Contribution of Current Photosynthesis and Reserves Remobilization in Grain Filling and Its Composition of Durum Wheat Under Different Water Regimes

Assia Bouzid, Ali Arous, Oum Cheikh Felouah, Othmane Merah, Ahmed Adda

ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume 68 86 Number 6, 2020

CONTRIBUTION OF CURRENT PHOTOSYNTHESIS AND RESERVES REMOBILIZATION IN GRAIN FILLING AND ITS COMPOSITION OF DURUM WHEAT UNDER DIFFERENT WATER REGIMES

Assia Bouzid[1], Ali Arous[2], Oum Cheikh Felouah[1], Othmane Merah[3, 4], Ahmed Adda[1]

[1] Laboratory of Agro-biotechnology and Nutrition in Semi Arid Zones, Department of Nature and Life Sciences, University Ibn Khaldoun of Tiaret, 14000, Algeria

[2] Laboratory of Research ERP, Department of Biology, University Djilali Bounaama of Khemis Miliana, 44225, Algeria

[3] University of Paul Sabatier, IUT A, Department of Biological Engineering, 32000 Auch, France

[4] Laboratory of Agro Industrial Chemistry, LCA, University of Toulouse, INRA, 31030 Toulouse, France

Link to this article: https://doi.org/10.11118/actaun202068060937
Received: 22. 12. 2019, Accepted: 24. 11. 2020

To cite this article: BOUZID ASSIA, AROUS ALI, FELOUAH OUM CHEIKH, MERAH OTHMANE, ADDA AHMED. 2020. Contribution of Current Photosynthesis and Reserves Remobilization in Grain Filling and Its Composition of Durum Wheat Under Different Water Regimes. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 68(6): 937–945.

Abstract

In Algeria, drought affects grain weight and modified its biochemical composition. The present study was conducted to evaluate the effect of two water supplies (100% FC, 30% FC) on grain weight and composition of five genotypes of durum wheat (*Triticum durum* Desf.). We also examined the effects of shading of peduncle, spike and the entire plant and excision of awns, flag leaves and foliar system on grain weight, starch and amylose/amylopectin ratio. From this study, we found that grain weight was significantly reduced by the application of water deficit. However, this action is greatly related to genotype type. It is admitted that this trait is strongly conditioned by the grain filling process. The morphological characteristics of plants were implicated to grain weight elaboration. Among organs studied, the photosynthetic rate of spick and reserves remobilization from stem announced determinant in grain filling.

We found also that starch content which is associated to amylose/amylopectin ratio is strongly related to grain weigh. Finally, grains weight variations were associated to starch content and mainly related to the water supply condition.

Keywords: durum wheat, drought, grain weight, starch, amylose/amylopectin ratio, photosynthetic activity, remobilization

INTRODUCTION

The drought is a major cause of reduced cereals crops productivity and quality worldwide (Merah *et al.,* 2001; Mohammadi *et al.,* 2015; Boudjabi *et al.,* 2017). This is particularly true under Mediterranean zones where plants are subject to low and irregular rainfall.

In Algeria, the cereal growing area is localized in semi-arid bioclimatic zones. These areas are often subject to the effects of high temperature coupled with low rainfall occurring during grain formation, affecting its filling and quality (Samarah and Alqudah, 2011; Dettori *et al.,* 2017).

Most of studies shows that drought tolerance were associated to several morphological, physiological and biochemical characteristics and plants responded to drought through many modifications occurring in all plant organs (El Hafid *et al.,* 1998; Adda *et al.,* 2005; Monneveux *et al.,* 2006; Zerrad *et al.,* 2008; Li *et al.,* 2010; Megherbi *et al.,* 2012). Among these studies, little is known about effects of drought on grain filling and its quality.

According to Flagella *et al.* (2010), drought influence on grain composition and its technological quality depends on stress level and timing of occurrence. It has been confirmed, that the reproductive stage is the most sensitive for water deficit (Nielsen *et al.,* 2018). During the grain filling period, the source of assimilates is the current photosynthesis except that it is conditioned by the longevity of different organ's involved. Otherwise, re-mobilization of reserves, source of nutriments is considered to be important. Indeed, for durum wheat, grain growth is supported by transient photosynthesis and translocation of stored reserves accumulated in green organs prior to flowering (Maydup *et al.,* 2012; Royo *et al.,* 2018).

Grains weight is closely related to the pattern of seed growth and the deposition of two main compounds, starch and proteins. Studies show that post-anthesis drought affects these process (Muurinen *et al.,* 2009) by decreasing the participation of green parts of plant (Mahpara *et al.,* 2015). Starch accumulation in endosperm it comprises from 65% to 75% of final dry weight (Yang *et al.,* 2004) and it varies markedly among cultivars and water supply (Yi *et al.,* 2014).

Carbon fixed in green leaves is translocated to the sink organs and converted to starch (Nakamura *et al.,* 1989). This insoluble polyglucane is mixture of two glucose polymers, amylose and amylopectine (Dian *et al.,* 2003). Amylopectin constitutes 70–80% of total starch, containing linear chains of various degree of polymerization (Buléon *et al.,* 1998; Li *et al.,* 2000). Drought stress occurring during early stage of grain development decrease grains sink potential by reducing the number of endosperm cells and amyloplasts formed (Yang and Zhang, 2006).

To date, some works on the dynamics of starch formation and the accumulation of reserves during the development of durum wheat have been published. But the effect of water deficit during the growing stage of wheat plants and the results on seeds composition especially starch, amylose and yields components has remained unclear. According to some studies (Alqudah *et al.,* 2011; Gaju *et al.,* 2014), effects of the environment on grain formation and its quality elaboration remain largely related to the nature of the cultivars studied. An additional problem is the difficulty to control the effect of genotypic variations, drought and organs participations under uncontrolled environmental conditions.

The main objectives of our study, is to elucidate the water deficit effect of the grain final weight and its starch content. The amylose/amylopectin ratio of starch is determined. The present study is also interested in the implication of different plant organs in these processes. Therefore, different genotypes were conducted under different water supply in controlled conditions

MATERIALS AND METHODS

Plant Materials

The study used five durum wheat genotypes (*Triticum durum* Desf.) different by their origin and the degree of tolerance to water deficit, among them, OUED ZENATI, LANGLOIS are landrace and WAHA, ACSAD1361, MEXICALI75, are advanced line (Tab. I).

I: *List of the durum wheat genotypes used in this study*

Genotypes	Origin	Type
1. ACSAD1361	ACSAD (Syria)	Advanced line
2. LANGLOIS	Algeria	Landrace
3. MEXICALI75	CIMMYT	Advanced line
4. OUED ZENATI	Algeria	Landrace
5. WAHA	ICARDA (Syria)	Advanced line

Experimental Set-up and Plant Treatments

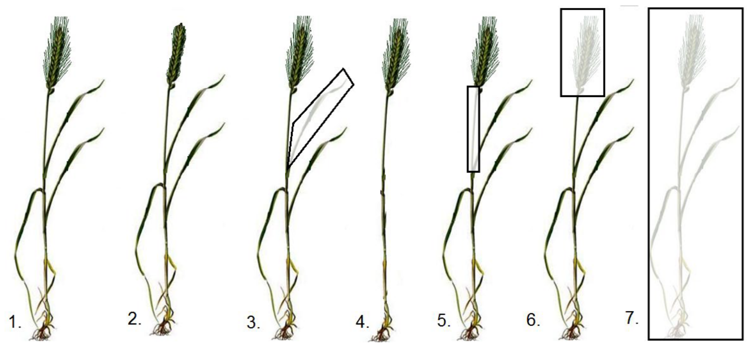
A greenhouse experiment was conducted at Ibn Khaldoun University of Tiaret, Algeria, (34°04'; 35°11'N, 1° 33' and 1°53'E). A randomized complete block design was used with two blocks. In each block, five replicates for each genotype were used and four plants were planted per cylinder. Sterilized seeds were pre-germinated. Then, the seedlings were grown in PVC cylinders, 120 cm high and 16 cm in diameter, filled with a mixture of sand, soil and organic dry matter (8 : 3 : 1). Plants were maintained at field capacity. At anthesis, controlled plants were conducted at 100% of field capacity until complete maturity. For other treatment, plants received 30% of field capacity.

After anthesis, six treatments were applied to investigate the influence of some organs of plant on grain weight and its composition (Fig. 1).

Measurements

Measurements of Morphological Characteristics of Five Genotypes Used

At maturity, the data of the following parameters of controlled plants growing under 100% as plant height (m), last internode length (m), peduncle length (m) and width (mm), spike length (m), awns length (mm) and width (mm) were observed.



1: *Treatment of excision and shading: 1. Plant control, 2. Plant with excised awns, 3. Plant with excised flag leaf, 4. Plant with whole foliar system excised, 5. Plant with shaded peduncle, 6. Plant with shaded spike, 7. Entire plant shaded*

Effect of Water Supply and Treatment on Grain Weight and Its Quality

At maturity, plants of each treatment were harvested. 30 grains were weighted per treatment (organs treatment and water supply condition) so grain weight was determined.

Starch and Amylose content of wheat grains were carried out following the procedure of Thivend *et al.* (1965) reported by Lanouari *et al.* (2015). Approximately 100 mg of grounded durum wheat grains were steeped in 5 ml of 1N KOH. The above solution was neutralized with 5 ml of 1N HCl, and placed in a boiling water bath for 15 min, then centrifuged at 3000 xg for 10 min; the supernatant was incubated with I_2KI reagent to measure starch and amylase content. A blank was prepared in the presence of standard starch and analyzed under the same conditions. The color read with Spectrophotometer (UV-1600PC-VWR) at 580 and 720 nm for starch and amylose respectively. Both starch and amylose were calculated from the standard curve developed by using following the above mentioned method and expressed in $g.100g^{-1}$ of dry matter. The spectral difference is intended to dose amylopectin. The ratio amylose/amylopectin was determined.

Statistical Analysis

All data were subjected to analysis of variance and correlations using STATISTICA 0.8 with ANOVA. Comparisons between the main morphological characteristics of the five studied genotypes were based the Duncan test at 5% probability level.

RESULTS

Morphological Characteristics of Genotypes Used

Tab. II summarize results of morphological traits such as plants height, last internodes length, peduncles length and width, spikes length, awns length and width. These selected morphological traits were very distinct among genotypes studied. A significant difference in plant height was noticed between local and advanced lines. Genotypes are divided into two groups. First group assemble those called high straw represented by OUED ZENATI and LANGLOIS with 1.511 m and 1.527 m respectively. Second groups include introduced genotypes where values ranged from 0.892 m (ACSAD1361) to 0.998 m (MEXICALI75). Last internodes length values rang from low value of 0.373 m obtained by WAHA to high value of 0.554 m registered by LANGLOIS. Slight variations were noticed for peduncle length, values of this letter varied between 0.203 m and 0.238 m respectively for ACSAD1361 and MEXICALI75. Peduncle width showed a high difference between the study genotypes, values ranged from 2.03 mm by ACSAD1361 to 2.43 mm by LANGLOIS. For spike length, values ranges from low value of 0.066 m (WAHA) to high value of

II: *Means values of the main morphological characteristics of the five studied genotypes. For each trait, means followed by a different letter are significantly different by Duncan's multiple range test at $p < 0.05$.*

Genotype	Plant height (m)	Last internode length (m)	Peduncle length (m)	Peduncle width (mm)	Spike length (m)	Awn length (m)	Awn width (mm)
ACSAD1361	0.892^{a}	0.407^{ab}	0.203^{b}	2.03^{a}	0.071^{a}	0.158^{a}	0.40^{ab}
LANGLOIS	1.527^{b}	0.554^{d}	0.233^{a}	2.43^{c}	0.084^{b}	0.191^{c}	0.51^{a}
MEXICALI75	0.998^{a}	0.440^{b}	0.238^{a}	2.37^{bc}	0.070^{a}	0.147^{a}	0.47^{ab}
OUED ZENATI	1.511^{b}	0.491^{c}	0.232^{ab}	2.06^{ab}	0.070^{a}	0.134^{ab}	0.51^{a}
WAHA	0.961^{a}	0.373^{a}	0.212^{ab}	2.19^{abc}	0.066^{a}	0.109^{b}	0.31^{b}

0.084 m (LANGLOIS). Values of awns length ranged from 0.109 m to 0.191 m for WAHA and LANGLOIS respectively.

Effects of Water Supply and Sink-Source Modification (Shading and Excision) on Grain Weight

The ANOVA revealed significant effects among genotypes, organs treatments and water supply conditions on grain weight (Tab. III). Organs contributions to this trait were made by comparing the grain weight average of plant control and those obtained in the other treatments in each genotype under each water supply condition (Tab. IV). For the control plant (plant witness) grown under 100% of field capacity, values of grain weight were noticed very high, ranging from 1.42 g (WAHA) to 2.01 g (LANGLOIS). At 30% FC, mean values were lower ranging from 1.03 g for MEXICALI75 to 1.69 g for LANGLOIS.

For all genotypes obtained under 100% FC, values of grain weight of plants, witness and treated by shading and excision were significantly higher than plants leaded to 30% FC. Also, photosynthesis and reserve's remobilization lead to different values (Tab. III).

Grain weight means of shaded plants were significantly lower and values are between 0.590 g and 0.275 g for WAHA and MEXICALI75 respectively.

At 30% FC, the highest value was recorded by WAHA with 0.445 g. Spike's shading of local genotype reduces grain weight to 1.148 g for LANGLOIS followed by OUED ZENATI with 0.858 g at 100% FC. For introducing genotypes, values were lower and limited between 0.945 g (MEXICALI75) and 0.988 g (WAHA). This reduction increase due to water deficit and records values between 0.560 g (LANGLOIS) and 0.186 g (MEXICALI75) at 30% FC.

Flag leaf excision lead to values comprised between 1.930 g (LANGLOIS) and 1.181 g (MEXICALI75) respectively. With the increase of water deficit (30% FC), the highest values were recorded by OUED ZENATI (1.437 g).

Awns excision affects significantly this trait. At 100% FC, values rang from 1.915 g and 1.113 g for LANGLOIS and ACSAD1361 respectively. At 30% FC, values were comprised between 1.380 g and 0.783 g for the same genotypes respectively.

Means values of grains weight of plants with shaded peduncle growing at optimal conditions of water supply were limited between 1.738 g (LANGLOIS) and 1.261 g (WAHA). At 30%, values were limited between 1.520 g for LANGLOIS and 0.882 g for MEXICALI75.

Finally, the different foliage stages record reduction values ranging from 1.878 g at 100% FC, to 1.427 g at 30% FC for genotype LANGLOIS.

III: *Effects of water supply, genotype, organs treatments and their interactions on the grain weight per spike measured on five genotypes grown under three water treatments (100% FC, 30% FC)*

	Genotype	Water supply	Treatments	Genotype × water supply	Genotype × treatment
Grain weight	215.94***	810.44***	499.06***	8.12***	8.90***

***, ** Significant at 0.1% and 1% of probability levels

IV: *Mean values of grain weight (g) measured on five genotypes grown under two water supply (100% FC, 30% FC) and the different plants treatment (shading and excision). The standards errors are also displayed.*

Treatments	Water supply (% FC)	ACSAD1361	LANGLOIS	MEXICALI75	OUED ZENATI	WAHA
Shaded peduncle	100	1.376 ± 0.028	1.738 ± 0.014	1.432 ± 0.021	1.652 ± 0.014	1.261 ± 0.011
	30	0.942 ± 0.016	1.520 ± 0.009	0.882 ± 0.000	1.186 ± 0.096	0.985 ± 0.095
Shaded plant	100	0.330 ± 0.016	0.571 ± 0.075	0.275 ± 0.005	0.549 ± 0.062	0.590 ± 0.036
	30	0.282 ± 0.013	0.560 ± 0.012	0.186 ± 0.015	0.486 ± 0.029	0.445 ± 0.025
Shaded spike	100	0.959 ± 0.027	1.148 ± 0.055	0.945 ± 0.021	0.858 ± 0.011	0.988 ± 0.032
	30	0.545 ± 0.032	0.603 ± 0.016	0.648 ± 0.054	0.766 ± 0.057	0.773 ± 0.045
Plants witnesses	100	1.511 ± 0.021	2.016 ± 0.014	1.533 ± 0.007	1.675 ± 0.017	1.489 ± 0.023
	30	1.075 ± 0.008	1.625 ± 0.025	1.009 ± 0.037	1.336 ± 0.071	1.213 ± 0.052
Excised awns	100	1.311 ± 0.033	1.915 ± 0.024	1.427 ± 0.035	1.530 ± 0.021	1.313 ± 0.010
	30	0.783 ± 0.061	1.380 ± 0.050	0.785 ± 0.012	0.862 ± 0.030	1.014 ± 0.052
Excised flag leaf	100	1.196 ± 0.043	1.930 ± 0.039	1.181 ± 0.037	1.582 ± 0.039	1.271 ± 0.086
	30	0.984 ± 0.027	1.437 ± 0.044	0.862 ± 0.049	1.017 ± 0.034	1.131 ± 0.033
Excised foliar system	100	1.075 ± 0.005	1.878 ± 0.027	1.116 ± 0.041	1.529 ± 0.074	1.156 ± 0.063
	30	0.815 ± 0.061	1.427 ± 0.062	0.850 ± 0.018	1.005 ± 0.055	1.049 ± 0.011

Effects of Water Supply and Sink-Source Modification on Grain Starch, Amylose/Amylopectin Ratio

Results analysis (Tab. V) shows that the effects of genotypic variability and water treatment applied were highly significant for all measured traits ($p < 0.001$). The interaction of these two factors indicates that genotypes used in this study responded differently following the water supply condition and shading/excision treatments. The mean values of starch content in mature grains expressed on $g.100^{-1}$ of DM and Amylose/Amylopectin ratio in different water supply conditions, and among five genotypes with shading/excision treatments were presented in Tab. VI.

For controlled plant and under well watered conditions, genotypes MEXICALI75, OUED ZENATI and LANGLOIS were characterized by a high value of starch, amylose/amylopectin ratio were 0.57, 0.64 and 1.07 respectively. Low value was recorded by ACSAD1361 of 22.9 $g.100^{-1}$ of DM. with r(AM/AP) = 0.58.

At 30% FC, higher values of starch were recorded by OUED ZENATI and MEXICALI75 with 72.50 and 60.26 $g.100^{-1}$ of DM respectively with a high fraction of amylopectin.

Among the analyzed samples, some differences in the relative amounts of starch, amylose and amylopectin content were observed among genotype due to shading and excision treatments. The results of this study indicated that great variations could be ascribed to different water supply conditions contributing to total variations of amylose and amylopectin fraction content in starch where the percentages of each fraction changed with water situation applied.

In our study, starch amount of grains were affected by peduncle shading particularly under 30% FC, for both advanced line and landrace. Values of starch were considered low comparing with grains from treatment of 100% FC. At 30% FC, starch was significantly composed for high content of amylopectin. Shading and excision relatively affect the ratio of amylose/amylopectin of starch. In general, for all treatment, the application of water stress at level of 30% FC reduces amylose and increase amylopectin fraction. The exception was noticed for genotype LANGLOIS, for both treatments of plant shading and awns excision.

Otherwise, starch was affected by spike shading. Thus, for advanced line the decrease in starch amount was highly associated with increase in water deficit applied (Tab. VI). The effect of spike shading on amylose content in starch was significant and values were lower than other treatments. Among all cultivars and at 100% FC, shading of plant caused a strong decrease in starch amount and this rate is more accentuated for MEXICALI75. Values of starch in plant without awns were similar to control plant except that highest values of starch were noticed for landrace cultivars under 30% FC for this treatment. Excision of foliage system caused ½ reduction of starch at 100% FC. At 100% FC, advanced lines registered a mean of 25.2 $g.100^{-1}$ of DM where landraces give a mean of 47.1 $g.100^{-1}$ of DM from all plant leaves, excision of flag leaf affected starch amount significantly, at 100% FC, landrace registered 58.7 $g.100^{-1}$ of DM, and this value was reduced to 38.7 $g.100^{-1}$ of DM at 30% FC. Flag leaf excision increase the amylose and decrease amylopectin content in starch for both water treatments 100% and 30% FC for genotype ACSAD1361.

DISCUSSION

In this study, we founded that the variation of durum wheat grain weight is significantly correlated to water supply conditions (r = -0.39**). Thus, the application of water stress at anthesis negatively affects the values of grain weight (Tab. VII). According to Alqudah *et al.* (2011), this could be due to accelerated days of flowering, shorter duration of grain filling and lower accumulation of dry matter. Troccoli *et al.* (2000), confirmed that abiotic environmental factors are considered to be the main source (71%) of yield reduction.

Our results show that the effect of water deficit on grain weight also depends on the genetic variability and the contribution of vegetative organs by their assimilates after anthesis (Tab. VII). According to some authors, The development of grain weight results from photosynthetic activity of various organs, mainly the flag leaves (Merah, Monneveux, 2015; Ying-Hua *et al.,* 2014; Blandino *et al.,* 2009), peduncles (Li *et al.,* 2010), spikes (Gaju *et al.,* 2014; Xu *et al.,* 2016) and awns (Maydup *et al.,* 2014; Merah, Monneveux, 2015).

V: *Effects of water supply, genotype, organs treatments and their interactions on the starch, amylose and amylopectin contents in mature grain measured on five genotypes grown under three water treatments (100% FC, 30% FC)*

	Genotype	Water supply	Treatments	Genotype × water supply	Genotype × treatment
Starch content	170.97***	18.46***	78.93***	90.65***	37.53***
Amylose content	117.89***	10.56***	23.56***	44.92***	26.88***
Amylopectine content	74.69***	8.86***	61.93***	62.79***	20.11***

*** Significant at 0.1% of probability level

VI: *Mean values of starch content and amylose/amylopectin ratio in mature grain measured on five genotypes grown under two water treatments (100% FC, 30% FC). Treatment of shading and excision were applied at anthesis and powders from mature grain were analyzed.*

Starch ($g.100g^{-1}$ of DM)	Water supply (%FC)	Control		SP		SPL		SS		EA		EFL		EFS	
		Mean	Ratio	Mean	Ratio	Mean	Ratio	Mean	Ratio	Mean	Ratio	Mean	Ratio	Mean	Ratio
ACSAD1361	100	22,933 ± 1,543	0.58	14,400 ± 0,980	1.50	33,200 ± 1,617	0.42	6,400 ± 0,231	1.51	31,000 ± 1,337	0.76	24,356 ± 1,420	0.85	35,200 ± 1,592	0.51
	30	25,600 ± 0.854	0.40	62,400 ± 0,533	0.69	14,867 ± 0,900	0.65	15,200 ± 1,903	0.57	11.200 ± 1,579	0.24	97,600 ± 0.654	0.46	50,933 ± 0,399	0.34
LANGLOIS	100	67,022 ± 2,294	1.07	84,600 ± 2,580	0.51	38,400 ± 2,847	0.45	49,600 ± 0.654	1.05	29,200 ± 1,388	0.63	54,400 ± 1,619	0.46	48,800 ± 0.854	1.03
	30	17,067 ± 1,037	0.80	87,200 ± 3,266	0.74	32,200 ± 0,600	0.24	73,045 ± 2,832	1.89	88,800 ± 0.952	0.76	17.307 ± 0.741	1.51	86,538 ± 2,554	1.00
MEXICALI75	100	72,711 ± 2,616	0.57	51,467 ± 2,778	0.60	14,400 ± 0,653	1.11	21,600 ± 1,699	1.22	50,200 ± 1,133	0.69	28.400 ± 0,400	0.68	22,933 ± 1,135	0.91
	30	60,267 ± 2,620	0.70	79,200 ± 2,040	0.57	66,133 ± 1,147	0.88	26.666 ± 0,857	0.91	50,400 ± 0.925	0.35	64,600 ± 3,800	0.22	46,800 ± 3,926	0.35
OUED ZENATI	100	92,711 ± 1,997	0.64	80,978 ± 1,708	0.48	29,867 ± 1,676	0.25	15,667 ± 1,224	0.83	85,200 ± 1,449	0.40	62,967 ± 0,702	0.83	45,333 ± 1,815	0.54
	30	72,504 ± 1,229	0.82	45,400 ± 1,305	0.80	76,800 ± 0,494	0.41	54,667 ± 3,491	0.73	56,000 ± 0.825	1.08	64,000 ± 1,394	0.69	71,315 ± 1,103	0.88
WAHA	100	51,200 ± 1,633	0.30	93,500 ± 1,900	0.45	69,600 ± 1,942	0.57	53,200 ± 2,078	0.61	44,000 ± 1,307	0.97	33,867 ± 1,148	1.36	17,400 ± 1,400	2.42
	30	21,333 ± 0,074	0.47	37.530 ± 0.550	0.61	28,600 ± 1,925	1.34	15,200 ± 0,327	0,78	33,600 ± 1,932	0.69	29,600 ± 0,771	0.12	23,400 ± 1,793	0.29

SP: shaded peduncle, SS: shaded spike, SPL: shaded plant, EA: excised awns, EFL: excised flag leaf, EFS: excised foliar system

VII: *Relationship between water deficit, genotype and treatment with the measured traits*

Factors of variation	Water supply	Genotype	Treatments	Grain weight	Starch content
Genotype	0.00				
Treatments	0.00	0.00			
Grain weight	-0.39**	-0.02	0.34**		
Starch content	0.07	0.12	-0.01	0.25*	
Amylose/amylopectin ratio	-0.11	0.01	-0.06	0.03	-0.19*

VIII: *Relationship between water deficit, genotype and treatment with the measured traits*

Factors of variation	Water supply	Genotype	Treatments	Grain weight	Starch content
Genotype	0.00				
Treatments	0.00	0.00			
Grain weight	-0.39**	-0.02	0.34**		
Starch content	0.07	0.12	-0.01	0.25*	
Amylose/amylopectin ratio	-0.11	0.01	-0.06	0.03	-0.19*

In our study, the difference observed between watered and dry condition. In fact, under limited water conditions, the contribution of spikes by their current photosynthesis provides the largest reserves to grains. This is confirmed by the work of Maydup *et al.* (2014), which shows the importance of the components of spikes in grain development. The influence of awns excision on grain weight under these conditions also appears significant. Many works (Bort *et al.,* 1994; Maydup *et al.,* 2014) have reported the importance of awns in grain formation in cereals and confirmed by the decline in grain weight in our experiment due to awns excision (Tab. III). Participation of assimilates provides from flag leaves and leaves system to final grain weight were limited, we can explain this results by the limitation in organs longevity specially those under the last internodes when leaves photosynthesis decline during grains filling. These results were similar to those found by Merah and Monneveux (2015).

Under water deficit, the photosynthetic activity is limited by longevity of implicated organs. Consequently, in this work, the reserve's remobilization constitutes the important source of grain filling and its quality elaboration (Ying-Hua *et al.,* 2014; Merah and Monneveux, 2015). Our results indicated the complexity of the effect of drought stress on grains composition, and how different plant organ may's conditioned the starch structure.

After shading and excision treatment, the variation in starch follows the same tendency of grain weight among genotypes. We notice significant changes in amylose/amylopectin ratio. As expected, changes in starch amount and amylose/amylopectin content are related to the ability of genotypes to maintain a high accumulation of starch under limited water supply conditions. In fact, our results showed that starch content is related to the grain weight ($r = 0.25^*$), and because this last is highly composed of amylopectin with a low fraction of amylose, a negative correlation was found between amylose/amylopectin ratio and this trait for all used genotype ($r = -0.19^*$). These correlations confirmed that grain weight reduction is associated with changes in grain composition.

CONCLUSION

Durum wheat grain weight was significantly influenced by drought stress. Starch accumulation under optimal condition was significantly important but drought stresses alters this process and results some changes in amylose/amylopectin ratio. Shading and excision treatments affect all measured traits. The major decrease in grain yield was due to shading of entire plant followed by spike and peduncle shading. We retain average effects of awns and foliar system excision on measured traits. Flag leaf contribution was noticed different from genotype to another. Variations in grains weight were associated to starch content and mainly related to the water supply condition.

REFERENCES

ADDA, A., SAHNOUNE, M., KAID-HARCH, M. and MERAH, O. 2005. Impact of water deficit intensity on durum wheat seminal roots. *Comptes Rendus - Biologies*, 328(10–11): 918–927.

ALQUDAH, A. M., SAMARAH, N. H. and MULLEN, R. E. 2011. Drought Stress Effect on Crop Pollination, Seed Set, Yield and Quality. In: LICHTFOUSE, E. (Ed.). *Alternative Farming Systems, Biotechnology, Drought Stress and Ecological Fertilisation*. Sustainable Agriculture Reviews. Springer, pp. 193–213.

BLANDINO, M., PILATI, A. and REYNERI, A. 2009. Effect of foliar treatments to durum wheat on flag leaf senescence, grain yield, quality and deoxynivalenol contamination in North Italy. *Field Crops Research,* 114(2): 214–222.

BORT, J., FEBRERO, A., AMARO, T. and ARAUS, J. 1994. Role of awns in ear water-use efficiency and grain weight in barley. *Agronomie*, 14(2): 133–139.

BOUDJABI, S., KRIBAA, M. and CHENCHOUNI, H. 2017. Sewage sludge fertilization alleviates drought stress and improves physiological adaptation and yield performances in Durum Wheat (Triticum durum): A double-edged sword. *Journal of King Saud University – Science*, 31(3): 336–344.

BULÉON, A., COLONNA, P., PLANCHOT, V. and BALL, S. 1998. Starch granules: Structure and biosynthesis. *International Journal of Biological Macromolecules*, 23(2): 85–112.

DENYER, K. A. Y., JOHNSON, P., ZEEMAN, S. and SMITH, A. M. 2001. The control of amylose synthesis. *Journal of Plant Physiology*, 158(4): 479–487.

DETTORI, M., CESARACCIO, C. and DUCE, P. 2017. Simulation of climate change impacts on production and phenology of durum wheat in Mediterranean environments using CERES-Wheat model. *Field Crops Research*, 206: 43–53.

DIAN, W., JIANG, H., CHEN, Q., LIU, F. and WU, P. 2003. Cloning and characterization of the granule-bound starch synthase II gene in rice: Gene expression is regulated by the nitrogen level, sugar and circadian rhythm. *Planta*, 218(2): 261–268.

EL HAFID, R., SMITH, D. H., KARROU, M. and SAMIR, K. 1998. Morphological attributes associated with early-season drought tolerance in spring durum wheat in a mediterranean environment. *Euphytica*, 101(3): 273–282.

ERCOLI, L., LULLI, L., MARIOTTI, M., MASONI, A. and ARDUINI, I. 2008. Post-anthesis dry matter and nitrogen dynamics in durum wheat as affected by nitrogen supply and soil water availability. *European Journal of Agronomy*, 28(2): 138–147.

FLAGELLA, Z., GIULIANI, M. M., GIUZIO, L., VOLPI, C. and MASCI, S. 2010. Influence of water deficit on durum wheat storage protein composition and technological quality. *European Journal of Agronomy*, 33(3): 197–207.

GAJU, O., REYNOLDS, M. P., SPARKES, D. L., MAYES, S., RIBAS-VARGAS, G., CROSSA, J. and FOULKES, M. J. 2014. Relationships between physiological traits, grain number and yield potential in a wheat DH population of large spike phenotype. *Field Crops Research*, 164(1): 126–135.

LANOUARI, S., NASSER, B., EL HADDOURY, J. and BENKCHARI, B. 2015. Physico-chemical characterization of the seeds of bread wheat (Triticum aestivum) under herbicide treatment with 2, 4-dichlorophenoxyacetic acid [in French: Caractérisation physico-chimique des graines de blé tendre (Triticum aestivum) sous traitement herbicide par l'acide 2, 4-dichlorophénoxyacétique]. *International Journal of Innovation and Applied Studies*, 10(2): 604–620.

LI, H., JIANG, D., WOLLENWEBER, B., DAI, T. and CAO, W. 2010. Effects of shading on morphology, physiology and grain yield of winter wheat. *European Journal of Agronomy*, 33(4): 267–275.

LI, Z., MOUILLE, G., KOSAR-HASHEMI, B., RAHMAN, S., CLARKE, B., GALE, K. R., APPELS, R. and MORELL, M. K. 2000. The Structure and Expression of the Wheat Starch Synthase III Gene. Motifs in the Expressed Gene Define the Lineage of the Starch Synthase III Gene Family. *Plant Physiology*, 123(2): 613–624.

MAHPARA, S., HUSSAIN, S. T. and FAROOQ, J. 2015. Drought Tolerance Studies in Wheat (*Triticum Aestivum* L.). *Cercetari Agronomice in Moldova*, 47(4): 133–140.

MAYDUP, M. L., ANTONIETTA, M., GRACIANO, C., GUIAMET, J. J. and TAMBUSSI, E. A. 2014. The contribution of the awns of bread wheat (*Triticum aestivum* L.) to grain filling: Responses to water deficit and the effects of awns on ear temperature and hydraulic conductance. *Field Crops Research*, 167: 102–111.

MAYDUP, M. L., ANTONIETTA, M., GUIAMET, J. J. and TAMBUSSI, E. A. 2012. The contribution of green parts of the ear to grain filling in old and modern cultivars of bread wheat (*Triticum aestivum* L.): Evidence for genetic gains over the past century. *Field Crops Research*, 134*:* 208–215.

MAYDUP, M. L., ANTONIETTA, M., GUIAMET, J. J., GRACIANO, C., LÓPEZ, J. R. and TAMBUSSI, E. A. 2010. The contribution of ear photosynthesis to grain filling in bread wheat (*Triticum aestivum* L.). *Field Crops Research*, 119(1): 48–58.

MEGHERBI, A., MEHDADI, Z., TOUMI, F., MOUEDDENE, K. and BOUADJRA, S. E. B. 2012. Drought tolerance of durum wheat (*Triticum durum* Desf.) and identification of morpho-physiological adaptation parameters in the Sidi Bel-Abbès region (Western Algeria) [in French: Tolérance à la sécheresse du blé dur (*Triticum durum* Desf.) et identification des paramètres morpho-physiologiques d'adaptation dans la région de Sidi Bel-Abbès (Algérie occidentale)]. *Acta Botanica Gallica*, 159(1): 137–143.

MERAH, O. and MONNEVEUX, P. 2015. Contribution of Different Organs to Grain Filling in Durum Wheat under Mediterranean Conditions I. Contribution of Post-Anthesis Photosynthesis and Remobilization. *Journal of Agronomy and Crop Science*, 201(5): 344–352.

MERAH, O., DELEENS, É., TEULAT, B. and MONNEVEUX, P. 2001. Productivity and carbon isotope discrimination in durum wheat organs under a Mediterranean climate. *Comptes Rendus de l'Academie Des Sciences - Serie III*, 324(1): 51–57.

MOHAMMADI, R., SADEGHZADEH, B. and AHMADI, H. 2015. Evaluation of durum wheat landraces for prevailing abiotic and biotic stresses in highland rainfed regions of Iran. *Science Direct Field, CJ*, 3(5): 423–433.

MONNEVEUX, P., REKIKA, D., ACEVEDO, E. and MERAH, O. 2006. Effect of drought on leaf gas exchange, carbon isotope discrimination, transpiration efficiency and productivity in field grown durum wheat genotypes. *Plant Science*, 170(4): 867–872.

MUURINEN, S., PELTONEN-SAINIO, P., RAJALA, A., HAKALA, K. and MA, P. 2009. Spring wheat response to timing of water deficit through sink and grain filling capacity. *Field Crops Research,* 114: 263–271.

NAKAMURA, Y., YUKI, K., PARK, S. and OHYA, T. 1989. Carbohydrate Metabolism in the Developing Endosperm of Rice Grains. *Plant and Cell Physiology*, 30(6): 833–839.

NIELSEN, D. C., VIGIL, M. F. and HENRY, W. B. 2018. Field Crops Research Skip row planting configuration shifts grain sorghum water use under dry conditions. *Field Crops Research*, 223*:* 66–74.

ROYO, C., AMMAR, K., ALFARO, C., DREISIGACKER, S., FERNANDO, L. and VILLEGAS, D. 2018. Field Crops Research Effect of Ppd-1 photoperiod sensitivity genes on dry matter production and allocation in durum wheat. *Field Crops Research*, 221: 358–367.

SAMARAH, N. and ALQUDAH, A. 2011. Effects of Late-Terminal Drought Stress on Seed Germination and Vigor of Barley (*Hordeum Vulgare* L.). *Archives of Agronomy and Soil Science*, 57(1): 27–32.

THIVEND, P., MERCIER, C. and GUILBOT, A. 1965. Measure of starch in complex media [in French: Dosage de l'amidon dans les milieux complexes]. *Ann Biol Anim Bioch Biophys*, 5(4): 513–526.

TROCCOLI, A., BORRELLI, G. M., DE VITA, P., FARES, C. and DI FONZO, N. 2000. Durum Wheat Quality: A Multidisciplinary Concept. *Journal of Cereal Science,* 32(2): 99–113.

XU, C.-L., TAO, H.-B., WANG, P. and WANG, Z.-L. 2016. Slight shading after anthesis increases photosynthetic productivity and grain yield of winter wheat (*Triticum aestivum* L.) due to the delaying of leaf senescence. *Journal of Integrative Agriculture*, 15(1): 63–75.

YANG, J. and ZHANG, J. 2006. Grain filling of cereals under soil drying. *New Phytologist*, 169(2): 223–236.

YANG, J., ZHANG, J., WANG, Z., XU, G. and ZHU, Q. 2004. Activities of Key Enzymes in Sucrose-to-Starch Conversion in Wheat Grains Subjected to Water Deficit during Grain Filling. *Plant Physiology*, 135: 1621–1629.

YI, B., ZHOU, Y. F., GAO, M. Y., ZHANG, Z., HAN, Y., YANG, G. D., XU, W. and HUANG, R. D. 2014. Effect of drought stress during flowering stage on starch accumulation and starch synthesis enzymes in sorghum grains. *Journal of Integrative Agriculture*, 13(11): 2399–2406.

YING-HUA, Z., NA-NA, S. U. N., JIA-PEI, H., QI, Z., CHAO, W. and QING-WU, X. U. E. 2014. Effect of Source-Sink Manipulation on Photosynthetic Characteristics of Flag Leaf and the Remobilization of Dry Mass and Nitrogen in Vegetative Organs of Wheat. *Journal of Integrative Agriculture*, 13(8): 1680–1690.

ZERRAD, W., MAATAOUI, B. S., HILALI, S., DE BIOCHIMIE, L., DE MOHAMMEDIA, T. and DE SETTAT, T. 2008. Comparative Study of Biochemical Stress Resistance Mechanisms [in French: Etude Comparative des Mécanismes Biochimiques De Resistance au Stress]. *Lebanese Science Journal*, 9(2): 27–36.

Contact information

Assia Bouzid: assia1bouzid@gmail.com
Ali Arous: arousalibio@gmail.com
Oum Cheikh Felouah: felouah.felouah@gmail.com
Othmane Merah: othmane.merah@ensiacet.fr
Ahmed Adda: adda2ahmed@yahoo.fr