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# Kernel quality, germination rate and seedling performance of eight wheat varieties produced under three different irrigation regimes

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**Abstract**

The effects of three different irrigation treatments were tested on kernel quality (i.e. kernel size), germination rate and seedling performance of eight wheat varieties. The irrigation treatments used were as follows: (i) rainfed treatment with 262.8mm annual rainfall received during the growing season, (ii) partial irrigation (PSI) treatment receiving 482.8 mm of water (262.8mm rainfall + 220mm irrigation at anthesis) and (iii) continuous supplementary irrigation (CSI) receiving 640 mm water (262.8 mm rainfall + 377.2 mm supplementary irrigation at 2-3 weeks interval). Seven durum wheat varieties (Sham1, Omqais, Acsad65, Bani Suef6, Bani Suef4, Horani Nawawi, Dairalla6) and one bread wheat variety (Ammon) were included in this study. Split-plot design was used with three replications. The main plots were the irrigation treatments, while the sub-plots were varieties nested within irrigation treatments. Kernels weight was recorded under different irrigation treatments in addition to the germination rate parameters (mean germination time and the time to attain 10% and 50% of complete germination percentage) and seedling attributes (shoot length, maximum seminal root length, coleoptile length, shoot fresh weight and seminal root fresh weight). The thousand kernel weight (TKW) was maximum under PSI (46.21g), followed by CSI (43.20g) and rainfed treatment (41.70g). TKW was maximum in Cham1 (45.37g) and BaniSuef6 (45.22g), while the minimum TKW was recorded in Ammon bread wheat variety (39.19g). Smaller wheat kernels released under rainfed condition were notoriously faster to germinate as compared with kernels released under CSI and PSI, and consequently smaller kernels would be desirable to accelerate the time required from sowing to seedling emergence. Hourani Nawawi and DairAlla 6 gave a more vigorous seedling with longer seminal roots and larger seedling biomass, which might indicate their high adaptability to early drought. In conclusion, smaller kernels were faster in germination, which minimize the time required from germination to emergence for a good stand establishment, while heavy kernels would have seedlings with a more vigorous root system which may help the crop to withstand early drought.

**Keywords:** Germination, germination rate, kernel size, root and shoot traits, wheat.

**Abbreviations:** CL_Coleoptile length; CSI_Continuous supplementary irrigation; FGP_Final germination percentage; MGT_Mean germination time; MSRL_Maximum seminal root length; NSR_ Number of seminal roots; PSI_ Partial irrigation; rp and rg_phenotypic and genotypic correlation coefficients, respectively; SL_ Shoot length; SFW_ Shoot fresh weight; SRFW_Seminal root fresh weight; SI_Supplemental irrigation; t10 and t50_ The time to attain 10% and 50 % of complete germination percentage; TKW_ Thousand kernel weight; WANA_West Asia and South Africa.

## Introduction

Wheat grain yield in West Asia and South Africa (WANA) is low and does not exceed 2000 kg ha-1 at best (FAOSTAT, 2010-2020). Drought is a main constraint limiting grain yield in WANA, where arid and semi-arid environments are prevailing. There are two critical periods of drought in WANA to which the wheat crop is exposed (Abdel-Ghani et al., 2015; Shavrukov, 2017): (i) early drought, which may lead to complete crop failure at the early stages of crop growth and (ii) late drought where the crop is exposed to drought during anthesis and grain filling. The selection for drought-tolerant varieties has become a necessity, especially with the climate change that affects the dry areas with frequent drought waves (Kelleya et al., 2015). Selection of genotypes with accelerated germination and a more vigorous root system would help the crop to withstand early drought and increase yield under water limiting environments. Kernel size is a limiting factor that determines the germination rate and the strength of the root system especially at early growth stages and consequently the crop yield (Desiderio et al. 2019; Su et al. 2018).

Crop cultivated under limited growth factors partition photosynthetic assimilate for vegetative growth and kernels development (Madani et al., 2010; Li et al., 2013). Carbohydrate partitioning with sufficient water in the soil during reproductive phase can affect the kernels quality (i.e. kernel size) produced under field conditions (Farooq et al. 2015; Madani et al. 2010). Favorable conditions during the cropping season can produce plumbed kernels and higher number of kernels per plant (Drenovsky and Richards, 2005; Dziki and Laskowski, 2005). However, the differences in kernel size among wheat varieties are existed (Wiersma et al., 2001; Breseghello and Sorrells, 2006), and kernel size can even vary within an individual plant (Ferrante et al., 2015).
Early vigor and good stand establishment of wheat seedlings are highly affected by seed size and carbohydrates stored in grains during grain filling (Bockus and Shroyer, 1996; López-Castañeda et al., 1996). Large kernels in wheat can give a more vigorous seedling with a good stand establishment, especially under drought (Harris et al., 1999; Mustafa et al., 2018) . Various studies showed a positive advantage of large kernel on seedling growth and wheat productivity (Cheplick and Sung, 1998; Yang et al., 2009, 2010). Previous studies revealed that large kernels lead to higher grain yield (Stougaard and Xue, 2004), better crop stand (Kristensen, 2003), acceleration in germination (Abdel-Ghani, 2009), and a more vigorous root system under drought stress (Singh and Singh, 2003). Kernel quality is a critical factor that affects germination percentage and rate. Therefore, the present study aimed at studying the effect of supplemental irrigation (SI) on kernel quality and both germination rate and seedling traits of wheat kernels using eight wheat varieties.

## Results

The SI effects were significant (P<0.01) on full germination percentage (FGP), mean germination time (MGT), the time to attain 10% and 50% of complete germination percentage (t10 and t50, respectively), thousand kernel weight (TKW), number of seminal roots (NSR) and seedling length (SL). Other traits were not significantly affected by SI treatments. Variety effects were significant (P<0.01) on FGP, germination rate related parameters (MGT, t10 and t50) and all seedling attributes including NSR, SL, maximum seminal root length (MSRL), coleoptile length (CL), shoot fresh weight (SFW), seminal roots fresh weight (SRFW) and root to shoot ratio (RSR). Mean separations for all recorded parameters are presented in Tables 1, 2 and 3. Mean squares due to irrigation by variety interaction (IR×V) were not significant on all recorded parameters (Tables 1, 2 and 3).

### *Effect of supplemental irrigation on kernel quality and germination parameters*

SI had a significant effect on TKW (Table 1). The effects of SI on TKW was maximum when irrigation was performed at reproductive stage (TKW< 46.21g), followed by CSI treatment (TKW< 43.20g), although non-significant when compared with TKW produced under rainfed condition (41.70g). FGP in control (98.8%) did not significantly differ from kernels released under PSI (98.9%), but both treatments showed significantly higher FGP values as compared with kernels released under CSI (97.0%; Table 1). Even though that TKW was higher under CSI, but a delay in germination was observed as compared to kernels released under PSI and rainfed conditions (Table 1). MGT, t10 and t50 were significantly higher in kernels released under CSI (values<31.14h, 16.00h and 31.75h, respectively) as compared with kernels released under PSI (values<26.35h, 12.27h and 24.3h, respectively) and rainfed treatment (values<22.63h, 10.053h and 20.12h respectively). Seedling attributes (SL, MSRL, CL, SFW and SRFW) were slightly affected by SI treatments (Tables 2 and 3).

### *Means and ranges of genotypes for thousand kernel weight, germination and germination rate parameters*

Means for varieties over irrigation treatments for TKW, FGP and germination rate parameters (MGT, t10 and t50) are shown in Table 1. The average FGP of the eight varieties over the irrigation treatments ranged from 91.1% in Cham1 to more than 97% for other tested varieties. The fastest germination was observed in the bread wheat variety (Ammon) with MGT<12.54h, t10 6.89h and t50<11.86h, followed by DairAlla 6, Acsad65, Bani Suf4, Bani Suf6, Horani Nawawi and Cham1. Omqais showed a delay in germination, with average MGT, t10 and t50 of 60.10, 33.25 and 57.34h, respectively.

### *Genetic variation in seedling traits*

The variations in seedling traits for the eight wheat varieties are wide (Tables 2 and 3). The ranges for NSR and CL were narrower than those obtained for SL and MSRL (Table 2). NSR, MSRL, SL and CL ranged over the eight wheat varieties from 4.40 to 5.33cm, from 9.31 to 13.28cm, from 11.83 to 18.41cm and from 2.08 to 3.26cm, respectively. The maximum SL and MSRL were observed in Horani Nawawi and DairAlla 6 (values < 18.41 and 15.50cm for SL and 13.28 and 12.56cm for MSRL, respectively). The maximum CL was observed in Horani Nawawi (3.27cm) and Omqais (3.96cm).
SFW and SRFW over varieties ranged from 346.18 to 656.28 mg/seedling and from 166.53 to 304.71 mg/seeding, respectively (Table 3). The maximum SFW was obtained in Horani Nawawi (656.28 mg/seedling), followed by DairAlla (591.44 mg/seedling), Bani Suf6 (484.64 mg/seedling), Omqais (445.78 mg/seedling), and Bani Suf4 (408.20 mg/seedling). The maximum SRFW values were observed in Bani Suef6 (304.71 mg/seedling), followed by DairAlla 6 (290.96 mg/seedling) and Ammon (265.82 mg/seedling). The maximum RSR values were obtained in Ammon (0.77), followed by Bani Suef6 (0.63) and Omqais (0.58).

### *Correlations among recorded parameters*

The phenotypic and genotypic correlation coefficients (rp and rg, respectively) were relatively equal in magnitudes and signs. Therefore, only genotypic correlation coefficients will be presented and discussed in the following sections (Table 4). FGP was positively correlated with SL (-0.40++), MSRL (-0.66++), SFW (0.36+) and SRFW (0.42+), while it displayed significant negative correlations with t50 (-0.47+), NSR (-0.59++) and TKW (-0.55+). Germination rate parameters were positively correlated with rg values of 0.96++ and 0.99++ between MGT and both t10 and t50, respectively. Germination rate parameters were positively correlated with TKW with rg values of 0.61++, 0.40+ and 0.66++ with MGT, t10 and t50, respectively). TKW also showed positive correlations with NSR (0.46+) and CL (0.62+), but it was negatively and significantly correlated with MSRL (-0.58+) and RSR (-0.51+). The correlations amongst SL, MSRL, NSR and SFW were always positive and significant.

### *Variance components and heritability estimates*

Broad sense heritability estimates ($h^2$) and variance components for FGP, germination rate parameters and

**Table 1. E**ffects of irrigation treatments, varieties and their interaction on thousand kernel weight (TKW, g), final germination percentage (FGP), mean germination time (MGT, hour) and the time (hour) to attain 10% and 50% of complete germination ($t_{10}$ and $t_{50}$; respectively).

| Treatments | TKW | FGP | MGT | $t_{10}$ | $t_{50}$ |
|---|---|---|---|---|---|
| Irrigation treatments (IR) | | | | | |
| Control | 41.70b | 100a | 22.63b | 10.05b | 20.13b |
| Partially supplementary irrigation | 46.21a | 99a | 26.35ab | 12.28b | 24.30ab |
| Continuous supplementary irrigation | 43.20b | 97b | 31.14a | 16.00a | 31.75a |
| LSD (0.05) | 2.40 | 1 | 4.82 | 3.05 | 8.65 |
| Variety (V) | | | | | |
| Horani Nawawi | 43.37ab | 100a | 23.97bc | 13.96b | 22.46bc |
| DairAlla 6 | 43.98a | 99a | 18.88c | 7.95c | 16.27c |
| Cham 1 | 45.37a | 91b | 28.41b | 10.03bc | 34.70b |
| Omqais | 44.91a | 97a | 60.10a | 33.26a | 57.34a |
| Acsad 65 | 44.73a | 100a | 22.15c | 11.70bc | 20.12c |
| Ammon | 39.19b | 100a | 12.55d | 6.89c | 11.86c |
| BaniSuef 4 | 42.83ab | 99a | 22.93bc | 10.49bc | 20.55c |
| BaniSuef 6 | 45.22a | 100a | 24.66bc | 8.22c | 19.84c |
| LSD (0.05) | 4.65 | 3 | 6.12 | 5.41 | 12.63 |
| IR×V | ns | ns | ns | ns | ns |

Means followed by the same letter(s) are not significantly different at *P*<0.05.

**Table 2. E**ffects of irrigation treatments, varieties and their interaction on on the number of seminal root (NSR) and shoot length (SL), maximum seminal root length (MSRL) and coleoptiles length (CL).

| Treatments | NSR | SL | MSRL | CL |
|---|---|---|---|---|
| | | | | |
| Irrigation treatments (IR) | | | | |
| Control | 4.94a | 14.15ab | 11.00a | 2.54a |
| Irrigation at reproductive phase | 5.05a | 14.36a | 11.24a | 2.58a |
| Full Irrigation treatment | 4.82b | 14.05b | 11.05a | 3.10a |
| LSD (0.05) | 0.12 | 0.28 | Ns | ns |
| | | | | |
| Variety (V) | | | | |
| Horani Nawawi | 4.91cd | 18.41a | 13.28a | 3.27ab |
| DairAlla 6 | 5.33a | 15.50b | 12.56ab | 2.80ab |
| Cham 1 | 5.30ab | 12.08d | 9.31e | 2.16b |
| Omqais | 4.98c | 14.00c | 9.55e | 3.96a |
| Acsad 65 | 4.40e | 13.716c | 10.19de | 2.31b |
| Ammon | 4.64de | 11.83d | 11.72bc | 2.08d |
| BaniSuef 4 | 4.88cd | 13.71c | 10.87cd | 2.47b |
| BaniSuef 6 | 5.03bc | 14.10c | 11.32bcd | 2.80ab |
| LSD (0.05) | 0.28 | 0.82 | 1.26 | 1.25 |
| | | | | |
| IR×V | ns | ns | Ns | ns |

Means followed by the same letter(s) are not significantly different at *P*<0.05.

**Table 3.** Effects of irrigation treatments, varieties and their interaction on seminal root and shoot fresh weights (SRFW and SFW; respectively) and root to shoot ratio (RSR)

| Treatments | SRFW (mg/seedling) | SFW (mg/seedling) | RSR |
|---|---|---|---|
| Irrigation treatments (IR) | | | |
| Control | 224.30a | 458.25a | 0.51a |
| Irrigation at reproductive phase | 244.51a | 469.02a | 0.53a |
| Full Irrigation treatment | 245.92a | 452.02a | 0.56a |
| LSD (0.05) | 39.034 | 39.11 | 0.08 |
| | | | |
| Variety (V) | | | |
| Horani Nawawi | 252.44a | 656.82a | 0.38d |
| DairAlla 6 | 290.96a | 591.44b | 0.49cd |
| Cham 1 | 183.57b | 358.11f | 0.53bc |
| Omqais | 257.78a | 445.78cd | 0.58bc |
| Acsad 65 | 184.13b | 386.91ef | 0.47cd |
| Ammon | 265.82a | 346.18f | 0.77a |
| BaniSuef 4 | 166.53b | 408.2de | 0.40d |
| BaniSuef 6 | 304.71a | 484.64c | 0.63b |
| LSD (0.05) | 53.723 | 42.791 | 0.12 |
| | | | |
| IR×V | ns | ns | ns |

Means followed by the same letter(s) are not significantly different at *P*<0.05.

**Table 4.** Phenotypic correlation coefficients ($r_p$, above diagonal) and genetic correlation ($r_g$) coefficients (below diagonal) among various pairs of germination and seedling traits for the eight wheat genotypes exposed to different water treatments. FGP, final germination percentage; MGT, mean germination time (day); $t_{10}$ and $t_{50}$, respectively, the time (day) required to reach 10% and 50 % germination (day); SL, seedling length (cm); MSRL, maximum seminal root length (cm); NSR, number of seminal roots; CL, coleoptiles length (cm); SFW, shoot fresh weight (mg/seedling); SRFW, seminal roots fresh weight (mg/seedling); root to shoot ratio (RSR); TKW, thousand kernel weight (g).

| No. | | FGP | MGT | t10 | t50 | SL | RL | NSR | CL | SFW | SRFW | RSR | TKW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FGP | 0 | -0.31 | -0.12 | -0.5 | 0.4 | 0.62 | -0.54 | 0.14 | 0.35 | 0.4 | 0.03 | -0.41 |
| 2 | MGT | -0.29 | 0 | 0.96** | 0.97** | 0.02 | -0.54 | 0.18 | 0.79* | -0.01 | 0.02 | -0.04 | 0.5 |
| 3 | $t_{10}$ | -0.08 | 0.96++ | 0 | 0.91** | 0.13 | -0.41 | -0.01 | 0.83* | 0.05 | 0.02 | -0.07 | 0.32 |
| 4 | $t_{50}$ | -0.47+ | 0.99++ | 0.92++ | 0 | -0.07 | -0.63 | 0.24 | 0.68 | -0.1 | -0.1 | -0.04 | 0.51 |
| 5 | SL | 0.40+ | 0.03 | 0.14 | -0.06 | 0 | 0.7 | 0.14 | 0.56 | 0.95** | 0.28 | -0.64 | 0.19 |
| 6 | MSRL | 0.66++ | 0.57++ | -0.43+ | 0.67++ | 0.71++ | 0 | 0.05 | 0.07 | 0.76* | 0.52 | -0.15 | -0.42 |
| 7 | NSR | -0.59++ | 0.19 | 0.01 | 0.28 | 0.14 | 0.05 | 0 | 0.21 | 0.36 | 0.29 | -0.1 | 0.39 |
| 8 | CL | 0.33 | 1.00++ | 1.00++ | 0.88++ | 0.81++ | 0.07 | 0.32 | 0 | 0.55 | 0.41 | -0.19 | 0.36 |
| 9 | SFW | 0.36+ | -0.01 | 0.05 | -0.1 | 0.95++ | 0.78++ | 0.37+ | 0.74++ | 0 | 0.51 | -0.47 | 0.19 |
| 10 | SRFW | 0.42+ | 0.02 | 0.03 | -0.09 | 0.3 | 0.52+ | 0.31 | 0.49+ | 0.52++ | 0 | 0.49 | -0.1 |
| 11 | RSR | 0.03 | -0.05 | -0.07 | -0.05 | -0.66++ | -0.19 | -0.1 | -0.33 | -0.50+ | 0.46+ | 0 | -0.43 |
| 12 | TKW | -0.55+ | 0.61++ | 0.40+ | 0.66++ | 0.2 | -0.58+ | 0.46+ | 0.62+ | 0.23 | -0.12 | -0.51+ | 0 |

**Table 5.** Variance component and heritability ($h^2$) estimates for the eight wheat genotypes combined over irrigation treatments. FGP, final germination percentage; MGT, mean germination time (hour); $t_{10}$ and $t_{50}$, respectively, the time required to reach 10% and 50 % germination (hour); SL, seedling length (cm); MSRL, maximum seminal root length (cm); NSR, number of seminal roots; CL, coleoptiles length; SFW, shoot fresh weight (mg/seedling); SRFW, seminal roots fresh weight (mg/seedling); RSR, root to shoot ratio; TKW, thousand kernel weight (g).

| No. | Trait | Variance components | | | |
|---|---|---|---|---|---|
| | | Variety | Irrigation treatment × variety | Error | $h^2$ |
| 1 | FGP | 47.58 | 11.85 | 32.19 | 0.71 |
| 2 | MGT | 16.83 | 9.33 | 20.01 | 0.68 |
| 3 | T10 | 28.60 | 10.97 | 50.31 | 0.67 |
| 4 | T50 | 138.87 | 45.40 | 440.46 | 0.59 |
| 5 | SL | 57.87 | 20.35 | $26.97\times10^{-3}$ | 0.65 |
| 6 | MSRL | $2.3\times10^{-3}$ | $1.60\times10^{-3}$ | 6.30 | 0.55 |
| 7 | NSR | 37.74 | 47.78 | 313.5 | 0.33 |
| 8 | CL | $1.10\times10^{4}$ | $5.62\times10^{3}$ | $1.48\times10^{4}$ | 0.68 |
| 9 | SFW | 3.36 | 0 | 16.32 | 0.69 |
| 10 | SRFW | 65.09 | 29.86 | 141.69 | 0.63 |
| 11 | RSR | 1.42 | 0.053 | 3.45 | 0.70 |
| 12 | TKW | 0.96 | 0 | 2.118 | 0.93 |

seedling traits combined across irrigation treatments are presented in Table 5.
Genotypic effects were highly significant (P<0.01) for most recorded parameters. IR×V interactions were not significant for most traits. The results revealed that heritability values were extremely high for most traits (range<0.55 to 0.71) except for NSR ($h^2$<0.33).

**Discussion**

This study revealed positive correlations between germination rate parameters and kernel size. In other words, varieties with larger kernels were slower in germination than those with smaller kernels. This is evident from the positive rg values between TKW and germination rate parameters (MGT, t10 and r50). Even though, TKW was higher under PSI (46.2 g) as compared with kernels obtained under CSI (43.2g) and rainfed conditions (41.6g), but they displayed a delay in germination as compared to kernels released under rainfed condition. Accelerated germination is a desirable trait under early drought to shorten the time between germination and seedling emergence and consequently a good early crop stand establishment at early stages of crop development (Al-Karaki, 1998; Abdel-Ghani, 2009; Abdel-Ghani et al., 2015). In contrast to our result in this study, Abdel-Ghani et al. (2015) found that larger kernels can accelerate germination because they contain more stored carbohydrates (energy) and consequently, large kernels are considered an important element that could lead to a more vigorous seedling. Unexpected positive correlation between kernel size and germination rate in this study might be due to limited number of varieties used in this study and might be also due to conditions where the germination experiments were conducted. The germination evaluation experiments were conducted at 22 °C and long days (16h light), where seedlings partially relied on stored carbohydrate with presence of light that enhanced photosynthetic tissue formation. Our results can be also explained by high amylase activity in small and medium kernels as compared with large kernels (Sulewska et al., 2014).

Considerable variations in germination and germination rate parameters were observed among wheat varieties released under different irrigation treatments. Varieties with a reduced MGT, t10 and t50 would have a better seedling establishment and a more vigorous seedling. High FGP and accelerated germination rate are prerequisites for a more vigorous seedling (Al-Karaki, 1998; Abdel-Ghani, 2009; Abdel-Ghani et al., 2015). From this perspective, some wheat varieties displayed faster germination including the bread wheat variety (Ammon), DairAlla 6, Acsad65, BaniSuf4, Bani Suf6, Horani Nawawi and Cham1. Wheat varieties that germinate faster (with short MGT, t10 and t50) had longer seminal roots than those with delayed germination. This might indicate that wheat varieties that germinate faster will give deeper roots, which would be advantageous for a better seedling stand establishment. The rg between MSRL and MGT, t10 and t50 were -0.57++, -0.43+ and -0.67++, respectively. Severe drought at early growth stages of small grain cereals might cause complete failure of seedlings if varieties germinate and followed by extended period of drought with high temperature that accentuates drought effect (Ceccarelli et al., 2004; Abdel-Ghani et al., 2004). Consequently, varieties that germinate faster can withstand drought that follows germination (Harris et al., 2001; Kaya et al., 2006). In order to enhance crop growth and development at early stages, varieties with faster germination with a deep seminal root system should be advantageous under early drought (Grando and Ceccarelli, 1995; Fábián et al., 2008).
Horani Nawawi and DairAlla 6 gave the maximum values for SL and MSRL combined with high SRFW and SFW, which might indicate their better adaptability to early drought. Seminal roots in wheat are the primary organ that used by the plant for the absorption of water and nutrients at early stages of crop development. When the crop exposed to drought, the crop might reach maturity with seminal roots only (Belford et al., 1987), and nodal roots might become less important than seminal roots (Grando and Ceccarelli, 1995).
In this study, the variation in SRN was narrow ranging from 4.40 to 5.33, while ranges for other seedling traits were

wider. The narrow range for NSR might be due to the limited number of varieties used in this study that adapted to the same geographic region. Many authors (Zubaidi et al., 1999; Lynch and Brown, 2001; Rubio et al., 2003; Abdel-Ghani et al., 2015; Canè et al., 2014) showed that a more vigorous root system is required for efficient absorption of nutrients and water available in the soil under drought (Středa et al., 2012; Rich et al., 2016).

Longer coleoptiles were observed in Horani Nawawi (3.27cm) and Omqais (3.96cm). Longer coleoptiles would have a better stand establishment and a more vigorous seedling because they can emerge faster (Duwayri, 1983) and they will have a higher emergence percentage and a greater plant biomass (Grando and Ceccarelli, 1995; Rebetzke et al., 2004, 2007). Breeders and wheat growers prefer varieties with longer coleoptiles under rainfed conditions because they can be seeded deeper in the soil, and hence germination will only occur when the crop is received sufficient rains to support seedlings after emergence to avoid the risks of extended drought after germination and emergence (Duwayri, 1983; Grando and Ceccarelli, 1995).

Root to shoot ratio is an important trait that could be used to improve the performance of wheat under drought. In this study, the RSR ranged from 0.38 to 0.77. The maximum RSR was obtained in Ammon (0.77), followed by Bani Suef6 (0.63) and Omqais (0.58). High RSR might be considered as an indirect selection trait under early drought, because genotypes with high RSR might have the ability to absorb more water from soil profile when water is depleted from the soil (Eghball and Maranville, 1993; Pandey et al., 2000). Under drought, crops used roots morphological plasticity to enhance adaptation by increasing RSR (Takahashi et al., 1990; Tuberosa et al., 2003). ().

The results showed that TKW was positively correlated with NSR (0.46+) and CL (0.62+) but negatively correlated with MSRL (-0.58+) and SRFW (-0.52+). Such results indicate that larger kernels were positively affecting some seedling parameters such as NSR and CL, but they had negative impacts on NSR and SRFW. Other studies showed that varieties with large kernels have a better seedling biomass as compared with varieties with small kernels (Palusk et al., 1979; Abdel-Ghani et al., 2012, 2015) and consequently genotypes with larger kernels might have a more vigorous seedling and high grain yields in small grain cereals (Kaufmann and Mcfadden, 1963; Thompson, 1971). However, other studies revealed no association between kernel size and root and shoot growth in maize (Manavalan et al., 2011; Kumar et al., 2012).

The heritability estimates were medium to high (0.55 to 0.71) for most traits under study, except for NSR which displayed low $h^2$ (0.33). In general, IR×V interactions were not significant for all traits under study. High heritability estimates indicate the effectiveness of selection with high genetic gain when such traits are used for indirect selection traits under drought. Similarly, high heritability for seedling traits in barley (Abdel-Ghani et al., 2015) and maize (Kumar et al., 2012) were previously observed, indicating that root and shoot attributes in cereals are highly heritable and could be efficient indirect selection. In accordance, many other studies revealed a positive correlation between root and shoot traits with grain yield (Chloupek et al., 2010; Sayed, 2011; Středa et al., 2012; Kumar et al., 2012a; Svačina et al., 2013), indicating the possibility of using root and shoot attributes as indirect traits to enhance yielding ability in cereals.

## Materials and methods

### *Plant materials*

Eight wheat varieties were included in this study: seven durum varieties and one bread wheat variety. Most of these wheat varieties were registered in Jordan during the last five decades and recommended for wheat growers in Jordan. Horani Nawawi and DairAlla 6 were released during 1970's, while Cham 1 and Acsad were released in 1980's. Omqais and Ammon were released in 2004. BaniSuef 4 and BaniSuef 6 were obtained from Egypt and they are still under experimentation. Names, pedigree, source, types and year of release of the tested wheat varieties used in the study were previously reported in Abdel-Ghani et al. (2020). All varieties were obtained from the National Agricultural Research Center (NARC), Jordan.

### *Field experiment*

A field experiment was carried out at Al-Wasiah area, Al-Karak, Jordan (31°16′ north latitude, 35° 45′ east longitude; 920 m above sea level). The experimental site is semi-arid with 300mm long-term rain-fall. Wheat kernels from field experiment were produced to assess the effect of three water treatments on kernel size; FGP, germination rate and seedling root and shoot traits. The three water treatments used were as follows: rainfed treatment (i.e. control) with 262.8mm rainfall received during the growing season, CSI receiving 640mm fresh water (262.8 mm rainfall + 377.2 mm irrigation at 2-3 weeks interval) and PSI receiving 482.8mm of water (262.8mm rainfall + 220mm irrigation at anthesis). The subplots were supplementary irrigated using a drip irrigation system. The experimental design was Randomized Complete Block Design (RCBD) with a split-plot arrangement with three replications. The main plots were the irrigation treatments, while the sub-plots were varieties nested within the irrigation treatments. Each plot nested within the main plots was considered as an experimental unit. The main plots and sub-plot were randomly distributed within replicates. The subplot size was 2m long and 1.5m width and consisted of six rows placed 25cm apart. At harvesting maturity when 95% of peduncles turned yellow, kernels were harvested and weighed to record thousand kernel weight (TKW).

### *Germination test*

Germination tests were carried out to assess the effect of three water treatments under field condition and eight wheat varieties on FGP, MGT and the time to attain t10 and t50. Germination was tested and seedling traits were collected from ten petri dishes that averaged to get one value for each experimental unit in each replicate. To perform germination test, two pieces of filter paper were placed in each petri dish and thereafter 10 seeds were placed on top of the filter paper that covered with a lid. The petri dishes were incubated at 20°C at 90% relative humidity for one week and exposed to 16h light and 8h dark. To record the germination rate, the accumulative number of kernels germinated was recorded at six hours intervals. One value was recorded from each petri dish to calculate FGP, MGT, t10 and t50, while seedling traits were obtained from five seedlings per petri-dish. Germinator software was used to estimate all these parameters (Germinator; a software package for high-throughput scoring and curve fitting of seed germination; Joosen et al 2010). Final germination percentage (FGP) was calculated as the total number of kernels germinated in each petri-dish with at least 2mm radicals divided by the total number of kernels after 7 days from the moment of starting seed moisturizing. Mean germination time (MGT) according to Lafond and Baker (1986) as follows:

$$\mathrm{MGT} = \frac{\sum(\mathrm{c} \times \mathrm{t})}{\sum(\mathrm{c})}$$

, where c is the number of seeds germinated at each time point recorded every 6 hours, and t is the time point (hours) of germinated kernels counting. t10 and t50 were estimated by calculating the time in hours at which 10% and 50% of germination was occurred.

***Seedling traits recorded***

Seven days after germination, five homogenous seedlings were chosen to record average values of different root and shoot traits from each petri dish. CL (the white sheath covers the seedling; cm), SL (cm) and MSRL (cm) were recorded by a scaled ruler. NSR was recorded by counting the total number of seminal root. Shoot and root system were separated by a shear then SFW and SRFW were recorded (in mg) using a sensitive balance. RSR was calculated as a ratio between SRFW and SFW.

***Statistical analysis***

Entry means from each treatment obtained from each variety were used in the combined analyses across water treatments. Thereafter, variance components were estimated following Snedecor and Cochran (1980). For each trait, broad-sense heritability ($h^2$) was estimated on plot basis using the following formula

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_{g\times Ir}^2}{n} + \frac{\sigma_e^2}{r \times n}}$$

(Hallauer and Miranda, 1981). Phenotypic and genetic correlations (rg) between traits were calculated using values of variance and covariance for each trait following the standard method developed by Mode and Robinson (1959). The least significant differences at P<0.05 were used to compare between means.

**Conclusion**

Supplemental irrigation had significant effects on kernel quality. Larger kernel was obtained when SI was performed at reproductive stage (TKW< 46.205 g), followed by CSI treatment (43.20g) and rainfed treatment (41.70g). Larger kernels gave a more vigorous seedling but smaller kernels would be desirable to accelerate the time required from sowing to seedling emergence. The fastest germination was observed in the bread wheat variety (Ammon), followed by DairAlla 6, Acsad65, Bani Suf4, Bani Suf6, Horani Nawawi and Cham1. Such genotypes might be recommended to accelerate germination to minimize the time required from germination to emergence for a better seedling stand establishment.

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