coefficient of variability (GCV %) ranged from 3.6% for days to maturity to 12.5% for spike length (Table 3). The PCV value was generally higher than their corresponding GCV value for all the characters considered. Phonotypic coefficient of variability and GCV values of approximately more than 20% are regarded as high whereas values less than 10% are considered low and values in between as medium (Deshmukh *et al.,* 1986). Considering this benchmark, PCV values were medium for kernel yield plant^{-1} (15.6%), spike length (13.2%), biomass yield (13.1%) and grain yield (13.1%) and were low for the rest of the characters. The GCV values, on the other hand, were low for most of the characters except for spike length (12.5%) and kernel yield plant^{-1} (12.3%). This result is partly in agreement with Getachew (1997) who reported medium PCV and GCV values for biomass yield and kernel yield plant^{-1}, respectively. In contrast to the present result, Getachew (1997) found high PCV values for number of tillers plant^{-1} and kernel yield plant^{-1}, and medium for number of kernels spike^{-1}, harvest index and thousand kernels weight. Similarly, the author also reported medium GCV values for number of kernels spike^{-1}, thousand kernels weight, biomass yield and harvest index. Amin *et al.* (1992) reported high GCV for grain yield, harvest index and number of kernels spike^{-1}. The difference between PCV and GCV values was high for grain filling period, number of productive tillers plant^{-1} and grain yield, showing the importance of environment in influencing these characters. This difference was small for spike length, plant height, thousand kernels weight, days to heading and maturity, number of spikelets spike^{-}

^{1}and harvest index suggesting minimal influence of environment on the expression of the characters.

3.3. Estimates of Broad Sense Heritability

Estimates of broad sense heritability were high (>80%) for spike length (89.2%), plant height (87.1%) and thousand kernels weight (80.2%), indicating that these characters were predominantly controlled by genetic factors. Thus, we could anticipate genetic advance under selection for these characters from different types and intensities of selection. Moderate broad sense heritability estimates (40-80%) were exhibited for the rest of the characters (Table 3). This result is partly in agreement with the report of Getachew (1997) who found high heritability estimate for thousand kernels weight, days to heading, days to maturity, number of tillers plant^{-1}, number of kernels spike^{-1}, number of spikelets spike^{-1}, kernel yield plant^{-1} and harvest index. Singh (1990) stated that if heritability of a character is more than 80%, selection for such characters could be fairly easy. This is because; there would be a close correspondence between the genotype and the phenotype due to the relative small contribution of the environment to the phenotype. However, for characters with low heritability, for example 40%, selection may be considerably difficult or virtually impractical due to the masking effect of the environment.

Although heritability estimates provide a basis for selection on the phenotypic performance, the estimates of heritability and genetic advance should always be considered simultaneously, because high heritability will not always be associated with high genetic advance (Johnson *et al.,* 1955). Swarup and Chaugale (1962) also reported that high heritability is not an indication of high genetic advance. Maximum genetic advance as percent of the mean (GAM) at 5% selection intensity was recorded for spike length (24.3%) followed by kernel yield plant^{-1} (20.0%), plant height (17.4%) and thousand kernels weight (15.9%) and the minimum was recorded for days to maturity (6.1%) followed by grain filling period (6.3%) and number of productive tillers plant^{-1} (8.4%) (Table 3). Genetic advance in absolute unit (GA) refers to the improvement of characters in genotypic value for the new population compared with the base population under one cycle of selection at a given selection intensity. Estimates of GA for grain yield was 0.4 ton ha^{-1} indicating that, whenever we select the best 5% high yielding genotypes as parents, mean grain yield of progenies could be improved by 0.4 ton ha^{-1}. That is, mean genotypic value of the new population for grain yield could be improved from 3.2 to 3.6 ton ha^{-1}. Similarly, the GA values for biomass yield, plant height, day to maturity, thousand kernels weight and harvest index were 1.3 ton ha^{-1}, 15.8 cm, 8 days, 6.2 g and 3.7%, respectively (Table 3). The present study revealed that spike length, plant height and thousand kernels weight had high heritability estimates and considerable genetic advance as percent of the mean. These characters, therefore, could be improved more easily than the rest of the characters. This result is partly in agreement with Getachew (1997) who reported high heritability with considerably high genetic advance for thousand kernels weight and kernel yield plant^{-1}. Amin *et al.* (1992) also reported high heritability estimates with considerably high genetic advance as percent of the mean for harvest index in durum wheat.

Table 3. Estimates of mean, phenotypic and genotypic coefficients of variations and genetic parameters for the durum wheat genotypes evaluated.

Character	Mean ± SE	Range	PCV(%)	GCV (%)	h^2 (%)	GA	GAM (%)
Days to heading (days)	75.1 ± 3.0	69.0-85.0	5.7	5.0	76.3	6.7	9.0
Days to maturity (days)	132.4 ± 4.1	123.0-141.0	4.1	3.6	71.7	8.0	6.1
Grain filling period (days)	57.3 ± 4.7	48.0-69.0	7.5	4.8	40.9	3.6	6.3
Plant height (cm)	90.4 ± 4.5	73.0-111.0	9.7	9.1	87.1	15.8	17.4
Productive tillers plant^{-1}	1.4 ± 0.02	0.9-2.2	9.5	6.2	42.9	0.1	8.4
Spike length (cm)	6.1 ± 0.4	4.8-7.7	13.2	12.5	89.2	1.5	24.3
Number of spikelets spike^{-1}	15.8 ± 0.7	14.1-18.1	6.5	5.6	75.2	1.6	10.1
Number of kernels spike^{-1}	27.9 ± 2.3	24.1-35.7	9.9	8.1	66.5	3.8	13.6
Kernel yield plant^{-1} (g)	1.1 ± 0.2	0.76-1.47	15.6	12.3	62.1	0.2	20.0
Biomass yield (ton ha^{-1})	8.8 ± 1.1	7.1-11.8	13.1	9.6	53.5	1.3	14.5
Thousand kernels weight (g)	38.9 ± 2.4	32.4-47.9	9.6	8.6	80.2	6.2	15.9
Harvest index (%)	36.6 ± 1.9	31.3-41.1	6.9	5.8	71.2	3.7	10.1
Grain yield (tons ha^{-1})	3.2.0 ± 0.4	2.4-4.2	13.1	9.0	47.1	0.4	12.7

3.4. Estimates of Phenotypic and Genotypic Correlations

Phenotypic and genotypic correlation coefficients of grain yield with other characters are presented in Table 4. Genotypic correlation coefficient values are greater for most of the characters than their corresponding phenotypic correlation coefficient values implying inherent association of the characters. At phenotypic level, grain yield had significant positive associations with biomass yield (r_p = 0.88**), plant height (r_p = 0.53**), thousand kernels weight (r_p = 0.41**), kernel yield plant^{-1} (r_p = 0.38*), number of kernels spike^{-1} (r_p = 0.32*) and harvest index (r_p = 0.32*). Similarly, at genotypic level, grain yield had a very strong positive correlation with kernel yield plant^{-1} ($r_g = 0.89^{**}$), plant height ($r_g = 0.84^{**}$), biomass yield ($r_g = 0.80^{**}$), thousand kernels weight ($r_g = 0.82^{**}$), number of kernels spike^{-1} ($r_g = 0.78^{**}$) and grain filling period ($r_g = 0.67^{*}$) implying that there might be common genes that control grain yield and these traits simultaneously. Thus, improving either one or all of these traits could result in high grain yield.

On the contrary, grain yield had strong negative correlation with days to heading ($r_g = -0.75^{**}$) (Table 4) suggesting that, selecting early heading accessions with a long grain filling period would give high grain yield in a moisture stress area. The present finding is in agreement with the previous reports. Amin *et al.* (1992) and Van Oosteron and Acevedo (1992) reported significant negative genotypic correlation of grain yield with days to heading, showing that early heading genotypes with adequate grain filling period escaped terminal moisture stress and thus, gave better grain yield. Hadjichristodoulou (1989) and Jaradat (1991) also reported negative genotypic correlation of grain yield with days to heading, indicating that early heading is an important escape mechanism in terminal stress conditions where crop plants experienced moisture and high temperature stresses during the grain filling period. Getachew (1997) also reported significant positive associations of grain yield with number of kernels spike^{-1} and thousand kernels weight at both genotypic and phenotypic levels. Moreover, in moisture stressed conditions of Syria, Jarrah and Geng (1997) found that grain yield was significantly and positively associated with grain filling period and number of kernels spike^{-1}. They also reported, significant negative association of grain yield with days to heading, indicating that a desirable plant under dry continental conditions should possess earliness with long grain filling period and high spike fertility.

Table 4. Genotypic (below diagonal) and phenotypic (above diagonal) correlations for some quantitative characters of the durum wheat accessions.

Characters	DH	DM	GFP	PH	NSS	NK	KYP	BY	TKW	HI	GY
DH		0.47^{**}	-0.32^{*}	-0.28^{ns}	0.37^{*}	0.07^{ns}	-0.06^{ns}	-0.09^{ns}	-0.17^{ns}	-0.29^{ns}	-0.23^{ns}
DM	0.80^{**}		0.69^{**}	-0.01^{ns}	0.42^{**}	0.19^{ns}	0.19^{ns}	0.02^{ns}	0.10^{ns}	-0.21^{ns}	-0.08^{ns}
GFP	-0.02^{ns}	0.58^{*}		0.23^{ns}	0.15^{ns}	0.14^{ns}	0.25^{ns}	0.10^{ns}	0.25^{ns}	0.01^{ns}	0.10^{ns}
PH	-0.54^{*}	0.05^{ns}	0.82^{**}		0.23^{ns}	0.38^{*}	0.47^{**}	0.60^{**}	0.37^{*}	-0.08^{ns}	0.53^{**}
NSS	0.50^{ns}	0.74^{**}	0.57^{*}	0.25^{ns}		0.63^{**}	0.48^{**}	0.23^{ns}	0.12^{ns}	-0.20^{ns}	0.12^{ns}
NK	-0.02^{ns}	0.30^{ns}	0.54^{*}	0.52^{*}	0.50^{ns}		0.77^{**}	0.30^{*}	0.23^{ns}	0.07^{ns}	0.32^{*}
KYP	-0.37^{ns}	0.28^{ns}	0.97^{**}	0.80^{**}	0.31^{ns}	0.73^{**}		0.33^{*}	0.53^{**}	0.139^{ns}	0.38^{*}
BY	-0.43^{ns}	0.13^{ns}	0.81^{**}	0.85^{**}	0.42^{ns}	0.73^{**}	0.77^{**}		0.30^{*}	-0.17^{ns}	0.88^{**}
TKW	-0.37^{ns}	0.25^{ns}	0.94^{**}	0.55^{*}	0.05^{ns}	0.40^{ns}	0.90^{**}	0.59^{*}		0.20^{ns}	0.41^{**}
HI	-0.47^{ns}	-0.51^{*}	-0.23^{ns}	-0.06^{ns}	-0.47^{ns}	0.06^{ns}	0.15	-0.37^{ns}	0.28^{ns}		0.32^{*}
GY	-0.75^{**}	-0.21^{ns}	0.67^{*}	0.84^{**}	0.11^{ns}	0.78^{**}	0.89^{**}	0.80^{**}	0.82^{**}	0.26^{ns}	

** and ** Significant at* $p < 0.05$ *and* $p < 0.01$*, respectively and ns = Non-significant at 5%. DH = Days to heading, DM = Days to maturity, GFP = Grain filling period, PH = Plant height, NSS = Number of spikelets spike*$^{-}$*NK = Number of kernels spike*$^{-1}$*, KYP = Kernel yield plant*$^{-1}$*, BY = Biomass yield, TKW = Thousand kernels weight, HI = Harvest index and GY = Grain yield.*

3.5. Estimates of Direct and Indirect Effects of Characters on Grain Yield

The phenotypic relationship exhibited between the dependent and independent characters was fully explained (99%) by the phenotypic path coefficient analysis model (Table 5). High and positive phenotypic direct effects on grain yield were exhibited by days to maturity (7.06) followed by biomass yield (0.96) and harvest index (0.47). The phenotypic correlation coefficients of grain yield with biomass yield and harvest index were almost equal to their corresponding phenotypic direct effect, indicating that phenotypic correlation coefficient explained the true relationship between them. On the other hand, the maximum positive phenotypic direct effect of days to maturity on grain yield was counterbalanced by the phenotypic indirect effects *via* days to heading and grain filling period (Table 5), resulting in weak negative phenotypic correlation (Table 4). The direct effects of grain filling period, days to heading and days to maturity on grain yield were counterbalanced by one another making their phenotypic correlation coefficients insignificant.

Similar to the phenotypic path coefficient analysis model, the genotypic path coefficient analysis had entirely explained (99%) the relationship between the dependent and independent characters (Table 6). Maximum positive direct effect on grain yield was exerted by biomass yield (1.08) followed by days to maturity (0.91) and harvest index (0.69). The genotypic correlation coefficient of biomass yield was almost equal to its genotypic direct effect, denoting that the genotypic correlation coefficient of biomass yield explained true relationship with grain yield (Tables 4 and 6). Despite strong positive genotypic correlations with grain yield, plant height, number of kernels spike^{-1}, thousand kernels weight and kernel yields plant^{-1} exhibited low genotypic direct effect on grain yield.

Maximum negative direct effect was exerted by days to heading (-0.72) followed by grain filling period (-0.52). Days to heading, in addition to the maximum negative direct effect on grain yield, had significant negative genotypic correlation with grain yield (Tables 4 and 6). The maximum negative direct effect of the grain filling period was counterbalanced by its positive indirect effects *via* days to maturity and biomass yield and rendered the genotypic correlation coefficient positive and significant. The present finding is in agreement with Srivastava *et al.* (1980) who reported negative and low direct effects of number of kernels spike^{-1} and thousand kernels weight on grain yield.

Table 5. Estimates of phenotypic direct effects (bold; diagonal values) and indirect effects (off-diagonal values) of different characters on grain yield of the durum wheat accessions.

Character	DH	DM	GFP	BY	TKW	HI
Days to heading	**-5.40**	3.33	2.07	-0.09	-0.002	-0.14
Days to maturity	-2.55	**7.06**	-4.51	0.02	0.001	-0.10
Grain filling period	1.70	4.85	**-6.55**	0.10	0.003	0.01
Biomass yield	0.50	0.15	-0.65	**0.96**	0.003	-0.08
Thousand kernels weight	0.92	0.71	-1.63	0.30	**0.011**	0.10
Harvest index	1.55	-1.47	-0.08	-0.16	0.002	**0.47**

Residual = 0.0083; DH = Days to heading; DM = Days to maturity; GFP = Grain filling period; BY = Biomass yield; TKW = Thousand kernels weight; HI = Harvest index

Table 6. Estimates of genotypic direct effects (bold; diagonal values) and indirect effects (off-diagonal values) of different characters on grain yield of the durum wheat accessions.

Character	DH	DM	GFP	BY	TKW	HI
Days to heading	**-0.72**	0.73	0.01	-0.46	0.009	-0.32
Days to maturity	-0.58	**0.91**	-0.30	0.14	-0.006	-0.35
Grain filling period	0.01	0.53	**-0.52**	0.87	-0.022	-0.16
Biomass yield	0.31	0.12	-0.42	**1.08**	-0.014	-0.25
Thousand kernels weight	0.29	0.23	-0.49	0.64	**-0.024**	0.19
Harvest index	0.34	-0.47	0.12	-0.39	-0.017	**0.69**

Residual = 0.0002; DH = Days to heading; DM = Days to maturity; GFP = Grain filling period; BY = Biomass yield; TKW = Thousand kernels weight; HI = Harvest index

4. Conclusion

Highly heritable, easily measurable traits could be used for rapid screening of large volumes of planting materials for specific traits and to select indirectly for associated traits with low heritability. Therefore, in the present study, plant height, spike length, thousand kernels weight, kernel yield plant^{-1}, number of kernels spike^{-1} and biomass yield showed significant heritable genetic variability with considerable genetic advance. Moreover, thousand kernels weight, plant height, number of kernels spike^{-1}, biomass yield and kernel yield plant^{-1} had strong positive genotypic correlations with grain yield. However, except biomass yield, neither of them had strong direct effect on grain yield. Days to heading, on the other hand, had negative correlation with grain yield, exerting negative direct effect on grain yield, explaining the importance of selecting early heading durum wheat accessions. From this study, it could be concluded that earliness coupled with high biomass yield could be considered as an indirect selection criterion for durum wheat grain yield improvement in moisture stressed areas.

5. References

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