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*Full Length Research Paper*

# Response of Ethiopian durum wheat genotypes to water deficit induced at various growth stages

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**Understanding the effect of water stress on yield and its components is the essential step in developing of high yielding and stable genotypes. Substantial reduction in grain yield can be caused by water deficit depending on the intensity, duration and the developmental stage at which water stress occurred. An experiment was conducted in the lathouse at Sinana Agricultural Research Center in 2006/2007 to evaluate the effect of water deficit on grain yield and yield components of eighteen durum wheat genotypes induced at different growth stages. Grain yield and other agronomic traits of all genotypes were significantly reduced and the reduction was much more pronounced under stress induced from tillering to crop maturity. Grain yield per plant was reduced by 72, 37 and 17.1% due to stress induced at tillering, flowering and grain-filling stages as compared to the well-watered treatment, respectively. Kilinto and Gerardo were found to be stable and drought tolerant genotypes whereas S-17B and Boohai were highly susceptible. The most drought tolerant genotypes were found to maintain relatively high levels of kernel numbers per spike and hundred-kernel weight. Mean kernel weight was associated to the duration of grain filling and grain filling rates and these traits contributed to a greater yield under water stress conditions.**

**Key words:** Durum wheat, water deficit, yield components.

## INTRODUCTION

Climate change could have a dramatic impact on the wheat crop, which supplies 21% of the world's food calories and covers 216 million hectares of farmland worldwide (Food And Agriculture Organization Of The United Nations, 2011). Climate change induced temperature increases and annual rainfall decrease are estimated to reduce wheat production in developing countries by 20-30% (International Maize and Wheat Improvement Center, 2011). Making genetic gains in yields of wheat under rainfed conditions has always been a difficult challenge for plant breeders (Richards et al., 2002). This is evident from the smaller grains harvested in dry regions compared with those in wetter environments or where irrigation is applied. The bulk of durum wheat in Ethiopia is produced under rainfed condition, often in places where rainfall is erratic in distribution and scarce during the grain-filling period. The random variations of rainfall from year to year and across locations due to this global climate change usually affect the crop yield (Simane et al., 1993; Deselegn et al., 2001). Understanding the effect of water stress on yield formation becomes the essential step in the development of higher-yielding and more stable cultivars.

Apart from environmental conditions, the final grain yield of wheat determined by the product of three components: number of spikes per unit area, number of grains per spike and individual kernels weight (Moragues et al., 2006). Each of these yield components can be affected by water stress, the extent depending upon intensity, the duration of the exposure and the stage of plant development when stress conditions occurs (Simane et al., 1993; Giunta et al., 1995; El Hafid et al., 1998). Water stress at various stages before flowering can reduce the number of spike per unit land area and kernels per spike (Innes and Blakwell, 1981). Many

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**Table 1.** Description of the genotypes used and average yield performance, drought susceptibility index (S) under different water regimes.

| Genotypes name | Origin | Year of release for commercial use | Average GY(g/plant) | Drought susceptibly index (S) |
|---|---|---|---|---|
| Asassa | CIMMYT/Ethiopia | 1997 | 1.89 | 1.07 |
| Bekelecha | CIMMYT/Ethiopia | 2005 | 2.06 | 1.20 |
| Boohai | CIMMYT/Ethiopia | 1982 | 1.68 | 1.49 |
| B5-5B | Ethiopia | Land race | 1.91 | 0.73 |
| CDSS 93Y107 | CIMMYT/Ethiopia | Advanced line | 2.32 | 0.93 |
| CD 94523 | CIMMYT/Ethiopia | Advanced line | 2.20 | 0.90 |
| Egersa | CIMMYT/Ethiopia | 2005 | 2.29 | 0.74 |
| Foka | CIMMYT/Ethiopia | 1993 | 1.81 | 0.81 |
| Gerardo | CIMMYT | 1976 | 1.87 | 0.62 |
| Ilani | CIMMYT/Ethiopia | 2004 | 2.07 | 1.04 |
| Kilinto | CIMMYT/Ethiopia | 1994 | 1.81 | 0.58 |
| Obsa | CIMMYT/Ethiopia | 2006 | 1.98 | 0.90 |
| Oda | CIMMYT/Ethiopia | 2004 | 2.08 | 0.80 |
| Qaumy | CIMMYT/Ethiopia | 1996 | 1.92 | 1.06 |
| S-17 B | Ethiopia | Land race | 1.64 | 1.55 |
| Tob-66 | CIMMYT/Ethiopia | 1996 | 1.89 | 0.86 |
| WA-13 | Ethiopia | Land race | 1.41 | 1.21 |
| Yeror | CIMMYT/Ethiopia | 2002 | 1.83 | 1.39 |

studies showed that reproductive stage was more sensitive to water deficit than the vegetative growth stage (Simane et al., 1993; Ravichandran and Mungs, 1995), and environmental stress during anthesis mainly affect the number of grains and the final yield due to the number of grains produced per spike (Christen et al., 1995). The principal cause of yield reduction by post-anthesis water deficit is associated with the reduction in kernel growth or low kernel weight (Ozurk and Aydin, 2004) through reduction in post-anthesis photosynthesis and amount of current assimilates (Kobata et al., 1992).

The effect of water stress on the yield and yield components of durum wheat at different growth stages have been the subject of many studies (Simane et al., 1993, Solomon et al., 2003). Experimental results showed that the grain yield and other yield components response is both genetic and environment specific. Moreover, there is little information that shows the relationship between grain yields its various components for Ethiopian durum wheat genotypes under different stress conditions. The aim of this work was to study the effect of water stress induced at different growth stages on yield and yield components of different durum wheat genotypes.

## MATERIALS AND METHODS

The study was conducted in a lathhouse at Sinana Agricultural Research Center (SARC) during the 2006/2007 main season. It is located at 7° 7'N latitude, 40° 10'E longitude and 2400 m.a.s.l altitude in Bale Zone of Oromia Region, Ethiopia. To embrace the variability existing among the Ethiopian durum wheat genotypes, three landrace, thirteen commercial cultivars and two advanced lines from the breeding program were selected (Table 1). The examined genotypes are different in genetic background, origin and several characteristics. Plants were grown in 21 cm diameter and 18 cm length plastic pots filled with a textural class of clay (49.7% clay, 27.3% silt and 23% sand). Each pot was filled with 4 kg uniformly air-dried soil (17.1% moisture). The field capacity and permanent wilting point of the soil were 47.8 and 11.5%, respectively. Pots were arranged in randomized complete block design (RCBD) in factorial combination of the eighteen genotypes and four water regimes with three replications. A total of 216 pots, of which 12 pots were assigned to each genotype. 2 g N and 2 g $P_2O_5$ fertilizers were applied to each pot during planting and additional 0.5 g N was applied at the first tillering. Planting was done on August 10, 2006. Eight seeds were sown per pot and the seedlings were thinned to four at two leaf growth stages. Five hundred ml of water was added to each pot every other day for a period of a month until the plants reach four leaf growth stages.

Following the Zadock's scale (Zadock et al., 1974), plants were subjected to water stress at different growth stages: stress continuously from tillering to physiological maturity (M1), stress from anthesis to physiological maturity (M2), and stress from grain-filling stage to physiological maturity (M3) and well-watered control (C) treatments. The water levels were maintained in the range of 35 to 50% field capacity in the stress treatments while above 75% in the control treatment. These water stress conditions are designed to simulate the environments that experience very low water supply after crop establishment in different parts of the country. During the stress period, plants were left without water for 12 days by withholding irrigation until early morning wilting is observed. Then pots were weighted and irrigated until the weight of every pot became equal to the weight of the predetermined water level. The amount of water depleted from pots was obtained by weighing pots every two to three days, and the loss in weight was restored by watering pots with the amount of water equal to the loss in weight.

**Table 2.** Partial analysis of variance of the effect of water deficit treatments (E) induced at three growth stages on agronomic performance of 18 durum wheat genotypes (G).

| Variable | Mean squares | | | | CV (%) |
|---|---|---|---|---|---|
| | Water Stress (E) | Genotypes (G) | G x E | Error | |
| Days to heading (DH) | 77.6*** | 291.6*** | 10.6*** | 4.17 | 3.3 |
| Vegetative growth period (VP) | 73.4*** | 241.2*** | 11.02*** | 5.87 | 3.3 |
| Days to maturity (DM) | 691.0*** | 49.6*** | 8.7NS | 6.94 | 2.3 |
| Grain filling period (GFP) | 559.1*** | 113.0*** | 9.99NS | 8.41 | 6.1 |
| Plant height (PH) | 10158.7*** | 1536.3*** | 130.2*** | 33.2 | 7.3 |
| Grain yield (GY) | 35.9*** | 0.87*** | 0.43*** | 0.11 | 17.4 |
| Aboveground biomass yield (BY) | 212.3*** | 1.93*** | 1.34*** | 0.52 | 15.5 |
| Harvest index (HI) | 0.57*** | 0.0057*** | 0.0062*** | 0.0014 | 9.2 |
| 100 kernels weight (KW) | 9.82*** | 2.03*** | 0.44*** | 0.124 | 7.8 |
| Spike length (SPL) | 11.7*** | 3.81*** | 0.19NS | 0.15 | 7.3 |
| Kernels per spike (KS) | 4823.3*** | 205.9*** | 49.9*** | 14.9 | 12.7 |
| Kernels per spikelet (KPS) | 10.9*** | 0.81*** | 0.16** | 0.085 | 13.4 |
| Grain filling rate (GFR) | 14716.3*** | 331.9*** | 196.5*** | 61.9 | 19.7 |

NS, ** and ***= not significant, significantly different at 1 and 0.1% level of probability, respectively.

The studied characters were days to heading (DH) (when spike completely emerged from the flag leaf ligule) and days to physiological maturity (DM) (when the entire plant turns to yellow). The length of vegetative period (VP) was calculated as days from sowing to anthesis (growth stage 65 according to Zadok's scale). Duration of grain filling period (GFP) was considered to be the days from anthesis to physiological maturity (growth stage 91). Grain-filling rate (GFR) was determined as the ratio of final dry grain yield (mg/plant) to the duration of grain-filling period. Data were also collected for plant height, number of kernels per spike, 100 kernel weight, spike length, air-dried aboveground biomass and grain yield per plant. Harvest index was determined as the proportion of grain yield to the overall aboveground biomass per plant.

Drought susceptibility index (S) was calculated from genotype means by using the generalized formula of Fischer and Maurer (1978) for grain yield per plant as:

$$S = \frac{(1 - Y_d / Y_p)}{D}$$

where S = drought susceptibility index, $Y_d$ and $Y_p$ are mean yield of the genotypes under water deficit and well-watered condition, respectively, and, D is drought intensity index, which is obtained as: $D = 1 - (Y_d/mY_p)$, where $mY_d$ = mean yield of all genotypes under water deficit condition, and $mY_P$ = mean of yield of all genotypes under well watered conditions. The drought susceptibility index (S) was used to characterize each genotype in the stress treatment, which represents different stress environments. Low values of S (S<1) are considered as indicators of high drought tolerance whereas high S values show drought susceptibility.

Data were analyzed using SAS GLM procedure (SAS Institute, 1996) for the variance analysis. Means comparisons were carried out to estimate the differences between water deficit treatments and genotypes using Duncan's Multiple Range Test values.

## RESULTS AND DISCUSSION

The analysis of variance revealed that grain yield and all other yield components were highly significantly (P < 0.001) affected under water stress treatments (Table 2). In addition, the genotypic effect was shown highly significant for days to heading, vegetative period, days to maturity, grain filling period, plant height, grain yield per plant, biomass yield per plant, HI, 100-kernels weight, spike length, number of seed per spike and grain filling rate. Moreover, interaction effect of water stress treatment × genotype was highly significant for these characteristics except for spike length and grain filling period. The significant of genotypes x water stress treatment interactions indicated the difference in water stress sensitivity among genotypes depend on the reaction of each genotype to water stress and suggests the selection of superior genotypes accordingly for different water supply environments. Bekelecha, CDSS93Y107, Ilani and Kilinto exhibited significantly higher mean grain yield per plant in the M1 treatment while Yeror was the lowest yielder. Gerardo showed high yield potential under stress induced at anthesis stage (M2) while S-17B followed by Boohia were found to be lowest yield potential. Similarly, CDSS93Y107 followed by Egersa and CD94523 exhibited significantly the highest yielding potential under late stress (M3) and across all water regimes (Table 1).

The result of the present study indicated that water stress treatments significantly reduced the grain yield of all genotypes and the reduction was much more pronounced under stress induced from tillering to crop physiological maturity (Figure 1). Grain yield per plant was reduced by 72, 37 and 17.1% due to stress induced at M1, M2 and M3 as compared to the well-watered treatment, respectively (Table 3). Sensitivity of different crop species to water deficit varies greatly according to the severity and duration of the stress and stage of

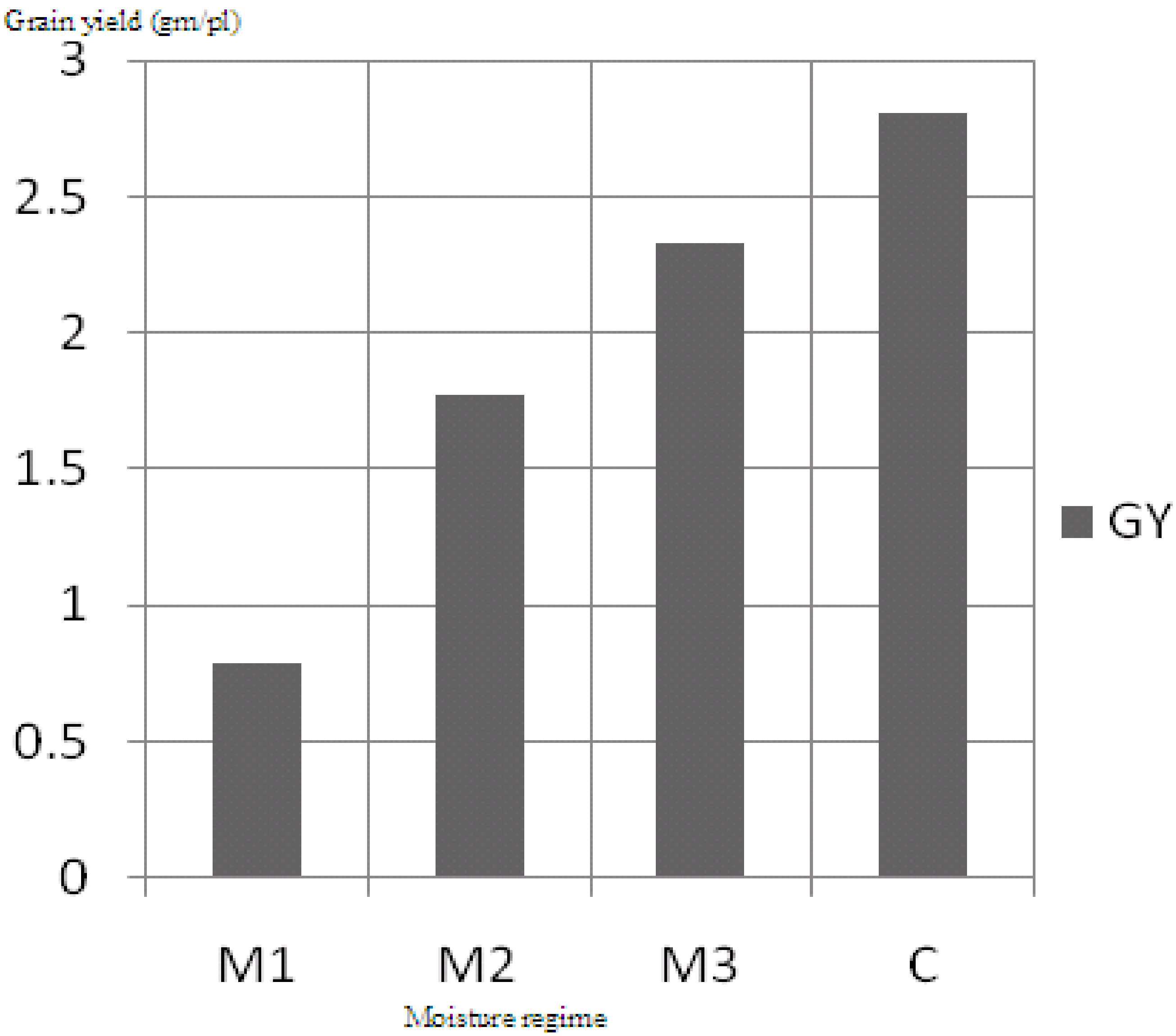


**Figure 1.** Effect of water stress on grain yield of 18 durum wheat genotypes induced at three growth stages.

growth when the stress occurs (Simane et al., 1993; Giunta et al., 1995). These results are in agreement with Solomon et al. (2003) and Ozturk and Aydin (2004). The reductions inflicted in grain yield in the M1 and M2 treatments were associated with the concomitant decrease of the number of kernels per spike and kernel weight. When wheat suffers drought stress before anthesis, a yield reduction is associated mainly with a reduced number of grains per spike and numbers of spike (Innes and Blackwell, 1981). The reduction in grain yield per plant in the M3 treatment was mainly associated with the reduction of 100-kernel weight. This result clearly indicated that kernel number per spike and hundred-kernel weight had the greatest influence on yield of durum wheat under water stress conditions. The importance of number of kernels per spike and kernels weight is well documented to be determining the final grain yield under water stress environment (Simane et al., 1993; García et al., 2003; Moragues et al., 2006).

Drought tolerance and stability of the genotypes were characterized using drought susceptibility index (S) of Fischer and Murer (1978). Genotype raking based on S varied among the water stress treatments. According to Bansal and Sinha (1991) and Simane et al. (1993), smaller values of S indicate yield stability as well as drought tolerance. Accordingly, across water stress treatments, Kilinto and Gerardo were found to be stable and drought tolerant genotypes followed by B5-5B, Egersa and Oda whereas S-17B, Boohai, Yeror and WA-13 were highly susceptible to water stress (Table 1). The

**Table 3.** Mean grain yield and yield components of 18 durum wheat genotypes as influenced by water stress induced at three growth stages.

| Water stress treatment | GY (g/pl) | BY (g/pl) | HI | 100 KWT | No. kernel/spike | Spike length | Plant height | Grain filling period | Grain filling rate (mg $pl^{-1}day^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| M1± | 0.79 | 2.10 | 0.36 | 4.48 | 16.6 | 4.7 | 58.3 | 46.9 | 16.9 |
| M2 | 1.77 | 4.19 | 0.41 | 3.92 | 32.3 | 5.5 | 84.0 | 45.4 | 39.1 |
| M3 | 2.33 | 5.32 | 0.42 | 4.57 | 36.7 | 5.6 | 86.3 | 44.9 | 52.1 |
| C | 2.81 | 6.60 | 0.43 | 5.02 | 37.6 | 5.7 | 87.0 | 51.9 | 54.3 |
| Mean | 1.93 | 4.55 | 0.41 | 4.50 | 30.8 | 5.4 | 78.9 | 47.3 | 40.6 |
| LSD (P< 0.05) | | | | | | | | | |
| G | 0.11 | 0.24 | 0.01 | 0.12 | 1.29 | 0.13 | 1.93 | 0.98 | 2.64 |
| E | 0.25 | 0.61 | 0.01 | 0.15 | 2.89 | 0.28 | 4.14 | 2.14 | 6.23 |
| G x E | 0.56 | 1.39 | 0.05 | 0.62 | 6.47 | NS | 10.72 | NS | 12.67 |
| CV (%) | 17.4 | 15.5 | 9.2 | 7.8 | 12.7 | 7.3 | 7.3 | 6.1 | 19.7 |

±M1, Stress induced from tillering to crop maturity; M2, stress induced from anthesis to crop maturity; M3, stress induced from grain filling stage to crop maturity; C, well-watered controlled treatment.

**Table 4.** Correlation coefficients of hundred kernel weight with grain filling period and grain filling rates of 18 durum wheat genotypes grown under water deficit treatments induced at three growth stages.

| Character | M1 | M2 | M3 | C |
|---|---|---|---|---|
| Grain filling period | 0.643*** | 0.480* | 0.494* | 0.327 |
| Grain filling rate | 0.673*** | 0.080 | 0.003 | 0.057 |

*and *** significant at P < 0.05 and 0.001, respectively.

most drought tolerant genotype (Kilinto) was found to maintain relatively high levels of yield components, mainly kernel weight and kernels number per spike as compared to the most susceptible one (S-17B).

The water stress treatments induced at the different growth stages caused a substantial reduction in biomass yield. Maximum biomass yield reduction (68.2%) was observed under stress induced from tillering to physiological maturity. Elias (2003) indicated that wheat plant reaches its maximum biomass potential under sufficient water availability. Where there is drought, a marked decrease in plant biomass, which is associated with a decrease in plant growth rate (Villegas et al., 2001). The reduction in harvest index under water stress condition mainly due to the reduction of aboveground biomass yield by stress. The reduction in HI has also been observed under conditions of severe stress, which was attributed to a reduction in ear size (Giunta et al., 1993) and individual kernel weight (Gonzalez et al., 2007).

Effects of water deficit on grain yield components were most apparent in kernel numbers per spike, showing that the response of the genotypes to water stress at different growth stages leads to differences in the number of kernels per spike. Greater reduction in number of kernels per spike was observed due to M1 than any other water stress treatments. Christen et al. (1995) and Bindraban et al. (1998) indicated that water deficit largely influenced the number of grain per spike in the period between the flag-leaf stage and the end of anthesis. In another study, water deficit that occurred between floral initiation and differentiation, anthesis, and/or grain-filling stages primarily affected the number and/or the size of kernels via floral abnormalities (Westgate et al., 1996).

The mean kernel weight reduction was 10.8, 21.9 and 8.9% due to M1, M2 and M3 treatments, respectively relative to the mean kernel weight of the control (Table 4). It has been reported that in most cases, kernel weight was the most stable yield component (Giunta et al., 1993; Guttieri et al., 2001) and the reduction was usually evident if water deficit is accompanied by high temperature during grain-filling period (Royo et al., 2000). The reduction of mean kernel weight due to M1 and M3 treatments is possibly because of the negative effect of water stress on kernel weight through a reduction of post-anthesis photosynthesis and the amount assimilates (Kobata et al., 1992; Yang et al., 2001). Large reduction in kernel weight was observed at M2 at present study was because of marked reduction of grain filling period and grain filling rate under water stress. This result agrees with the previous reports by Royo et al. (2000) who stated moisture stress from anthesis to maturity

**Table 5.** Stepwise regression showing the relative contribution (partial and model $R^2$) in predicting grain yield per plant of durum wheat genotypes grown across water deficit treatments.

| Character included | Partial $R^2$ | Model $R^2$ | SE ofestimate | Probability |
|---|---|---|---|---|
| Across all moisture regimes | | | | |
| Grain-filling rate | 0.929 | 0.929 | 0.232 | $P < 0.01$ |
| Grain-filling period | 0.059 | 0.988 | 0.097 | $P < 0.01$ |

hasten leaf senescence, reduces the duration and rate of grain filling, and hence reduces mean kernel weight. This might be due to post-anthesis water stress limits the duration of transport and depositions of assimilates during the grain-filling period (Voltas et al., 1998).

The water stress treatments significantly affected the grain-filling period and grain-filling rate of the genotypes. Duration of gain filling and hundred kernel weights were positively correlated under water stress conditions while grain filling rate strongly correlated with kernel weight under severe water stress condition only (Table 4). Length of the grain-filling period is the phenological trait that influences grain yield mostly in water stress conditions (Gonzalez et al., 2007). This is mainly because it leads to premature desiccation of the endosperm, which limits embryo size and consequently results in the reduction of the weight of grain produced (Bindraban et al., 1998). Stepwise regression analysis also showed that grain filling rate together with grain filling period explained more than 98.8% of the grain yield variation of the tested genotypes across water regimes (Table 5). This suggests that grain filling rate and duration of grain filling could be used as stable selection criteria for improving the grain yield of durum wheat in different water supply environments.

## Conclusion

Water availability is the main constraint limiting durum wheat production in many parts of the world. Substantial reduction in grain yield can be caused by water deficit depending on the intensity of the stress and the developmental stage at which water deficit occurred. Understanding the effect of water stress on yield formation becomes the essential step in the development of higher-yielding and more stable cultivars. Water stress induced at different growth stages significantly reduced grain yield per plant, plant height, aboveground biomass, HI, hundred-kernel weight, spike length, kernels number per spike, grain filling period and grain filling rate but the reduction was much more pronounced under stress induced from tillering to crop physiological maturity. Significant variation for these phenology and agronomic traits were observed among genotypes across water stress treatments. The variation in grain yield under water deficit treatments were predominantly determined by number of kernels per spike and hundred- kernel weight. Mean kernel weight was associated to the length of grain filling period and grain filling rates. Longer grain filling duration and high grain filling rate contributed to greater yields under water stress conditions.

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