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Assessment of durum wheat (*Triticum durum*) genotypes on grain filling parameters

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ABSTRACT

Durum wheat (*Triticum durum* Desf.), a crucial crop in the Mediterranean basin, faces challenges due to drought, resulting in substantial yield losses. This study was carried out during the winter (*rabi*) season of 2020–2021 to determine the influence of grain filling parameters on individual grain weight variation and their relationship to yield components in 3 durum wheat genotypes (Boussellam, Oued El-Bared and GTA-dur) grown at 3 different locations with varying rainfall patterns under a semi-arid condition of Algeria. Samples were collected from each genotype on 9 different dates to assess grain number, dry weight and grain filling parameters. The experimental results revealed significant genotype effects on grain yield, 1000-kernel weight and most grain filling parameters across all 3 locations, except for the parameter SFR (supreme fill rate). Boussellam recorded higher grain yield, kernel weight and maximum final weight parameter (MFW) due to its longer grain filling duration and higher rate of grain filling. Linear regression analysis indicated decrease of 0.001 mg/day in the rate of grain filling led to a loss of 0.9527 mg in the maximum final weight. Correlation analysis highlighted the interdependence between the rate and grain filling duration, which varied across different environments and influenced dry-matter accumulation, ultimately led to higher grain yield.

Keywords: Durum wheat, Grain filling, Grain yield, Linear regression, Sigmoid curve

Algeria is the second largest cereal consumer in Africa and the fifth largest cereal importer in the world behind Egypt, China, Indonesia and Turkey (Benalia 2022). Drought limits the yield and quality of cereal crops worldwide (Boudjabi *et al.* 2017), especially in Mediterranean regions where plants are subject to low and irregular rainfall. In Algeria, the cereal basin is located in semi-arid bioclimatic zones. These regions frequently experience high temperatures and limited precipitation during grain formation, which can impact their filling process and overall quality (Dettori *et al.* 2017). The grain yield of durum wheat (*Triticum durum* Desf.) depends on 3 elements: the weight of the grain, the number of grains per ear and the number of ears per unit area. The final grain weight is the result of the grain filling process, which is defined by two parameters: duration and rate of grain filling (Hutsch *et al.* 2019). The accumulation of dry-matter increases as the grain filling duration is prolonged with a constant or rapid rate of grain filling, loss in grain yield caused by the shortening of the grain filling period could not compensated by a higher filling rate (Impa *et al.* 2021). Thus, grain filling, the final process associated with yield performance, is an important component of grain yield variability in cereal crops (Dubey *et al.* 2020). Therefore, we need to better understand the sources of variation in 1000-kernel weight because climate change can lead to increased abiotic stress (drought and heat) during durum wheat grain filling and therefore limit its productivity (Scafaro and Atkin 2016). Keeping the above facts in view, an experiment was conducted to assess grain filling from anthesis to physiological maturity of durum wheat cultivars, with the objective to determine the rate of grain filling, grain filling duration and their relationship with grain weight and grain yield at 3 different locations in the semi-arid region of the Mediterranean basin.

MATERIALS AND METHODS

Plant material and experiment designs: The plant material consists of 3 genotypes of durum wheat, viz. Boussellam (BOS), Oued El-Bared (OB) and GTA-dur (GTA) which were sown during the winter (*rabi*) season of 2020–2021 (20-12-2020) in randomized block design with 3 replicates and a sowing density of 300 seeds/m^2. The experiment was conducted at 3 different locations in Setif province, Algeria, namely Ain Oulmene (35º 55'30"N.

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5º 22'07"E, 934 m amsl), the technical institute of field crops-ITGC- (36º 08'22"N. 5º20'55"E, 973 m amsl) and Beni Fouda (36°15'08"N, 5°29'43"E, 1199 m amsl). The experimental site is bestowed with semi-arid climate. The mean annual rainfall of the experimental sites ranged from 295 to 587.33 mm, which was received from September to August.

Agronomic measures and grain filling parameters: From flowering stage to physiological maturity, samples were taken from each genotype during 9 different dates to determine the number of grains, dry weight and grain filling kinetics. For each genotype, 5 ears were harvested from each sample starting from the grain-filling stage and dried in an oven at 80°C for 48 h. The evaluation dates were expressed as sums of post-flowering mean temperatures. To assess the variation in grain filling, 6 grain filling parameters were utilized, with the calculation as:

1. Maximum final weight (MFW mg) was determined by calculating the average dry weight of grains collected on the final sampling date (Vesna *et al.* 2018).
2. Rate of grain filling expressed in absolute intensity (AFI mg/day) was calculated as (Radford 1967):

$$AFI = W2 - W1/T2 - T1$$

3. Dry matter accumulation over time was expressed as growing degree days (GDD°C) accumulated since anthesis, that were calculated by summation of daily degree days (Td) as (Baker *et al.* 1986):

$$Td = [(Txm + Tls)/2 - Tz]$$

4. Grain filling duration (DGF ˚C), was calculated according to Vesna *et al.* (2018):

DGF= Accumulated GDD from anthesis.

5. Rate of grain filling (RGF mg/day) was calculated as (Vesna *et al.* 2018):

RGF= Dry weight of final grain/ DGF

6. Supreme fill rate (SFR mg/day) was calculated as (Brdar *et al.* 2004):

SFR= Appreciated as a function of the AFI for every genotype

where, W1 and W2 are dry weights of grains at time T1 and T2, respectively. Td, daily degree-day; Txm, extreme daily-temperature; Tls, littlest daily-temperature; Tz, Zero temperature (0°C).

Grain yield (GY Q.h-1) is the weight of grain harvested per 2.25 m^2, converted into quintal and determines the thousand kernel weight (TKW g).

Statistical analysis: To evaluate significant differences between genotypes, the one-way analysis of variance (ANOVA) was performed. Fisher's LSD test was used for comparisons of means. Pearson's correlation analysis and Simple linear regression were used to determine the statistical relationship between variables and to assess the significance of the effects using CoStat version 6.4 and Microsoft Excel. Ranking Test: The data is sorted in ascending or descending order, according to the strength of individuals across all the variables studied.

RESULTS AND DISCUSSION

Evolution of grain filling: The dry matter accumulation per grain followed a sigmoid curve pattern, consistent with previous research by Bendada *et al.* (2022). Grain growth initially proceeded slowly until the 15th day in Ain Oulmene and the 17th day in Beni Fouda, after which it underwent a rapid linear progression and eventually stabilized at physiological maturity (Fig 1). The grain filling duration varied among genotypes and locations. In Ain Oulmene, the filling duration ranged from 31 days for Oued El-Bared to 37 days for both GTA-dur and Boussellam. At the ITGC location, Boussellam exhibited the longest duration of 43 days, while GTA-dur and Oued El-Bared had durations of 31 and 37 days, respectively, with an overall mean of 37 days. Similarly, in Beni Fouda, the filling duration ranged from 37 days for Oued El-Bared to 43 days for both Boussellam and GTA-dur, with an overall mean of 41 days. Moreover, it was observed that Boussellam consistently exhibited higher grain weight at maturity compared to the other genotypes across all locations. This could be attributed to various factors, including genotypic traits and the influence of environmental conditions. According to Bergkamp *et al.* (2018), post-anthesis heat stress resulted in a reduction in grain filling duration, consequently leading to decreased grain weight.

Furthermore, in Ain Oulmene, although there was no significant difference in maximum final weight (MFW) between Oued El-Bared and GTA-dur (Table 1), GTA-dur exhibited a longer maturation period than Oued El-Bared. The variation in maturation time among genotypes at the ITGC location suggests differences in anthesis time. Therefore, to consider reducing time to maturity, both the grain filling period and pre-anthesis period must be taken into account. However, it is worth noting that MFW, a component of final yield (GY), converged between Boussellam and Oued El-Bared with values of 54.85 mg and 53.30 mg, respectively, while GTA-dur had the lowest MFW of 49.1 mg (Table 1). In Beni Fouda, Oued El-Bared matured earliest with a relatively short filling period and lower yield. According to Impa *et al.* (2021), an increase in grain filling rate does not compensate for the reduction in grain filling duration.

Grain yield and thousand kernel weight: The ANOVA analysis proved that the effect of genotypes was significant for grain yield (GY) and thousand kernel weight (TKW) under the different locations (Table 1), indicates that the variation in genotypes leads to substantial differences in GY and TKW.

In the Ain Oulmene location, there was a significant difference ($P<0.05$) in grain yield among the genotypes. Specifically, the grain yield ranged from 22.92 q/h for Oued El-Bared to 26.09 q/h for Boussellam. Boussellam showed an 8.48% increase above the overall mean (24.05 q/h), while

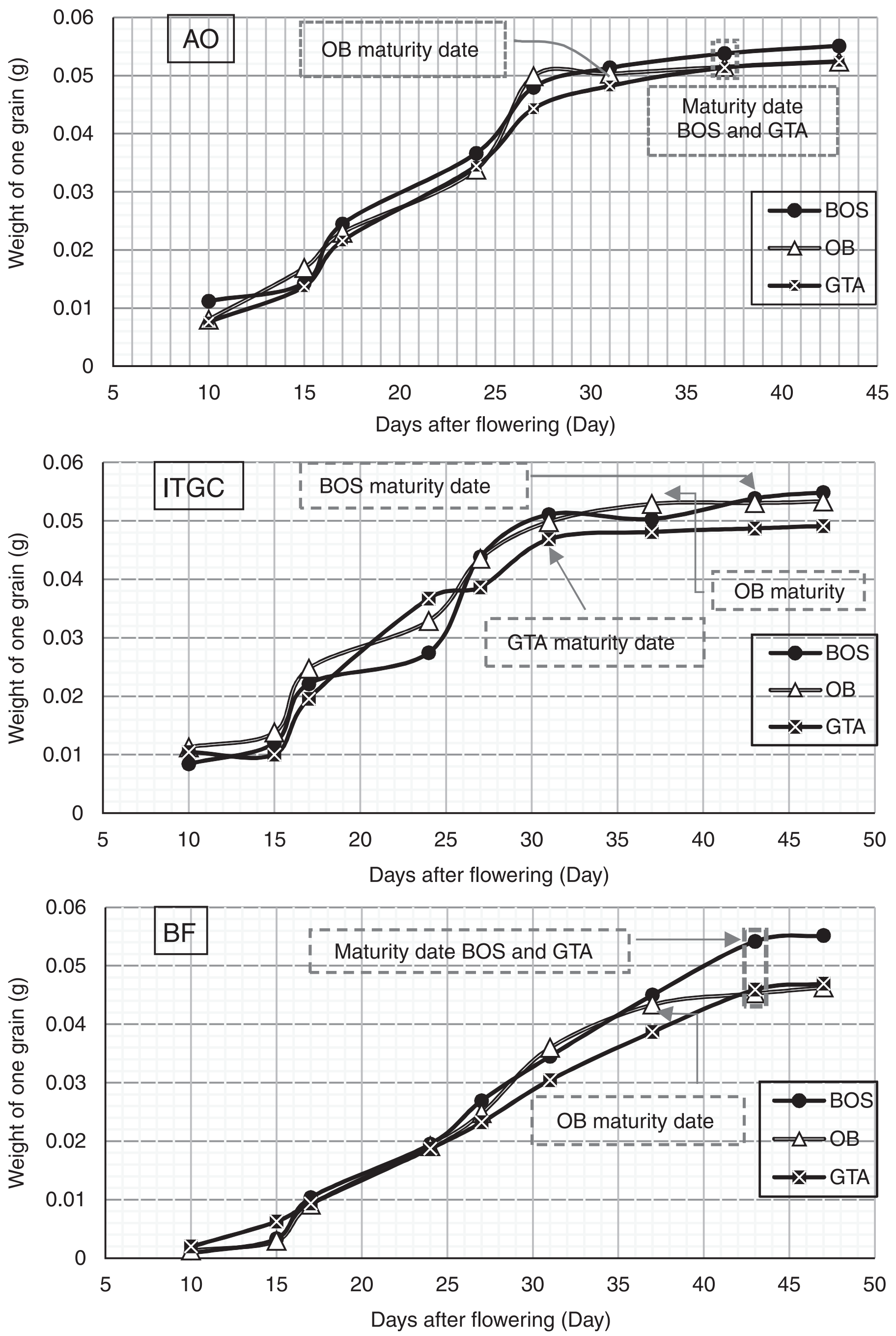

Fig 1 Grain filling kinetics (g) for 3 genotypes, viz. Boussellam (BOS), Oued El-Bared (OB) and GTA-dur (GTA), at the 3 cultivation sites: [Ain Oulmene (AO), Technical Institute of Field Crops (ITGC) and Beni Fouda (BF)].

GTA-dur and Oued El-Bared exhibited decreases of -3.78% and -4.70%, respectively. In the ITGC, the inter-varietal difference was very significant (P<0.01), GTA-dur records the low grain yield with a loss of 18.84% compared to the overall mean (24.1 q/h), while Boussellam and Oued El-Bared stand out with yields greater than the general average. In Beni Fouda, the difference was only significant between Boussellam and Oued El-Bared (P<0.05). The comparison of means test showed that the Boussellam genotype had the highest grain yield in the 3 study locations, which was accompanied by the maximum values of the 1000-kernel weight, while the correlation tests (Table 2) proved a very significant correlation at the ITGC between GY and TKW (r=0.81**), this is in agreement with the results of Bendada *et al.* (2022). In addition, there was no significant correlation between TKW and GY in Ain Oulmene and Beni Fouda locations, these results align with the findings of Isham *et al.* (2021).

Grain filling parameters: Analysis of variance showed that the genotypes effects were significant for all grain filling parameters except supreme fill rate (SFR) (Table 1).

The genotypic variation observed for DGF exhibits a very highly significant difference (P<0.001) between genotypes in all 3 locations. It varies from 585.4 to 724.85°C in Ain Oulmene, 846.65 to 724.85°C in ITGC and 846.65 to 949.4°C in Beni Fouda. A correlation analysis uncovered a significant positive correlation between DGF and TKW (r= 0.86**) in Ain Oulmene (Table 2). This finding suggests that there is a strong relationship between DGF and TKW; therefore, a relatively short pre-flowering period is generally associated with a longer stage flowering-maturity in certain environments (Royo *et al.* 2016), and a longer grain-filling period increase TKW (Joudi *et al.* 2014).

A very significant and positive correlation between DGF and GY (r=0.81**) in Beni Fouda (Table 2), this means that a longer grain filling duration allows durum wheat grains to achieve a larger size and accumulate more nutrients, resulting in a higher grain yield. These results are in agreement with the findings of Baye *et al.* (2020), who also reported that grain filling duration and 1000-kernel weight had a positive correlation with grain yield at genotypic and phenotypic levels. In Ain Oulmene and ITGC location, the results demonstrated a weak positive correlation between grain yield (GY) and grain filling duration (DGF), (r=0.50, r=0.51, respectively), similar to the results of Dabi *et al.* (2016).

The maximum final weight (MFW) was significantly

Table 1 Ranking of tested genotypes for grain yield, 1000-kernel weight and grain filling parameters

Location	Genotype	MFW	RGF	DGF	SFR	GY	TKW	Ranking
Ain Oulmene	BOS	55.29 (a)	0.058 (a)	724.85 (a)	0.27 (a)	26.09 (a)	52.08 (a)	1
	OB	52.59 (b)	0.055 (b)	585.4 (b)	0.27 (a)	22.92 (b)	48.14 (b)	3
	GTA	52.98 (b)	0.056 (b)	724.85 (a)	0.24 (a)	23.14 (b)	51.32 (a)	2
	Genotype effects	.014 *	.014 *	.000 ***	.97 ns	.03 *	.01 *	
	LSD 5%	1.72	0.002	2.78	0.36	2.28	2.04	
	Mean	53.62	0.06	678.37	0.26	24.05	50.51	
	BOS	54.85 (a)	0.058 (a)	846.65 (a)	0.28 (a)	26.77 (a)	53.55 (a)	1
ITGC	OB	53.30 (a)	0.056 (a)	724.85 (b)	0.26 (a)	25.97 (a)	52.52 (a)	2
	GTA	49.1 (b)	0.052 (b)	724.85 (b)	0.22 (a)	19.56 (b)	46.31 (b)	3
	Genotype effects	.0013 **	.0013 **	.000 ***	.825 ns	.008 **	.028 *	
	LSD 5%	2.35	0.002	3.11	0.21	3.48	4.88	
	Mean	52.42	0.06	765.45	0.25	24.1	50.79	
	BOS	55.13 (a)	0.058 (a)	949.4 (a)	0.17 (a)	44.69 (a)	48.74 (a)	1
	OB	46.22 (b)	0.049 (b)	846.65 (b)	0.15 (a)	40.72 (b)	48.42 (a)	3
Beni Fouda	GTA	46.87 (b)	0.049 (b)	949.4 (a)	0.17 (a)	43.44 (ab)	41.72 (b)	2
	Genotype effects	.042 *	.042 *	.000 ***	.954 ns	.039 *	.021 *	
	LSD 5%	7.35	0.008	1.39	0.23	2.79	4.51	
	Mean	49.41	0.05	915.15	0.16	42.71	46.29	
		1						
		3						
						BOS		1
		Ranking over all locations				OB		3
						GTA		2

Table 2 Correlation coefficients of grain filling and agronomic parameters

Location	Parameter	MFW	RGF	SFR	DGF	GY	TKW
Ain Oulmene	MFW	1					
	RGF	0.99***	1				
	SFR	0.27 ns	0.27 ns	1			
	DGF	0.36 ns	0.36 ns	-0.03 ns	1		
	GY	0.61 ns	0.61 ns	-0.14 ns	0.50 ns	1	
	TKW	0.33 ns	0.33 ns	0.24 ns	0.86**	0.40 ns	1
	MFW	1					
ITGC	RGF	1 ***	1				
	SFR	0.80**	0.80**	1			
	DGF	0.56 ns	0.56 ns	0.78*	1		
	GY	0.82 **	0.82**	0.85**	0.53 ns	1	
	TKW	0.94***	0.94***	0.68*	0.55 ns	0.81**	1
	MFW	1					
	RGF	1 ***	1				
Beni Fouda	SFR	0.23 ns	0.23 ns	1			
	DGF	0.35 ns	0.35 ns	0.03 ns	1		
	GY	0.43 ns	0.43 ns	-0.08 ns	0.81**	1	
	TKW	0.40 ns	0.40 ns	0.19 ns	-0.42 ns	-0.01 ns	1

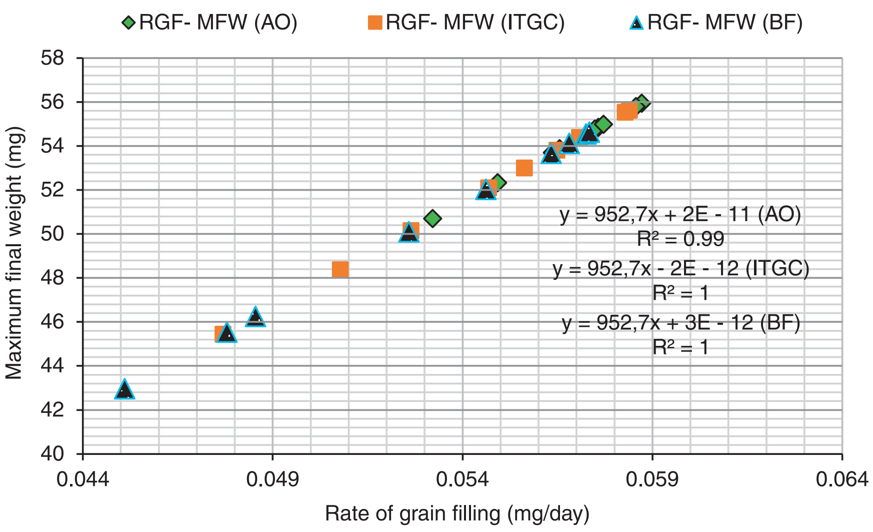

Fig 2 Linear regression between the rate of grain filling (RGF) and maximum final weight (MFW) at the 3 locations; Ain Oulmene (AO), Technical Institute of Field Crops (ITGC) and Beni Fouda (BF).

affected by genotypes, with positive and very highly significant correlations (P<0.001), observed between MFW and RGF at all 3 study locations (Table 2). Grain weight is mainly related to the significant decrease in rate of grain filling, the linear regression analysis revealed that a decrease of 0.001 mg/day in RGF resulted in a loss of 0.9527 mg in MFW (Fig 2). This is consistent with previous studies that wheat experienced high heat stress during the grain filling period, resulting in decreased grain weight and rate of grain filling (Jing *et al.* 2020, Mirosavljevic *et al.* 2021).

In ITGC location, the results showed a positive and significant correlations of GY with TKW, MFW, RGF and SFR (r=0.81**, r=0.82**, r=0.82** and r=0.85**, respectively) (Table 2). In addition, positive and significant correlations between MFW with SFR and TKW (r=0.80** and r=0.94***, respectively), these results are in agreement with the studies of Chen *et al.* (2019). The best correlation between MFW, SFR and TKW, GY, proved that the genotypes with high values of MFW and SFR had high TKW and GY.

The results of our study indicate that the supreme fill rate (SFR) is positively and significantly correlated with the grain filling duration (DGF) at the ITGC location (r=0.78*), which is in agreement with the findings of Rehman *et al.* (2021), the decrease in the supreme fill rate and the reduction in the duration lead to less accumulation of dry matter towards developing grains. According to Sattar *et al.* (2020), under stress conditions, the positive correlation was likely to be observed between reduction in grain filling duration and grain yield which is not compensated by an increase in the filling rate. The research by Xiaoli (2018) showed that the grain filling rate was not correlated with the duration of grain filling, which is consistent with our findings at Ain Oulmene and Beni Fouda, where there was no detectable correlation between SFR and DGF with a correlation coefficient of zero, this finding suggests that breeders have the opportunity to simultaneously increase the grain filling ratio and grain weight without extending the grain filling duration.

In conclusion, the results of this study indicate that the genotype has a significant impact on all studied parameters, except for supreme filling rate (SFR). Particularly, grain filling duration (DGF) was found to be more influenced by genotype effects compared to other grain filling parameters across all 3 locations. While maximum filling weight (MFW) showed a strong correlation with rate of grain filling (RGF) at all locations, it did not exhibit any correlation with DGF. This suggests that under semi-arid conditions with terminal drought, a low RGF leads to a low MFW, and this cannot be compensat by a longer filling period.

Specifically, in Ain Oulmene, DGF demonstrated a positive and highly significant correlation with TKW, while in Beni Fouda, DGF showed a positive and highly significant correlation with GY. Additionally, RGF exhibited a positive and highly significant correlation with MFW at all 3 locations. These findings emphasize the interdependent relationship between the rate and grain filling duration, which varies across environments and affects dry matter accumulation and grain yield. The Boussellam genotype exhibited the best performance in terms of GY, MFW and TKW, likely attributed to its longer DGF and higher grain filling rate. However, it should be noted that environmental variations at these locations can significantly impact grain weight and genotype behaviour. Therefore, different responses may emerge when genotypes are exposed to a wide range of growth conditions.

Based on the ranking test, the Boussellam genotype demonstrated superiority over other genotypes across all 3 locations. It was followed by Oued El-Bared in the ITGC location and GTA-dur in both Ain Oulmene and Beni Fouda. Therefore, the comprehensive genotype ranking, in descending order of performance, was as follows: Boussellam exhibited the highest ranking, followed by GTA-dur and finally Oued El-Bared.

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