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Grain filling and stem accumulation effects on durum wheat (*Triticum Durum* Desf.) yield under drought

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Abstract

In Mediterranean area, water deficit is the main factor limiting agricultural production. Durum wheat yield is greatly hampered by drought in the Mediterranean semi-arid areas. The duration and the rate of grain filling and the contribution of stem assimilates are likely to have important effects on yield performance under stress conditions. The objective of this study is to evaluate differences in durations and rates of grain filling and the contribution assimilates from the stem to the yield of 10 durum wheat genotypes (*Triticum durum* Desf.). Water stress was induced in booting stage by stopping irrigation, the differences of duration and rates of grain filling and the contribution of the assimilates of the stems to grain yield were determined. Genotypes' agronomic performances were estimated by measuring yield components: number of grains per ear (NGE), weight of one grain (P1G) and weight of 1000 grains (PMG). The results showed a significant effect of water stress, genotypes and of the interaction between genotype x water stress. A positive correlation between agronomic performance and the two key variables for the final grain weight: the rate and duration of grain filling was observed.

Keywords: Durum wheat, water stress, grain filling, yield components, semi-arid area.

1. Introduction

Durum wheat cropping in the arid and semi-arid regions is subjected to various abiotic stresses that limit significantly its grain yield.

The grain growth as pictured by grain filling rate follows a sigmoid curve comprising three phases: a) phase of low accumulation of dry matter, b) linear ascending phase and c) a plateau phase [1,2,3].

During grain filling, the determination of grain weight, defined as the product between the rate and duration of grain filling have explained 97% of grain weight variation [4].

Relationship between grain yield and its components showed that the number of grains per m² and the final weight of grain are the principal factors controlling grain yield [5].

For durum wheat, the grain filling stage largely determines the final grain yield through its action on the weight of the grain [5].

Under water deficit condition, grain yield, is the result of the rate of grain filling and the ability to transfer assimilates stored in the stems to the grain [6].

This study seeks a better understanding of the two variables characterizing the grain filling: duration (D) and rate (V) of grain filling and understand their role in developing the final weight of grain.

This objective of this work was to study: the relations between the duration of flag leaf life, the rate of grain filling, the ability to transfer assimilates from the stem to the grain and finally the correlations between these parameters and grain yield.

2. Materials and methods

The study used 10 durum wheat genotypes: Hedba, Razzak, Oued-Zenati, Kyperounda, Simeto, Jenah-Khertifa, Mrb5, Senator-Capelli, Massara-1 and Waha.

The experiment was conducted under greenhouse; seeds were directly germinated in plastic pots containing a mixture of clay soil and sand (2 / 3 soil and 1 / 3 sand).

Ten repetitions for each variety were used and ten plants were planted per pot.

The water stress was applied at the booting stage by stopping irrigation, while the control entries were still regularly irrigated.

Samples were collected at timing of five days.

The studied parameters were:

- The rate of grain filling (V mg.d^{-1}), determined by rate of increase in grain dry matter (ten grains per ear, dried in an oven at 60°C for 96 hours).
- The duration of filling (D, j), determined by the ratio of grain weight at maturity on the rate of grain filling (V) (ten grains per ear, dried in an oven at 60°C for 96 hours).
- The quantity of dry matter transferred from the stems to the grain (T %), estimated by the difference between the maximum weight of the dry accumulated in the stems (in heading stage) over the weight of stem matter measured at maturity (during of the stems in the oven at 60°C for 96 hours).
- The photosynthetic activity of the flag leaf, determined by total chlorophyll content. Extraction and dosage of total chlorophyll content were made using the method of Inskeep and Bloom [7].
- The yield components: number of grains per spike (NGE), the final weight of one grain (P1G) and weight of 1000 grains (PMG).

3. Results

3.1. Role of the rate and duration of grain filling on the development of grain weight

The rate of grain growth occurs following a sigmoid curve that begins with a phase of low accumulation of dry matter, followed by a strong upward linear phase, then by a plateau phase leading to the final weight. For the checks utilized, their duration of filling varied from 31 to 33 days and has a rate of filling which varied from 1.20 to 1.38 mg / day. The final weight for one grain varies from 39 to 44 mg.

Under water stress, evolution of the growth rate during the grain filling, has allowed to differentiate between three responses to stress. Table 1 shows statistical analysis of the different effects: variety, environment and interaction between variety and environment.

Table 1: Speed and duration of grain filling in ten durum wheat genotypes stressed.

	V (mg.d^{-1})	**D (d)**
Hedba	1,91	21
Razzak	2,10	23
Oued Zenati	2,02	21
Kyperounda	0,95	23
Simeto	0,93	25
Jenah Khertifa	1,07	37
Mrb5	1,18	35
Senator Capelli	0,98	38
Massara-1	1,11	36
Waha	0,93	38
RH	*	*
VAR	**	**
VAR-RH	***	***

V: speed of filling (mg.d^{-1}), D: duration of filling (mg), RH: water regime factor, VAR: varietal factor, VAR-HR: interaction variety x water regime. *, **, ***: Significant respectively at 0.05, 0.01 and 0.001.

Genotypes Hedba, Razzak and Oued Zenati had an important rate of filling and a short duration of filling that varied from 21 to 23 days. In this group, the decline of the rate of filling occurs from the 18th day since the beginning and continues until the end (Figure 1A).

Whereas varieties Jenah Khetifa, Senator Capelli, Mrb5, Massara-1 and Waha are characterized by a low rate of filling and the slight decline between the 10th and 15th day followed by a recovery until 32th day, the duration of filling varied from 35 to 38 days (Figure 1B).

However; Kyperounda and Simeto have a low rate of filling almost constantly during the filling period (Figure 1C).

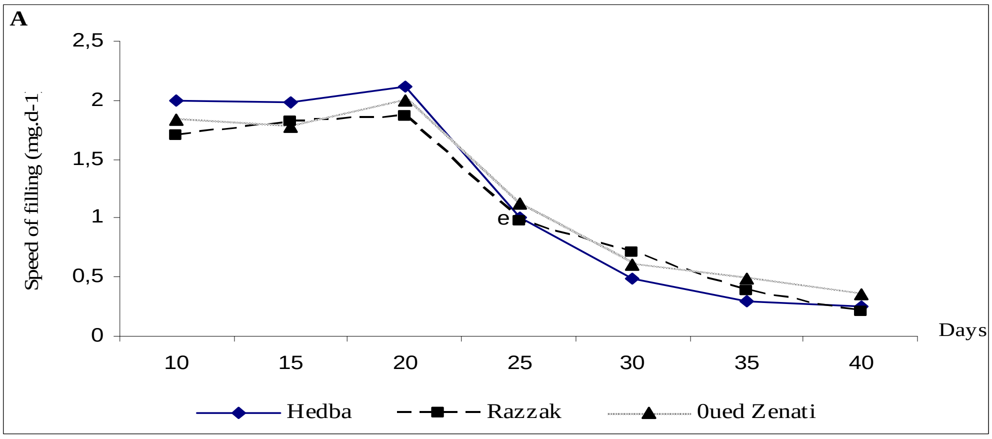

Figure 1A: The growth rate during the grain filling for Hedba, Razzak and Oued Zenati.

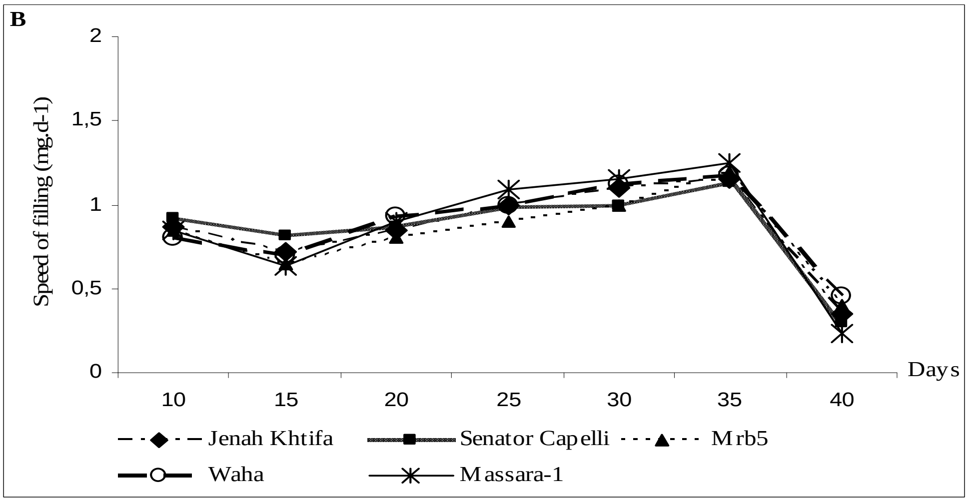

Figure 1B: The growth rate during the grain filling for: Jenah Khetifa, Senator Capelli, Marb5, Massara-1 and Waha.

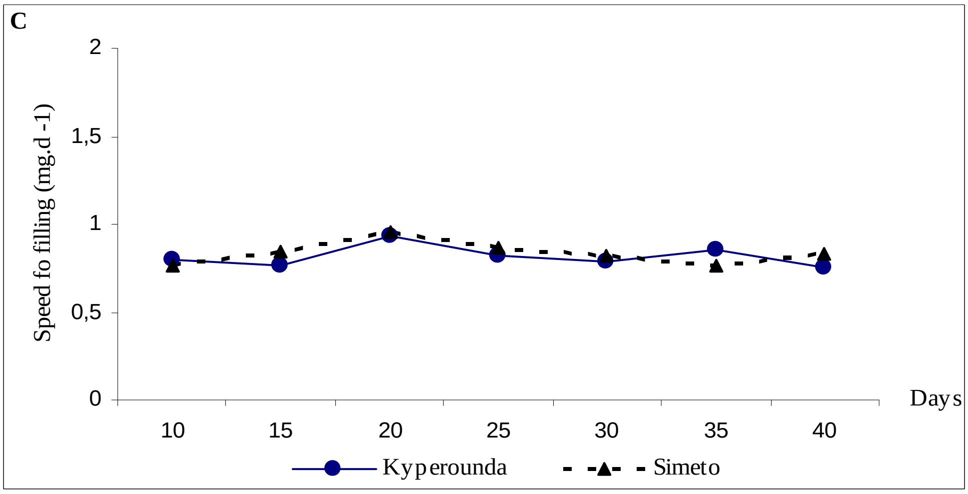

Figure 1C: The growth rate during the grain filling for Kyperounda and Simeto.

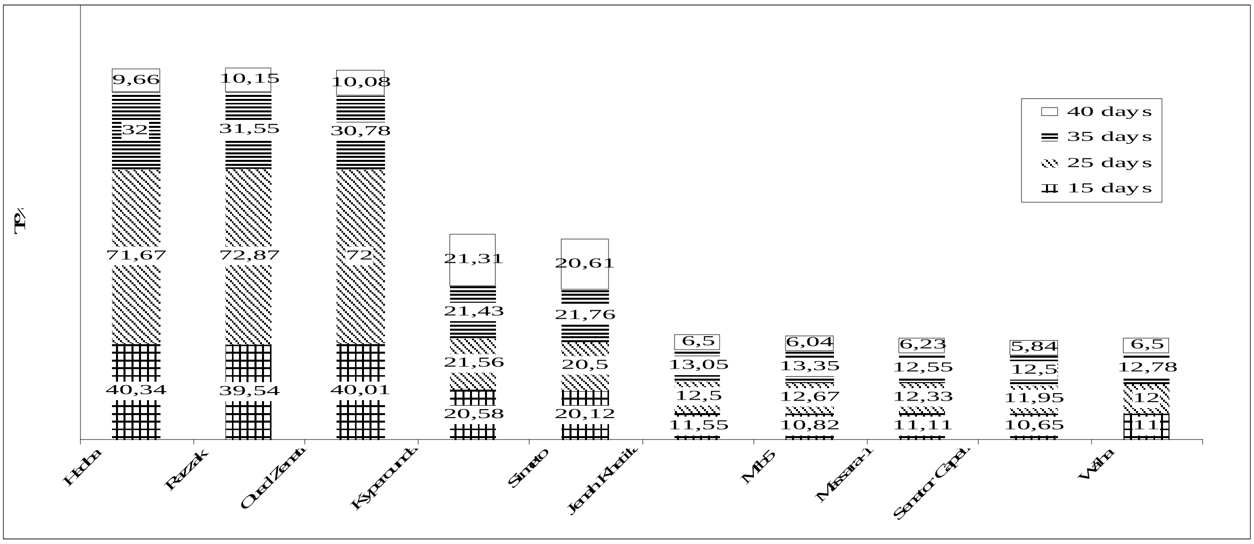

Figure 2: The relative quantity of assimilate translocated to the grain during the grain filling.15 days, 25 days, 35 days and 40 days: number of days in the beginning of heading

3.2. The assimilates stored and transferred from the stems to the grain filling

The water stress effect is significant, which explains the variations of the quantity of assimilates transferred (T %) from the stems to the grain, showing a significant inter varietal difference (Figure 2).

For Hedba, Razzak and Oued Zenati, an important quantity of assimilates (T ≠ 40%) transferred from the beginning of the grain filling phase and reached its maximum at 18th day of the filling phase (T ≠ 72%).

For the genotypes Kyperounda and Simeto, a constant quantity of assimilates is translocated during the grain filling phase (T ≠ 21%).

While for the others, the contribution of the assimilates of the stems to the grain filling is very low (T varied from 12,50% to 13,35% at 32th day of the filling phase).

3.3. The photosynthetic activity of flag leaf

The study of the stability of total chlorophyll pigments showed that the water stress effect is reflected by a decrease in the rate of total chlorophyll for the studied varieties.

Various factors (water regime and genotype) effected ~~on~~ the photosynthetic activity of the flag leaf, significantly to strongly significantly.

Compared with controls, after 10 days from the beginning of the active phase of grain filling, the reduction of photosynthetic activity of flag leaf~~,~~ is 32.90%, 35%, 33.62%, 17.40%, 15.67%, 11.17%, 12.54%, 10.80%, 11.88% and 13% respectively for Hedba , Razzak, Oued Zenati, Kyperounda, Simeto, Jenah Khetifa, Mrb5, Senator Capelli, Massara-1 and Waha.

Whereas after 20 days, the relative reduction is 64%, 66.54%, 62.10%, 38%, 39.51%, 24.56%, 21.80%, 23%, 21.66% and 20.80% for the same genotypes in the order mentioned above (Figure 3).

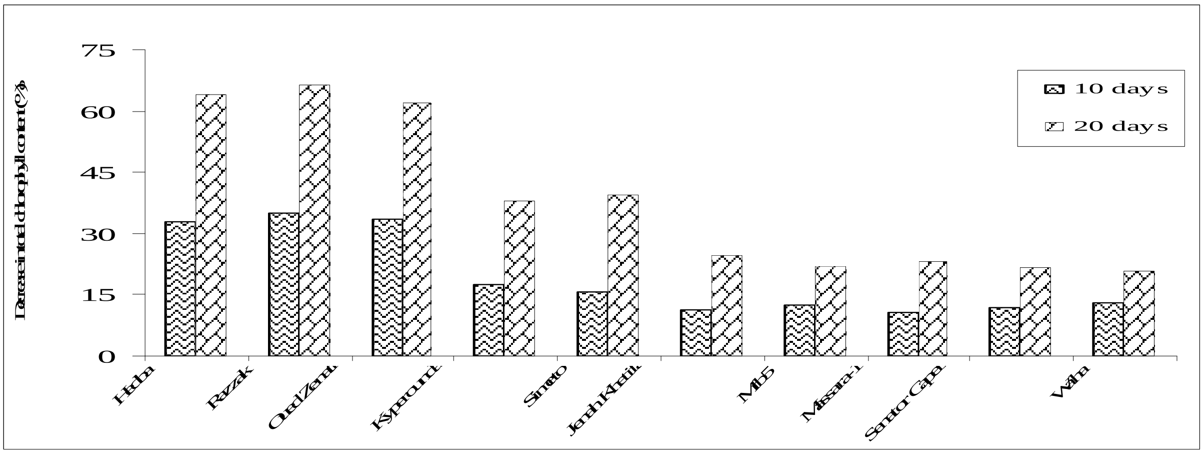

Figure 3: The percentage of decrease in total chlorophyll content of standard leaf during grain filling in genotypes stressed compared with controls.
10 days: 10 days to heading, 20 days: 20 days to heading

3.4. Components of grain yield

The purpose of the present work was to study the effect of continuous water stress on the yield components (number of grains per ear NGE, weight of one grain P1G and weight of 1000 grains PMG), and the water deficit caused a decrease in yield components for all varieties (Table2). This reduction is 10% for Hedba, Razzak and Oued Zenati, 30% for Jenah Khetifa, Mrb5, Senator Capelli, Massara-1 and Waha and 60% for Kyperounda and Simeto.

Statistical analysis determined a significant difference for the varietal factor ($P \leq 0.1$) and highly significant for the water factor ($P \leq 0.05$), while the interaction variety-water regime has a very high significant variation ($P \leq 0.001$).

Table 2: The water regime effect on yield components.

	NGE		P1G		PMG	
	I	S	I	S	I	S
Hedba	26	23	56,07	50,09	53,53	43,76
Razzak	34	30	53,96	47,12	49,91	39
Oued Zenati	40	36	55	48,78	50,15	40,05
Kyperounda	32	13	60,11	35,65	64,50	38,58
Simeto	35	14	58,95	33,89	62,33	39,03
Jenah Khetifa	33	23	54,25	36,76	51,16	35,50
Mrb5	30	20	52,05	34,15	48,57	37,86
Senator Capelli	38	26	50,65	32,50	47,27	23
Massara-1	32	22	49,34	31,66	44,28	30,02
Waha	25	17	51	33,91	47,66	33,32
RH	** ≤ 0,05		** ≤ 0,05		** ≤ 0,05	
VAR	* ≤ 0,1		* ≤ 0,1		* ≤ 0,1	
VAR-RH	*** ≤ 0,001		*** ≤ 0,001		*** ≤ 0,001	

NGE : number of grains per ear; P1G : weight of one grain; PMG: weight of 1000 grains; I: irrigated; S: stressed; RH : water regime factor; VAR : varietal factor; VAR-RH : interaction water regime x variety; P: probability ; $P < 0,05$: differences significant at 5%; $P < 0,01$: differences strongly significant at 1 % ; $P < 0,001$: differences highly significant at1 ‰.

4. Discussion

The grain filling phase is the continuity of the production process from the seedling emergence. During this phase, the rate and the duration of filling are the two variables characterizing the grain filling [8, 9, 10]. Results show that these variables are negatively correlated (r = -0.78), the decrease of the filling rate is compensated by the increase of the grain filling duration. So any increase in the rate of growth is accompanied by a decrease in duration filling and vice versa.

Concerning the role of these two parameters in the development of the final weight of grain, the rate of grain filling is positively correlated with final grain weight (r = 0.83), while duration of filling was negatively correlated with final grain weight (r = -0.48). These results confirm those of other researchers [1, 5, 11, 12, 13]. Some authors [1, 12, 14] have reversed our results showing that the rate of grain filling was positively correlated with grain weight (r = 0.64), while the duration filling was lowly correlated with grain weight (r = 0.40). These authors demonstrated that the determination of grain weight compared to the rate of growth is more influenced by environment factors than by genotype factors. As for the contribution of rate and duration of filling to grain yield; Gebeyehou and Wardlaw [15, 16] showed that duration contributes much more than rate to grain yield, whereas Nass et al. [17] reported that the rate effect on performance is more important than the duration of filling.

Moreover, during the filling phase, the accumulation of dry matter of grain is dependent on two principal sources of assimilates: photosynthetic activity of flag leaf and assimilates stored and transferred from the stems to the grain [18].

So, during the filling phase the contribution of the assimilates coming from the stems decreases when the environment allows the expression of a better grain yield, therefore, the grain filling is mainly determined by photosynthetic activity. Whereas, when climatic conditions are constrained, the photosynthetic activity decreases or stoppes and the contribution of stems assimilates increases; consequently, the duration of the vegetative phase decreases and the rate of filling increases [16].

The results of this study show that the contribution of the assimilates of the stems of grain filling in unfavorable conditions (water stress) is a dependent genotype characteristic.

For Bidding et al. [19], the contribution of stems assimilates to the yield ranged from 10% to 70% and it was a function of genotype and environment factors.

In this context, for the genotypes, Hedba, Razzak and Oued Zenati, the photosynthetic activity is highly affected and the grain filling is achieved by transferring the large quantity of assimilates stored in the stems. While the varieties, Jenah Khetifa, Mrb5, Massara-1, Senator Capelli and Waha are characterized by persistent photosynthetic activity, therefore stems assimilates contribute less to the grain filling. Whereas, according to Kyperounda and Simeto, the grain filling is provided by the product of photosynthetic activity and a part of assimilates of the stems.

The effect of water stress on yield components, and consequently on grain yield depends of the stage at which the water stress occurs.

At heading, the water deficit is characterized by a decrease in the number of grains per ear; this is a consequence of increased rates of spikelet abortion and the induction of male sterility, drought reduces the number of fertile flowers per spikelet [20,21]. The weight of grain was reduced by water deficit on post-flowering, caused by the alteration of the duration of filling and / or the rate of filling; the water stress causes a reduction in grain size resulting from grains scalding [22].

The present results show a negative effect of water stress on yield components , and the results of correlations indicate that the grain yield was positively correlated with the number of grains per ear, the weight of one grain and the weight of 1000 grains respectively (r = 0.903 ***, r = 0.862 *** and r = 0.789 **). Therefore, the grain yield is the product of the three mentioned factors with a compensation between them.

Bouzerzour et al. [23] showed that the contribution of the number of grain/m² to the yield was more important than the number of grains per ear, the number of ear/m² and the weight of 1000 grains, presenting a significant varietal effect. In addition, the weight of 1000 grains is generally not controllable, since it is strongly linked to environmental effects during the filling of the grain.

Other researchers affirm that the average weight of grain presents an important role in the grain yield determination in dry environments [24, 25].

Jonard and Koller [26] concluded in absence of compensation between the yield components that changing one yield factor causes a change of yield grain. In normal situations there is compensation between the yield components.

In conclusion, the grain yield was significantly and positively correlated with the number of grains per ear, the final weight per grain, the weight of 1000 grains and the quantity of stems assimilate assuring the grain filling.

5. Conclusion

Cereals production depends on climatic conditions and largely on genotype-environment interactions. The climatic factors and the nutritional statute, determine the intensity of the competition, the number, the size and the weight of the yield components.

The obtained results are grouped in the following points:

The components of the grain formation (rate and duration of filling) explain a significant proportion of the variation in final weight of grain.

The study of grain growth kinetics may constitute an important tool to test performances of genotypes.

The genotype presenting great ability in accumulation of biomass at heading stage, suffer less from the effects of water stress. However, we have to develop a plant characterized by a capacity to accumulate a high quantity of biomass at heading stage with a production of a high number of grains per ear.

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