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# EVALUATION OF THE ASSOCIATION AMONG YIELD AND CONTRIBUTING CHARACTERS THROUGH PATH COEFFICIENT ANALYSIS IN ADVANCED LINES OF DURUM WHEAT UNDER DIVERSE CONDITIONS

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## ABSTRACT

The present study was carried out at Sararood Dryland Agricultural Research Institute (DARI), during the growing season 2011-13 under rain-fed and irrigated conditions to investigate association among yield and yield contributing characters and to determine the suitable selection criteria in durum wheat breeding for higher yields. Field experiments were performed in a triplicated randomized block design. Combined analysis of variance revealed significant differences between lines for the most of traits studied. Traits of the number of fertile stems (NFS), number of grains per spike (NGPS) and thousand-kernel weight (TKW) were not affected by conditions × lines interaction effects. According to the stepwise regression analysis NFS and NGPS entered in the model and were recognized as the most effective traits on durum wheat grain yield under both irrigated and rain-fed conditions. Whiles NFS and NGPS have been recommended as selection criteria for increasing yield of durum wheat only in the rain-fed condition based on the result of path analysis and indirect effects. Advanced Wheat Line (ADWL)-3, ADWL-8, ADWL-10 and ADWL-7 are suggested useful considering production of desirable NFS, and ADWL-12 and ADWL-16 considering production of desirable NGPS, for further breeding programs and commercial release in the rain-fed condition. Days to physiological maturity (DM) has been recommended as a selection criterion only in the irrigated condition. ADWL-5 and ADWL-1 were selected considering maximum number of DM whiles these lines can adjust their buffered state in response to environmental fluctuations in such a way that they give maximum economic grain yield.

**Key words:** durum wheat, morpho-physiological characters, correlation analysis, path analysis, diverse conditions

## INTRODUCTION

Durum wheat (*Triticum durum Desf.*) is one of the pivotal cereals grown under rain-fed conditions in many parts of Iran including North Western, Central and extending up to the parts of North Eastern. Iran is currently an important producer of durum wheat globally. It enjoys promising position in the nation's economic perspective for production of 0.6 million tons during the crop season 2014-15 (Heidari *et al*., 2017). The increase of production in recent years has a positive reflection on regional and international market demand. In different parts of the world durum wheat is grown as an alimentation purpose for pasta, couscous and bulgur. The requirement and importance of durum wheat is increasing due to increment in human consumption, more compatibility with unsuitable environmental conditions compared with bread wheat (Edwards *et al*., 2007). Rain-fed cultivation of cereal often has been confronted with drought stress at the end of growth season. The economic yield in wheat is obtained from its grain yield, resulting from their relative contributions which are associated and water deficit severely affect these yield contributing attributes and subsequently, the productivity of crop plants (Rastegar, 2008). To subsist towards the stress, plants have adopted a number of complex morphological and physiological features. Many studies have been undertaken to identify the most important of these features in both field and controlled environments (Brancourt-Hulmel *et al.,* 2003); these studies effectually would be use for state-of-the-art crop plant research. Development of plants with desirable advantages under drought stress is one of the major challenges in wheat improvement programs. Plant breeders proclaim that morpho-physiological features are easy, rapid and still admissible to select the best genotypes as regard to exploration of new drought tolerant and high yielding wheat cultivars (Khalili and Naghavi, 2016). The efficiency of a breeding program depends primarily on the nature and magnitude of association pattern between yield and yield contributing characters and direct and indirect effects of these characters on yield. The correlation coefficient measures an extent *prima facie* of the inter relationship of the characters *per se*. When there is positive association of yield attributes, selection would be effective but when these attributes are negatively associated, it would be challenging to exploit synchronous selection for such attributes in breeding procedures. The path coefficient analysis which proposed theoretically by Wright (1921) and clarified by Dewey and Lu (1959) delineates direct effects of each variable on yield as well as indirect effects through other characters and illustrates the relative accentuation of each character evolved in contributing to the grain yield which is not disclosed from the correlation studies. There is rather an agreement among the plant breeders to increase the use of indirect selection to improve the grain yield (Benin *et al*., 2003). However, a few character association studies in the literature have been conducted for identification of association among traits which comparatively determine the importance of characters as selection criteria and also development of drought tolerant durum wheat genotypes under diverse environmental conditions. Evaluation of durum wheat genotypes was reported by Khalili and Naghavi (2016), traits *viz.* the number of grains per spike, thousand-kernel weight, biological yield and harvest index showed direct positive effects on grain yield while the number of grains per spike had the highest indirect effect on yield through biological yield and they reported that selection of genotypes on the basis of these traits seems to be more effective than the others to acquire more grain yield under rain-fed conditions. Rehman *et al*. (2017) showed that path analysis manifested traits including canopy temperature and days to physiological maturity had positive direct effect on the grain yield and may be selection criteria of best genotypes under water deficit condition. Naik *et al*. (2016) reported that biomass had the highest positive direct effect on grain yield followed by harvest index and root weight and the maximum indirect positive effect was exerted by spikes per meter, grains per spike and plant height through biomass under both irrigated and rain-fed environments through path analysis in durum wheat. Khan and Naqvi (2012) in similar researches under water stress and dry conditions revealed grain yield correlated positively with flag leaf area, plant height, biomass, number of spikes, spike length, number of spikelets per spike, number of grains per spike, 1000-grain weight and harvest index. Path coefficient analysis indicated grain yield had a positive direct effect with spike length and number of grains per spike. They deduced that these traits having a positive direct effect on grain yield can be considered as a suitable selection criteria for evolving high yielding wheat elite genotypes. The present study has been performed to investigate direct and indirect effects of yield related traits on grain yield of durum wheat under rain-fed and irrigated conditions.

## MATERIALS AND METHODS

**Station description:** Four field experiments were conducted during crop years 2011-12 and 2012-13 in west of Iran (Sararood Dryland Research Institute (DARI) located in Kermanshah), under both irrigated and rain-fed conditions. Climate in the region was classified as semi-arid with the long-term average of rainfall (445 mm). During the two years of this study, precipitation was generally below the long-term average, particularly in the 2011-12 (Table 1).

**Table 1. Environments description and agronomical details**

| Site and Coordinate | Sararood (34° 19´ N; 47° 17´ E) | | | |
|---|---|---|---|---|
| Altitude | 1351 m | | | |
| Soil Texture | clay loam | | | |
| Average long-term annual precipitation | 445 mm | | | |
| Year Conditions | 2011-12 | | 2012-13 | |
| | Rain-fed | Irrigated | Rain-fed | Irrigated |
| Seasonal rainfall + irrigation (mm) | 330.63 | 330.63+50 | 430.87 | 430.87+50 |
| Number of freezing days | 11 | | | 7 |
| Average temperatures (°C*) | | | | |
| T max | 17.98 | | | 19.17 |
| T mean | 10.60 | | | 12.00 |
| T min | 3.30 | | | 4.50 |
| Relative humidity | 47.16% | | | 51.31% |
| Evaporation amount (mm) | 101.64 | | | 97.62 |
| Agronomic practices | | | | |
| Fertilizers, kg $ha^{-1}$(applied at planting) | | | | |
| N | 41.00 | | | 45.00 |
| $P_2O_5$ | 46.00 | | | 50.00 |
| Sowing time | October | | | October |

* Average temperature of 9 months (October-June)

**Plant materials and field investigated characters:** Sixteen advanced breeding lines of durum wheat including three control genotypes (Table 2) were evaluated under two conditions vis., rain-fed and supplementary irrigation in a triplicated randomized complete block design (RCBD). Irrigation was done twice at the flowering stage for the maturity so that each stage received 25 mm. Seeds were sown using an experimental drill in 1.2×6 m plots consisting of 6 rows with 20 cm space between rows. The seeding rate was adjusted for a density of 350 viable seeds $m^{-2}$, according to the standard practices. Data on seed yield were taken from the middle two rows of each plot. Data were collected from each plot on some characters namely thousand-kernel weight (TKW) (g), grain yield (GY) ($gm^{-2}$), number of grains per spike in $m^2$ (NGPS), total number of fertile stems in $m^2$ (NFS), number of days to physiological maturity (DM), canopy temperature (CT) (°C).

**Table 2. Durum wheat genotypes used in the experiment and their pedigrees**

| No | Name/Pedigree | No | Name/Pedigree |
|---|---|---|---|
| ADWL-1** | Saji[c] | ADWL-10 | 19E-M141995 |
| ADWL-2 | Zardak[c] | ADWL-11 | 18E-M142005 |
| ADWL-3 | Sardari[c] | ADWL-12 | 19E-M142017 |
| ADWL-4 | 19E-TOPDY | ADWL-13 | 19E-M142025 |
| ADWL-5 | 19E-RASCON | ADWL-14 | 19E-MI142038 |
| ADWL-6 | 19E-M844859 | ADWL-15 | 19E-M142045 |
| ADWL-7 | 19E-M141979 | ADWL-16 | 19E-M142069 |
| ADWL-8 | 19E-M141982 | | |
| ADWL-9 | 19E-M141994 | | |

* = Sararood Dryland Agricultural Research Institute, ** = Advanced Durum Wheat Line, c = control genotypes

**Statistical analysis:** The analysis of variance for grain yield and other related characteristics were performed over trails after verifying the homogeneity of trail variance error using Bartlett's test (Bartlett, 1937) and the means were separated by Duncan's Multiple Range (DMR) Test (Duncan, 1955) at the 5% probability level. Stepwise regression analysis was carried out for identifying significant attributes affecting grain yield. The SAS (SAS Institute, Inc., 1997) procedures were used for these calculations. The simple correlation coefficients between the characteristics computed as suggested by Pearson (1920), subsequently partitioning the correlation coefficient, *rij*, into direct and indirect effects according to Dewey and Lu (1959) was performed using the PATH2 software.

## RESULTS AND DISCUSSION

**Analysis of variance:** Results of combined analysis of variance in the morpho-physiological characters showed significant differences between lines (L) for the most of traits studied. Result of combined analysis of variance for grain yield, number of fertile stems, number of grains per spike, thousand-kernel weight, days to physiological maturity and canopy temperature traits have been shown in Table 3.These indicated that genetic variability existed among lines for selection to identify the superior lines and to use them as a source for breeding. Mean comparison of grain yield and related traits of the advanced durum wheat lines including control is shown in Table 4 which indicated that supplementary irrigated condition was the best. Grain yield of durum wheat lines ranged between 557.8 and 818.0 $gm^{-2}$. ADWL-12, ADWL-10, and ADWL-1 as control, had yielded higher (818.0, 798.1 and 763.1, respectively).

The lines ADWL-3(c), ADWL-8, ADWL-10, ADWL-7 and ADWL-12 had the maximum number of fertile stems (1199.2, 789.1, 745.8, 734.1 and 733.3, respectively). Number of grains per spike for ADWL-3 was 20.5 and for ADWL-12, ADWL-16 and ADWL-7 were 40.6, 39.8 and 39.6, respectively. The ADWL-7 had the minimum thousand-kernel weight (29.0g). ADWL-3, ADWL-2 and ADWL-10 had the maximum TKW (40.3g, 34.5g and 33.3g, respectively). Days to physiological maturity for ADWL-3 were 214.2 days and for ADWL-5, ADWL-1 and ADWL-10 were (217.9, 217.3 and 217.0 days, respectively). The ADWL-2 had the minimum (36 °C) canopy temperature. ADWL-5 and ADWL-9 had the maximum CT (44.9 °C and 37.8 °C, respectively). Many researchers also reported significant differences between genotypes for grain yield, number of fertile stems, number of grains per spike and thousand-kernel weight (Hama *et al*., 2016; Singh *et al*., 2016; Bogale and Tesfaye, 2016; Singh, 2016; Ebrahimnejad and Rameeh, 2016; Naik *et al*., 2016; Mengistu *et al*., 2016; Bhutto *et al*., 2016).

In the present study, such considerable range of variations for traits provides a good opportunity for yield improvement and introducing commercial cultivars especially under drought stress condition. But direct selection for the grain yield could be misleading because of the selection for yield under drought stress conditions is intricate by environmental conditions and genotype x environment interaction which limits the selection efficiency (Ceccarelli *et al*., 2000). Furthermore, the grain yield itself is a result of actions of several component traits which influence the yield capacity both directly and indirectly. The usefulness of a breeding program, therefore, can be improved by selection for desired traits associated with grain yield under drought stress, which are less face to large genotype x environment interaction. In this study, traits of the number of fertile stems, the number of grains per spike and thousand-kernel weight were not affected by conditions (C) i.e., dry farming and irrigated and also interaction effects (Table 3), so these may be considered as worthwhile traits for selection of durum wheat. Drought stress is the main limiting factor against durum wheat production across the globe. Understanding the inter-relationship and relative contribution of various traits on grain yield in the diverse conditions is the basis of selection of high-yielding lines and tolerant wheat to dry environments.

**Stepwise regression and correlation of yield with yield related traits:** For elimination independent variables with negligible effect on the grain yield (GY) as dependent variable and fitting the best model, the stepwise regression method was carried out under two moisture conditions (rain-fed and irrigated). Results showed the number of grains per spike (NGPS), total number of fertile stems (NFS) and thousand-kernel weight (TKW) remained in the final model and eventually explained 95% of the GY variation under the rain-fed conditions in the first season and under irrigated condition. Finally traits *viz.* canopy temperature (CT), days to physiological maturity (DM) and NFS remained in the regression model and explained 83% of the GY variations (Table 5).

Regarding second season under rain-fed condition, NGPS, DM and NFS remained in the final model and explained 89% of the GY variations and under irrigated condition, eventually, two traits *viz.* NGPS and NFS remained in the model and explained 62% of the GY variations. Other studied traits affected non significantly on the model, thus, difference between lines from point of GY can be attributed to the difference in these mentioned traits. Use of the regression analysis in evaluation of wheat genotypes under stress was reported by Khalili and Naghavi (2016) where traits *viz.* NGPS and TKW entered to the model, respectively. Ahmadi *et al*. (2016) showed the TKW, DM, NGPS remained in the final model. Moghadam *et al*. (1997) showed that the traits of NGPS and TKW were the most effective traits determining the wheat GY based on the results of stepwise regression. Maas *et al*. (1996) showed that GY is dependent on the NFS by using the stepwise regression analysis in wheat. The Pearson's correlation coefficient among the all characters for the first and second season under the rain-fed and irrigated conditions was carried out (because of considerable content of information, the result of all data not shown). The correlation coefficients are presented in Table 6. Respecting to first season under rain-fed condition, it was highly significant and positive correlation between GY and NGPS which was 0.65. In many studies, it has been reported that inter-relationship between NGPS and GY had positive and highly significant correlation (Rudra Naik *et al*., 2016; Bhutto *et al*., 2016). In the present study, it was declared that GY correlated significantly with traits of NFS and TKW which were 0.49 and 0.58 consequently. Rudra Naik *et al*. (2016) and Bhutto *et al*. (2016) reported that NFS showed positive and highly significant correlation with GY. Similar result of significant and positive correlation between GY and TKW was presented by Golparvar *et al*. (2003). However, obtained results from present research were contrary to Mollasadeghi *et al*. (2011). Our findings are in agreement with the results of other researchers who reported positive and significant correlations between the GY and NGPS, TKW and NFS in wheat (Mecha *et al*., 2017; Khan and Hassan, 2017). This shows that any increase in these traits will result in proportionate increase in GY. In the present study, the character TKW correlated non-significantly with NGPS and NFS. NFS correlated non-significantly with NGPS. Inconsistently, Bhutto *et al*. (2016) reported the association of NFS and NGPS traits had the positive and highly significant correlation (r = 0.78).

Regarding first season, under irrigated condition, negative and significant correlation recorded between the character GY and CT which was -0.73. There was no significant correlation between GY and NFS. It was noticed that GY correlated highly significant and positive with DM trait which was 0.72. In contrast, RudraNaik *et al*. (2016) reported negative and non-significant correlations between the GY and DM (-0.06) under irrigated condition, while they reported highly significant and positive correlation between the GY and DM (0.33) under rain-fed condition. There was no significant correlation between NFS with CT and DM also between DM with CT. RudraNaik *et al*. (2016) reported similar results (negative and non-significant correlation) between the NFS and DM under both conditions. Dehghan *et al*. (2011) showed that the GY correlation was significant positive with DM in the study of lines of wheat. Ali *et al*. (2007) have pointed to poor correlation between GY and DM in Iran's native wheat genotypes. Respecting to second season under rain-fed condition, it was highly significant and positive correlation between GY and NFS which was 0.64, while it was noticed that GY correlated non-significantly with NGPS and DM which were 0.33 and -0.27 consequently. The character DM correlated non-significantly with NFS and NGPS. NGPS correlated non-significantly with NFS. Okuyama *et al*. (2004) showed that the wheat GY was positively correlated with NFS and NGPS. Respecting to second season under irrigated condition it was significant and positive correlation between GY and NFS which was 0.52, while it is reported that GY correlated non-significantly with NGPS which was 0.21. The character NFS correlated negatively and significantly with NGPS (-0.54). Mirakhoundi (2001) reported a positive correlation between GY, NFS, NGPS and TKW. In the present study on durum wheat, it was emphasized that the NGPS and TKW were correlated significant and positive with GY only in the rain-fed condition. RudraNaik *et al*. (2016) reported significant, but, negative correlation between TKW and GY under rain-fed condition while the results of this study are in conformity to the findings of RudraNaik *et al*. (2016) under irrigated condition showing there are no significant correlation between TKW and GY. RudraNaik *et al*. (2016) reported highly significant and positive correlation between NGPS and GY under both conditions. The DM (positively) and CT (negatively) were correlated to GY only under irrigated conditions and NFS positively was significant at both rain-fed and irrigated conditions. Similarly Garcia Del Moral *et al*. (2003) reported the trait of NGPS, although not significant, was positively correlated with GY under rain-fed conditions and the DM had a positive correlation with GY under irrigated conditions. Though, there is necessity of focusing on these traits which have a high correlation with grain yield and also utilize them in breeding programs to increase grain yield, but selections on the basis of simple correlations *per se* cannot display desired results. Determination of correlation between different traits, especially grain yield and its components along with determination of cause and effect relations between them allow breeders to select most suitable components which lead to higher yield.

**Table 3. Mean Squares from the combined analysis of variance for grain yield and related traits of ADWLs under two moisture conditions (rain-fed and irrigated) during two cropping seasons (2011-2013)**

| Source | DF | GY | NFS | NGPS | TKW | DM | CT |
|---|---|---|---|---|---|---|---|
| Year(Y) | 1 | 9443889 .10$^{**}$ | 13900000.00$^{**}$ | 638.30$^{**}$ | 331.00$^{**}$ | 18723.00$^{**}$ | 8.40$^{ns}$ |
| Conditions(C) | 1 | 12918431.00$^{**}$ | 56204.20$^{ns}$ | 5675.60$^{**}$ | 10168.90$^{**}$ | 320.30$^{**}$ | 2048.80$^{**}$ |
| Y × C | 1 | 3646739.20$^{**}$ | 324640.70$^{**}$ | 6234.60$^{**}$ | 1054.20$^{**}$ | 1170.10$^{**}$ | 1989.10$^{**}$ |
| Replication/YC | 8 | 98861.10$^{*}$ | 101367.50$^{**}$ | 29.40$^{ns}$ | 639.20$^{**}$ | 2.00$^{*}$ | 6.60$^{**}$ |
| Lines(L) | 15 | 77277.50$^{*}$ | 264601.60$^{**}$ | 303.00$^{**}$ | 80.00$^{*}$ | 10.80$^{**}$ | 51.45$^{**}$ |
| L × Y | 15 | 88574.80$^{**}$ | 90231.00$^{**}$ | 109.60$^{**}$ | 40.20$^{ns}$ | 8.40$^{**}$ | 5.00$^{**}$ |
| L × C | 15 | 91321.90$^{**}$ | 23512.60$^{ns}$ | 52.20$^{ns}$ | 70.00$^{ns}$ | 4.50$^{**}$ | 6.20$^{**}$ |
| L ×Y × C | 15 | 83465.90$^{*}$ | 17003.50$^{ns}$ | 61.80$^{ns}$ | 23.20$^{ns}$ | 8.70$^{**}$ | 7.80$^{**}$ |
| Error | 120 | 38317.80 | 27430.90 | 48.00 | 44.20 | 0.90 | 2.20 |
| Total | 191 | | | | | | |

$^{*}$ Significant at 0.05 probability level, $^{**}$ Significant at 0.01 probability level.

GY = Grain Yield, NFS = Number of Fertile Stem, NGPS = Number of Grain Per Spike, TKW = Thousand-Kernel Weight, DM = Days to Physiological Maturity, CT = Canopy Temperature.

**Path coefficient analysis:** The path coefficient analysis was carried out to understand the contribution of the varied components of the yield to the grain yields of the lines used in the present study. This analysis by partition of the relative contribution of yield components, provide an effective way to distinguish direct and indirect correlation effects. The direct and indirect effects of the components observed on grain yield are presented in Table 7. Regarding first season under rain-fed condition, the maximum positive direct effect on the yield was observed in NGPS (0.78), followed by NFS (0.58) and TKW (0.27), which were similar to the result of Abinasa *et al*. (2011); Naghavi and Khalili (2017) and Ahmadizadeh *et al*. (2011). Mecha *et al*. (2017) also pointed that NGPS and TKW had positive direct effect on GY. The indirect effects of the NGPS *via* NFS was negative and small (-0.15) and was too small and positive *via* TKW (0.02). Hence, correlation coefficient of NGPS with yield (0.65) did not reduce and remained significant. This suggested that direct selection through this character is effective. Naghavi and Khalili (2017) reported NGPS had negative indirect effect on GY through TKW which is contrary to the present results. The indirect effect of NFS *via* NGPS and TKW was negligible or negative. Hence, the correlation of NFS with GY (0.49) was largely due to the direct effects and remained significant. The indirect effect of TKW through NGPS was too low and positive (0.06) and *via* NFS was low and positive (0.26). Direct effect of TKW was 0.27 and its positive effects through NGPS and NFS caused its correlation with yield to be a significant and positive. These findings were not in accordance with those of Iftikhar *et al*. (2012) and Mecha *et al*. (2017) which showed negative indirect effect on GY *via* NGPS and NFS. Residual effect in the first season under rain-fed condition was 0.22 (Table 7) which represents the traits in the path analysis accounted for 78.4% of the variability in GY. In path analysis, the residual effect specifies how superior the independent variables account for the variability of the GY as a dependent variable (Gelalcha and Hanchinal, 2013) and also indicates that the existent variables can properly predict the yield.

**Table 4. Mean comparisons for six characters of durum wheat evaluated during 2011-13 by Duncan's Multiple Range (DMR) Test**

| Conditions & Lines | GY | NFS | NGPS | TKW | DM | CT |
|---|---|---|---|---|---|---|
| **Conditions** | | | | | | |
| Irrigated | 936.4$^{a}$ | 731.5 | 42.0$^{a}$ | 39.5$^{a}$ | 217.4$^{a}$ | 34.1$^{b}$ |
| Rain-fed | 417.6$^{b}$ | 697.2 | 31.1$^{b}$ | 24.9$^{b}$ | 214.9$^{b}$ | 40.6$^{a}$ |
| **Lines** | | | | | | |
| ADWL-1(c)* | 763.1$^{ab}$ | 730.0$^{bc}$ | 38.8$^{a}$ | 30.0$^{b}$ | 217.3$^{ab}$ | 37.2$^{bc}$ |
| ADWL-2(c) | 569.8$^{c}$ | 729.1$^{bc}$ | 29.4$^{b}$ | 34.5$^{b}$ | 214.6$^{gh}$ | 36.0$^{c}$ |
| ADWL-3(c) | 703.0$^{abc}$ | 1199.2$^{a}$ | 20.5$^{a}$ | 40.3$^{a}$ | 214.2$^{h}$ | 37.1$^{bc}$ |
| ADWL-4 | 611.5$^{bc}$ | 603.3$^{cd}$ | 37.0$^{a}$ | 31.8$^{b}$ | 216.5$^{bcde}$ | 37.1$^{bc}$ |
| ADWL-5 | 560.8$^{c}$ | 518.3$^{d}$ | 39.5$^{a}$ | 29.7$^{b}$ | 217.9$^{a}$ | 44.9$^{a}$ |
| ADWL-6 | 557.8$^{c}$ | 592.5$^{cd}$ | 36.7$^{a}$ | 30.7$^{b}$ | 215.7$^{ef}$ | 36.9$^{bc}$ |
| ADWL-7 | 661.1$^{abc}$ | 734.1$^{bc}$ | 39.6$^{a}$ | 29.0$^{b}$ | 216.3$^{cde}$ | 36.6$^{bc}$ |
| ADWL-8 | 713.2$^{abc}$ | 789.1$^{b}$ | 37.5$^{a}$ | 31.5$^{b}$ | 215.0$^{fg}$ | 37.0$^{bc}$ |
| ADWL-9 | 685.6$^{abc}$ | 695.0$^{bc}$ | 37.7$^{a}$ | 31.4$^{b}$ | 216.1$^{cde}$ | 37.8$^{b}$ |
| ADWL-10 | 798.1$^{ab}$ | 745.8$^{bc}$ | 38.5$^{a}$ | 33.3$^{b}$ | 217.0$^{bc}$ | 36.9$^{bc}$ |
| ADWL-11 | 678.3$^{abc}$ | 677.9$^{bc}$ | 38.7$^{a}$ | 31.1$^{b}$ | 215.9$^{def}$ | 37.4$^{bc}$ |
| ADWL-12 | 818.0$^{a}$ | 733.3$^{bc}$ | 40.6$^{a}$ | 32.3$^{b}$ | 215.9$^{def}$ | 36.6$^{bc}$ |
| ADWL-13 | 608.8$^{bc}$ | 636.6$^{bcd}$ | 37.5$^{a}$ | 32.8$^{b}$ | 216.5$^{bcde}$ | 36.5$^{bc}$ |
| ADWL-14 | 730.0$^{abc}$ | 719.1$^{bc}$ | 38.7$^{a}$ | 32.0$^{b}$ | 216.6$^{bcd}$ | 36.4$^{c}$ |
| ADWL-15 | 662.1$^{abc}$ | 595.0$^{cd}$ | 34.5$^{ab}$ | 31.9$^{b}$ | 216.8$^{bc}$ | 37.0$^{bc}$ |
| ADWL-16 | 710.5$^{abc}$ | 731.6$^{bc}$ | 39.8$^{a}$ | 33.0$^{b}$ | 216.2$^{cde}$ | 36.3$^{c}$ |
| LSD | 79.9 | 67.6 | 2.8 | 2.7 | 0.3 | 0.6 |

*(c): control

Means of a column followed by the same letter do not differ significantly using LSD at 5% level of probability. GY = Grain Yield, NFS = Number of Fertile Stem, NGPS = Number of Grain Per Spike, TKW = Thousand-Kernel Weight, DM = Days to Physiological Maturity, CT = Canopy Temperature.

**Table 5. Results of stepwise regression analysis for grain yield in ADWLs**

| Model | Unstandardized Coefficients | | Standardized | t | Sig | $R^2$ | Adj $R^2$ |
|---|---|---|---|---|---|---|---|
| | ***B*** | **Std. Error** | ***β*** | | | | |
| **First season** | | | | | | | |
| **Rain-fed condition** | | | | | | | |
| Constant | -613.53 | 69.89 | | -8.77 | .00 | | |
| NGPS | 11.27 | 0.92 | 0.78 | 12.22 | .00 | 0.95 | 0.94 |
| NFS | 0.56 | 0.07 | 0.57 | 7.99 | .00 | | |
| TKW | 11.38 | 2.96 | 0.26 | 3.84 | .00 | | |
| **First season** | | | | | | | |
| **Irrigated condition** | | | | | | | |
| Constant | -6818.07 | 2181.43 | | -3.12 | .00 | | |
| DM | 40.98 | 8.87 | 0.59 | 4.61 | .00 | 0.83 | 0.79 |
| NFS | 0.57 | 0.21 | 0.32 | 2.64 | .00 | | |
| CT | -48.09 | 16.35 | -0.39 | -2.94 | .00 | | |
| **Second season** | | | | | | | |
| **Rain-fed condition** | | | | | | | |
| Constant | -8827.67 | 3462.11 | | -2.55 | .00 | | |
| NFS | 0.66 | 0.06 | 1.04 | 9.73 | .00 | 0.89 | 0.87 |
| NGPS | 30.28 | 3.98 | 0.85 | 7.61 | .00 | | |
| DM | 34.69 | 14.87 | 0.24 | 2.33 | .00 | | |
| **Second season** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Irrigated condition** | | | | | | | |
| Constant | -766.74 | 455.27 | | -1.68 | 0.00 | | |
| NFS | 0.94 | 0.20 | 0.90 | 4.60 | 0.00 | 0.62 | 0.56 |
| NGPS | 21.76 | 6.06 | 0.70 | 3.59 | 0.00 | | |

GY = Grain Yield, NFS = Number of Fertile Stem, NGPS = Number of Grain Per Spike, TKW = Thousand-Kernel Weight, DM = Days to Physiological Maturity, CT = Canopy Temperature.

**Table 6. Analysis results of correlations between related traits and durum wheat grain yield under rain-fed and irrigated conditions of crop year 2011-13**

| **First season (2011-12)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Rain-fed** | | | | | **Irrigated** | | | |
| | **NGPS** | **NFS** | **TKW** | **GY** | | **CT** | **DM** | **NFS** | **GY** |
| NGPS | 1 | | | | CT | 1 | | | |
| NFS | -0.26 | 1 | | | DM | -0.42 | 1 | | |
| TKW | 0.07 | 0.45 | 1 | | NFS | -0.28 | -0.12 | 1 | |
| GY | 0.65$^{**}$ | 0.49$^{*}$ | 0.58$^{*}$ | 1 | GY | -0.73$^{**}$ | 0.72$^{**}$ | 0.36 | 1 |

| **Second season (2012-13)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Rain-fed** | | | | | **Irrigated** | | |
| | **NFS** | **NGPS** | **DM** | **GY** | | **NFS** | **NGPS** | **GY** |
| NFS | 1 | | | | NFS | 1 | | |
| NGPS | -0.41 | 1 | | | NGPS | -0.54$^{*}$ | 1 | |
| DM | -0.21 | -0.34 | 1 | | GY | 0.52$^{*}$ | 0.21 | 1 |
| GY | 0.64$^{**}$ | 0.33 | -0.27 | 1 | - | | | |

$^{*}$ Significant at 0.05 probability level, $^{**}$ Significant at 0.01 probability level.
GY = Grain Yield, NFS = Number of Fertile Stem, NGPS = Number of Grain Per Spike, TKW = Thousand-Kernel Weight, DM = Days to Physiological Maturity, CT = Canopy Temperature.

**Table 7. Direct and indirect effects of different characters towards grain yield in different environments**

| **Trait** | **direct effect** | **Indirect effect via** | | | | | **Total effect Correlation** |
|---|---|---|---|---|---|---|---|
| | | **NGPS** | **NFS** | **TKW** | **CT** | **DM** | |
| First season | | | | | | | |
| Rain-fed condition | | | | | | | |
| NGPS=X1 | 0.78 | | -0.15 | 0.02 | - | - | 0.65$^{**}$ |
| NFS=X2 | 0.58 | -0.21 | … | 0.12 | - | - | 0.49$^{*}$ |
| TKW=X3 | 0.27 | 0.06 | 0.26 | … | - | - | 0.59$^{*}$ |
| Residual Effect= 0.22 | | | | | | | |
| First season | | | | | | | |
| Irrigated condition | | | | | | | |
| DM=X1 | 0.60 | - | -0.04 | - | 0.17 | … | 0.72$^{**}$ |
| NFS=X2 | 0.32 | - | … | - | 0.11 | -0.07 | 0.36$^{ns}$ |
| CT=X3 | -0.39 | - | -0.09 | - | … | -0.25 | -0.74$^{**}$ |
| Residual Effect= 0.40 | | | | | | | |
| Second season | | | | | | | |
| Rain-fed condition | | | | | | | |
| NFS=X1 | 1.05 | -0.35 | … | - | - | -0.05 | 0. 64$^{**}$ |
| NGPS=X2 | 0.85 | … | -0.43 | - | - | -0.08 | 0. 34$^{ns}$ |
| DM=X3 | 0.24 | -0.29 | -0.22 | - | - | … | -0. 27$^{ns}$ |
| Residual Effect= 0.32 | | | | | | | |
| Second season | | | | | | | |
| Irrigated condition | | | | | | | |
| NFS=X1 | 0.90 | -0.38 | … | - | - | - | 0. 52$^{*}$ |
| NGPS=X2 | 0.70 | … | -0.49 | - | - | - | 0. 21$^{ns}$ |
| Residual Effect= | 0.62 | | | | | | |

GY = Grain Yield, NFS = Number of Fertile Stem, NGPS = Number of Grain Per Spike, TKW = Thousand-Kernel Weight, DM = Days to Physiological Maturity, CT = Canopy Temperature.

Regarding first season under irrigated condition maximum positive direct effect on the yield was DM (0.60), followed by NFS (0.32) which was similar to the result of Rehman *et al*. (2017) and Mecha *et al*. (2017) who showed that DM and NFS had positive direct effect on the wheat yield while their result was contrary to our finding under water deficit condition. This discrepancy in results could be due to difference in genotypes and environments in which the studies were carried out. The indirect effect of DM through the NFS was too small and negative (-0.04). Hence, the significant correlation coefficient of DM with GY (0.72) had been largely due to the direct effects; did not decline and remained significant. The indirect effect of DM through the CT was low and positive (0.17). Correlation coefficient of NFS with GY was insignificant due to indirect negative effects through DM. The indirect effect of NFS through the CT was low and positive (0.11). CT had negative significant correlation with GY (-0.74). Its direct effect on GY (-0.39) was also negative and smaller than its correlation value indicating indirect influence of the trait *via* other component characters. Indirect effect through DM (-0.25) supports this idea. This result is not in agreement with Rehman *et al*. (2017), who reported that CT had positive direct effect on the GY. Negative effects of CT through traits of DM and NFS caused significant negative correlation with the grain yield. Residual effect in first season under irrigated condition was 0.40 which shows the existent variables in the path analysis accounted for 60% of the variability in GY, so they can properly predict the grain yield. Mohammadi (2014) in the study on wheat reported that NFS had the most direct effect on GY. This trait also could indirectly through DM have a positive effect on GY. They reported that DM had the most direct effect on GY after NFS, this trait also affected indirectly through NFS on GY. Regarding second season under rain-fed condition, path analysis manifested high and positive direct effects on GY for NFS (1.05), NGPS (0.85) and DM (0.24). The direct effect of NFS on GY suggested its importance in breeding program for developing wheat genotypes with higher grain yield. NFS was positively and significantly correlated with GY (0.64) and its indirect effects through NGPS (-0.35) and DM (-0.05) were small. Generally, traits that showed positive direct effect and significant positive correlation coefficient with grain yield while the relevant indirect effects of these characters through other traits were either negligible or negative were recognized as having the true relationship and need much focus to improve grain yield. In that case, their correlation coefficient with grain yield was widely due to their direct effect. This implicit that a small enhancement in NFS and NGPS may directly contribute to grain yield and the direct selection *via* these traits will be more effective. The correlation of NGPS with GY was non-significant due to the high indirect negative effect through NFS (-0.43) and DM (-0.08). Correlation of DM with GY was negative and non-significant due to the indirect negative effect through NFS (-0.22) and NGPS (-0.29). This negative relationship between DM and GY is favorable if stresses conditions such as terminal drought and heat are expected during growing season. This suggestion can be justified by prior report of Gelalcha and Hanchinal (2013); Heidari *et al*. (2017) and Mecha *et al*. (2017). Residual effect in the second season under rain-fed condition was 0.32 which displays the traits in the path analysis accounted for 68% of the variability in GY. NFS and NGPS had high positive direct effects on yield which is in agreement with result of Okuyama *et al*. (2004). Regarding second season under irrigated condition, the highest positive direct effect on GY was exhibited by NFS (0.90) and NGPS (0.70). The indirect effect of NFS through NGPS was recorded negative with a value of (-0.38). Significant correlation coefficient of NFS with yield (0.52) did not decline and remained significant, although its indirect effect through NGPS was moderate and negative (-0.38). Correlation of NGPS with grain yield was non-significant due to high and negative indirect effect of this trait through NFS (-0.49). Residual effect in the second season under irrigation condition was 0.62 which implicates the traits in the path analysis accounted for 38.4% of the variability in GY. It is suggested that the reason of residual effect amount may be firstly, there are two variables in the model; secondly, there are probably other variables that are not measured and have effect on yield under these conditions due to the large fluctuations in the environment. Moghadam *et al*. (1997) showed that NGPS and TKW had a high correlation with wheat GY and they had a high direct and significant effect on this trait. Present study revealed that according to the stepwise regression analysis, NFS and NGPS entered in the model and were recognized as the most effective traits on durum wheat grain yield under both irrigated and rain-fed conditions. While the results of path analysis showed that (despite the fact that the NFS had the highest direct effect on GY under both moisture conditions) the indirect negative effect of this trait did not affect on its correlation with yield through the NGPS and it remained significant under rain-fed conditions. But under irrigated conditions indirect negative effect of this trait on the yield lead to non-significant correlation with yield through DM. As a result, path analysis showed that NFS is a factor affecting the yield under rain-fed condition. ADWL-3, ADWL-8, ADWL-10 and ADWL-7 cultivars could be recommended for wheat selecting, further breeding programs and commercial release in the rain-fed condition considering production of desirable number of fertile stems in $m^2$ (1199.2, 789.1, 745.8 and 734.1, respectively). Direct effect of NGPS on yield was also high under both moisture conditions, but when its correlation with yield was significant that the indirect effect of this trait through TKW did not caused to reduce the total effect of the trait. While the indirect effect of this trait *via* other traits caused the insignificant of its correlation with yield. So they can be used as selection criteria for wheat yield improvement in breeding programs under rain-fed condition and according to the direct and indirect effects of this trait through other characters on yield under every condition. ADWL-12 and ADWL-16 cultivars could be recommended for wheat selecting in the rain-fed condition considering production of desirable number of grains per spike in $m^2$ (40.6 and 39.8). TKW for increasing yield under rain-fed condition and CT in order to decrease the yield under irrigated condition were entered to the stepwise regression. Therefore, ADWL-3 was selected considering production of desirable thousand-kernel weight and ADWL-2 was selected considering minimum canopy temperature. DM had a high direct effect on yield under both conditions. None the less its correlation with yield was significant only under irrigated condition. But its correlation with yield was insignificant because of indirect negative effect of this trait through NFS and NGPS under rain-fed conditions. So, it can be suggested that DM is a useful criterion for selection under irrigated condition. ADWL-5 and ADWL-1 were selected considering maximum number of days to physiological maturity (217.9 and 217.3). Therefore we can deduce although estimation of correlation and regression analysis among yield and related yield components may provide effective selection criteria to improve durum wheat grain yield but since grain yield is a result of interaction between multiplicity of genes and environment and also based on the obtained result by Naik *et al*. (2016) the negative correlation between two favorite traits makes infeasible the selection of both traits simultaneously, So direct selection could not lead to factual outputs and has not successful to noteworthy enhancement in yield. Accordingly, we propose that selection of genotypes for the yield components should be based on the path coefficient analysis and also according to the genotypes which can adjust their buffered state in response to environmental fluctuations in such a way that they give maximum economic grain yield.

**Conclusions:** On the basis of these on-farm experiments, it was concluded that highly significant differences existed among lines for the most of traits studied. Such considerable range of variation for traits provide a good opportunity for selection to identify the superior lines and to use them as the genetic source for breeding aims *viz.* yield improvement and introducing commercial cultivars especially under drought stress condition. This study disclosed that simple correlation and regression analysis *per se* cannot discern substantial variables affecting wheat yield, the definitive judgment cannot be performed on the basis of these methods as such, it is imperative to use multivariate statistical methods for screening important traits of durum wheat in the multi environmental experiments. In this study, it has been tried to use path analysis as a predictive tool for analysis of interrelationships between yield-related traits in durum wheat. Information from this research would be valuable to wheat breeder for developing high yielding cultivars under diverse conditions and could be useful for wheat statisticians and agronomists to understand the nature of the relationship between the most important factors affecting the yield of wheat.

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