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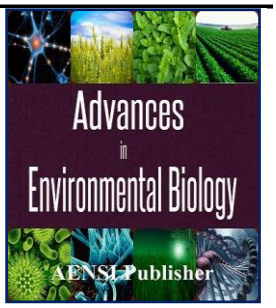

Flag Leaf and Awns Ablation and Spike Shading Effects on Spike Yield and Kernel Weight of Durum Wheat (Triticum Turgidum L. Var. Durum) Under Rainfed Conditions

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ABSTRACT

The present study was undertaken with the objective to investigate the photosynthetic contribution of flag leaf blade, awns and spike to the grain filling under semi-arid conditions. A field experiment including 13 durum wheat (*Triticum turgidum L. var. durum*) varieties and breeding lines was conducted at the Agricultural Research Station of the Field Crop Institute (ARS-ITGC) of Setif (Algeria) during the 2009-2010 cropping season. Source limitation treatments including a control, flag leaf blade ablation, awns removal and spike shading were applied at heading. Ten main stems were tagged per genotype and treatment in a random design with three replications. Grain yield and yield components were determined from two rows, one meter length per replicate. Compared to the control, the removal-shading treatments, averaged over varieties, induced significant declines of 14.7%, 21.7% and 8.0 % in the number of grains per spike, spike grain yield and kernel weight, respectively. The means of the control treatment were 46.8 kernels, 2.3 g per spike and 48.8 mg per kernel, for the number of grains per spike, spike grain yield and kernel weight, respectively. The differences between removal-shading treatments were not significant as indicated by the contrast analysis. The magnitude of the induced-declines, caused by the source limitation treatments, varied among the assessed varieties suggesting that compensation among plant organs was differential operating within the tested plant material. The analysis of the relationships between main stem traits and traits measured on an area basis suggested that genotypes with high number of fertile tillers/m² and those characterized by a high thousand-kernel weight had the ability to minimize declines due to source limitation through compensation among plant organs.

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INTRODUCTION

Drought and high temperature are common abiotic stresses prevailing under Mediterranean climate where durum wheat (*Triticum turgidum L. var. durum*.) is generally grown. These stresses accelerate leaf senescence, shorten grain filling duration, reduce the availability of assimilates for grain filling and thereby decrease wheat grain yield. Under these growth conditions, grain growth relies more on remobilization of assimilates, temporarily stored in vegetative plant parts than on current photosynthesis. These reserves buffer grain yield against the effect of harsh climatic conditions which depressed post-anthesis growth. Contribution of plant parts to grain fill is assessed, based on removal or shading or spraying chemicals, to inhibit photosynthesis of the targeted organs. Results of such studies demonstrated the importance of the contribution of the removed organ. This contribution appeared to be dependent on the genetic make-up of the plant material under study, the experimental conditions, and the plant organ targeted [1, 2, 3]. In this context, the ear contribution to grain was estimated to be somewhere between 10 to 76%. The inhibition of spike photosynthesis induced declines of grain yield, biomass, thousand kernel weight, grains per spike, and peduncle specific weight. The relative decline was more severe in the sensitive than in the tolerant cultivars [4, 5]. The contribution of flag leaf varied too, and it was reported to vary between zero to 43%. Flag leaf ablation affected the number of grains per spike, kernel

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weight, and spike grain yield [5, 6, 7, 8,]. Xu *et al.*, [9] mentioned that, compared with leaf blade, spike photosynthesis possesses higher tolerance, and proposed to select, for higher ear photosynthesis, to improve yield potential and adaptation to stressful environments. Evidence of compensation effects, triggered by the non-excised or unshaded photosynthetic organs, was observed in some cases. This underestimated the contribution of the removed-shaded organs due to the increased contribution of the unaffected photosynthetic organs and to the remobilization of the pre-anthesis stored reserves [10, 11]. The results of past studies suggested that grain yield was affected by the contribution of the flag leaf, the ear and by the remobilization of the stem stored reserves, with various degrees, depending on the genotype and the environment test. Lack of adapted cultivars, which make best use of all photosynthetic resources, is an important constraint in stressful regions. Little information is available regarding the reserves accumulation and translocation capacities of durum wheat under Algerian growing conditions. This study was conducted to evaluate the contribution of flag leaf blade, awns and spike photosynthesis to spike yield and kernel weight of durum wheat varieties evaluated under semi-arid conditions.

MATERIAL AND METHODS

Plant material:

The experiment was conducted, under rainfed conditions, at the Field Crop Institute, Agricultural Research Station of Setif (ITGC-ARS, Setif, Algeria) during the 2009/10 cropping season. Thirteen durum wheat (*Triticum durum* Desf.) genotypes, commercial varieties and advanced breeding lines from the national and Cimmyt-Icarda durum wheat breeding programs (Table 1), were utilized as experimental material, and sown with an experimental drill on November 22nd 2009, in strips, 1.2 m large and 150 m long (seed increase plot) at a rate of 300 seeds/m². Before sowing, the field trial was fertilized with 100 kg/ha of triple super phosphate 46%, and at the tillering stage, nitrogen fertilizer was applied at 75 kg/ha of urea. Weeds control was done by application of 12 g/ha of Granstar [*Methyl tribenuron*].

Measurements:

At heading stage, 40 main stems per genotype and replication, with similar plant height and spike size, were tagged and subdivided into four sets of 10 main stems, receiving the following treatments: ablation of the flag leaf blade, ablation of the awns and sheading of the spike, the last set served as control. At maturity, the following measurements were done on each main stem: count of the number of grains per spike, weight of the total number of grains per spike (spike grain yield), and kernel weight, which was derived as the ratio of spike grain yield to the number of grains per spike. At maturity, plant height, grain yield and yield components were determined from three randomly sampled stations of two rows, 1-m length, per strip.

Table 1: Name and parentage of the durum wheat breeding lines and cultivars used as plant material.

Genotype	Pedigree	Cross origin	Selection
Waha	Plc/Ruff//Gta/3/Rolette CM 17904	Cimmyt-Icarda	ITGC-Algeria
MBB	local variety	landrace	Algeria
Bousselam	Heider/Martes//Huevos de Oro	Cimmyt-Icarda	ITGC-Algeria
Setifis	Ofanto/Waha//MBB.	ITGC-Algeria	ITGC-Algeria
Badre	Boussalem/Ofanto	ITGC-Algeria	ITGC-Algeria
$Megress_1$	Ofanto/Waha//MBB	ITGC-Algeria	ITGC-Algeria
Benzitouni	Ofanto/*2/Waha	ITGC-Algeria	ITGC-Algeria
$Megress_2$	Ofanto/Waha//MBB	ITGC-Algeria	ITGC-Algeria
Bousselam/Ofanto	Bousselam/Ofanto	ITGC-Algeria	ITGC-Algeria
Ofanto	Appulo/Valnova	Italy	Introduction
MBB/Ofanto	MBB/Ofanto	ITGC-Algeria	ITGC-Algeria
Essalem	Ofanto/*2/Waha	ITGC-Algeria	ITGC-Algeria
$Megress_3$	Ofanto/Waha//MBB	ITGC-Algeria	ITGC-Algeria

Statistical analyses:

The experiment was arranged in a random design with three replicates. The analysis of variance was performed across removal-shading treatments and genotypes for each measured trait. Means comparisons were performed using the least significant difference at 5% probability level. Decrease, in the value of the measured traits, induced by leaf or awns removal or spike shading was expressed as percent relatively to the control as follow: % decline = [100*(Treated- control)/control]. Relationships between traits measured on the main stem, and grain yield and yield components, determined on a ground area basis, were examined using Ward clustering method and principal component analysis were performed on the correlation matrix. Data analyses were done using CropStat 7.2 [12] and Past [13] free software.

Results:

Shading-removal treatments effect on spike grain yield, kernels/spike and kernel weight:

Significant treatment, and genotype main effects and genotype x treatments interaction of the number of grains per spike, spike grain yield and kernel weight, were observed (Table 2). This suggested that the applied treatments generated a significant variability in the responses of the tested genotypes to organs removal and shading. Over averaged varieties, the removal-shading treatment means of the measured characters are given in table 3. The mean of the number of kernels/spike was 46.8 for the control and 38.7, 40.2 and 40.9 for awns removal, flag leaf removal and spike shading treatments, respectively. For spike grain yield of the same treatments, the mean values were 2.3, 1.8, 1.8 and 1.7 g, respectively. Kernel weight means were 48.8, 16.8, 45.8 and 42.2 mg for awns ablation, flag leaf removal and spike shading treatments, respectively. Contrast analysis indicated significant differences between control and removal-shading treatments for the measured traits, and no significant differences between removal-shading treatments. Compared to the control, the average decline, due to removal-shading treatments, was 14.7%, 21.7% and 8.0 % for number of grains per spike, spike grain yield and kernel weight, respectively (Tables 2 and 3).

Averaged over removal-shading treatments, means of the measured traits of the different genotypes are given in table 4. The number of grains per spike varied from 32.8 grains/spike, average of Megress-3 (Mg3) to 49.1 grains/spike, mean of the cultivar Waha (Wah). Based on the least significant difference value, the tested entries could be clustered into three groups which differed significantly for the number of grains/spike. The cluster, with high average number of grains/spike, included Waha, Setifis (Set), Badre (Bad), Megress-1(Mg1), Benzitouni (Ben) and Bousselam/Ofanto (Bof). Means of this cluster ranged from 43.1 to 49.1 grains/spike. The intermediate group included Ofanto (Ofa), Bousselam (Bou), Mbb and Mbb/Ofanto (Mof) with an average number of grains/spike varying from 39.5 to 42.3. The group, having low average of grains/spike included Megress-3 (Mg3), Essalem (Ess) and Megress-2 (Mg2). The means of this cluster varied from 32.8 to 38.3 grains/spike (Table 4).

High amount of variation existed among the tested entries for spike grain yield and kernel weight. The tested genotypes were clustered into three groups for the grain yield per spike which varied from 1.4 to 1.8 g in the low yielding group. This group included Megress-3, Essalem, Mbb/Ofanto, Megress-1 and Mbb. The intermediate grain yielding group included Bousselam, Setifis, Ofanto and Waha. The spike grain yield of this group varied from 1.9 to 2.1 g/spike. The high yielding group included Badre, Megress-1, Benzitouni and Bousselam/Ofanto with a grain yield per spike ranging from 2.2 to 2.4 g/spike (Table 4). Similarly the tested genotypes grouped into three clusters for kernel weight, which ranged from 40.0 mg, exhibited by Essalem to 53.0 mg ,expressed by Badre. Badre, Megress-1 and Benzitouni belonged to the clusters with high values for the three measured parameters. Essalem, Megress-3 and Megress-2, belonged to the clusters with low values for the three analyzed traits (Table 4). These results indicated that, besides of the effect of the removal-shading treatments, the tested genotypes differed significantly in their genetic make-up controlling the studied characteristics.

Mean values of the variables measured per variety and removal-shading treatment are given in table 5. Spike grain yield varied from 1.1 g/spike observed under spike shading effect of the variety Megress-3 to 3.0 g/spike observed under control treatment of the cultivar Ofanto. The reduction, in spike grain yield, induced by the removal-shading treatment varied from 0.2 g/spike, measured under leaf ablation treatment of the breeding line MBB/Ofanto to 1.3 g/spike, due to the effect of awns ablation of Ofanto cultivar (Table 5). Mean values of the number of grains/spike varied from 28.3, expressed by Megress-3, after leaf removal, to 54.3 grains/spike of the control treatment of Bousselam/Ofanto. The decline, induced by removal-shading treatments, varied from nil, in Setifis, after leaf ablation, to 18.7 grains/spike shown by Essalem under awns removal treatment (Table 5). Kernel weight varied from 57.3 to 32.8 mg per grain, and the reduction varied from 1.3 mg after awns removal of the variety Setifis to 20.9 mg after spike shading of the variety Megress-2 (Table 5).

Table 2:. Analysis of variance mean squares for the measured parameters.

Source of variation	df	KS	SGY (g)	KW (mg)
Replication	2	59.59	0.15	0.46
Treatment (T)	3	497.57**	2.48**	302.28**
Control vs removal-shading	1	106.09**	0.64**	33.64*
Awns vs flag leaf removal	1	0.34ns	0.00ns	1.50ns
shading vs removal	1	0.70ns	0.01ns	15.68ns
Genotype (G)	12	225.07**	1.12**	194.69**
T x G	36	59.68**	0.21**	62.75**
Residual	102	9.80	0.03	6.04

KS = number of kernels per spike, SGY = spike grain yield, KW = kernel weight,

Table 3. Means of the measured parameters averaged over varieties, absolute and relative reduction induced by removal-shading treatments

	kernels per spike			Spike grain yield (g)			Kernel weight (mg)		
Treatments	Mean	Δ	Δ (%)	Mean	Δ	Δ (%)	Mean	Δ	Δ (%)
Control	46.8	0.0	0.0	2.3	0.0	0.0	48.8	0.0	0.0
Removal-shading	39.9	-6.9	-14.7	1.8	-0.5	-21.7	44.9	-3.9	-8.0
Awns removal	38.7	-8.1	-17.3	1.8	-0.5	-21.7	46.8	-2.0	-4.1
Flag leaf removal	40.2	-6.6	-14.1	1.8	-0.5	-21.7	45.8	-3.0	-6.1
Spike shading	40.9	-5.9	-12.6	1.7	-0.6	-26.1	42.2	-6.6	-13.5
$Lsd_{5\%}$	3.5			0.2			3.6		

Δ = decline from the control value, Δ (%) = relative decline.

Table 4. Means of the measured parameters of the evaluated genotypes averaged removal-shading treatments

	Wah	Mbb	Bou	Set	Bad	Mg_1	Ben	Mg_2	Bof	Ofa	Mof	Ess	Mg_3	Lsd5%
KS	49.1	39.5	41.2	44.1	44.6	43.4	43.1	37.0	47.1	42.3	39.5	38.3	32.8	6.4
SGY	2.1	1.8	1.9	1.9	2.4	2.3	2.1	1.5	2.2	2.1	1.8	1.5	1.4	0.4
KW	42.7	45.1	46.9	43.3	53.0	51.8	49.3	42.3	45.5	49.6	44.9	40.0	42.0	6.6

Wah = Waha, Mbb = MBB = Mohamed Ben Bachir, Bou = Bousselam, Set = Setifis, Bad = Badre, Mg1 = Megress-1, Ben = Benzitouni, Mg2 = Megress-2, Bof = Bousselam/Ofanto, Ofa = Ofanto, Mof = MBB/Ofanto, Ess = Essalem, Mg3 = Megress-3.

The induced-decline in the measured parameters, expressed as % of the control value, showed large variation in the responses of the genotypes to the removal-shading treatments. The analysis of the reductions caused by the removal-shading treatment to the spike grain yield indicated that Ofanto, Bousselam/Ofanto, Essalem and Megress-3 were more affected by the removal-shading treatments, as a whole, than Megress-2 and MBB. Megress-1 spike grain yield responded more to leaf ablation (-25.8%), Bousselam spike grain yield to awns ablation (-24.2%), while spike grain yield of MBB/Ofanto, Essalem and Megress-3 showed high decline caused by spike shading (-42.3, -48.7 and -41.5%, respectively). Spike grain yield of Benzitouni, Ofanto and Bousselam/Ofanto expressed similar declines due to the three removal-shading treatments (Figure 1A**).** Similar variation pattern was observed in the % reduction, caused by the removal-shading treatments, expressed by the number of grains/spike and kernel weight of the different genotypes (Figure 1B and C).

Table 5: Means ($\bar{Y}$) of the variables measured per variety and removal-shading treatment (Treat) and induced- reduction from the control value (Δ)

		SGY		KS		KW				SGY		KS		KW	
Variety	Treat	$\bar{Y}$	Δ	$\bar{Y}$	Δ	$\bar{Y}$	Δ	Variety	Treat	$\bar{Y}$	Δ	$\bar{Y}$	Δ	$\bar{Y}$	Δ
Waha	C	2.4	0.0	53.0	0.0	46.2	0.0	Benzitouni	Spike	2.0	-0.7	43.0	-9.3	45.8	-8.4
	Awns	2.0	-0.4	49.0	-4.0	41.5	-4.8	Megress-2	C	1.7	0.0	40.7	0.0	53.8	0.0
	Leaf	1.9	-0.5	47.3	-5.7	41.7	-4.5		Awns	1.5	-0.3	27.7	-13.0	42.7	-11.1
	Spike	1.9	-0.5	47.0	-6.0	41.5	-4.7		Flag	1.6	-0.2	39.7	-1.0	39.6	-14.2
MBB	C	2.0	0.0	45.0	0.0	51.3	0.0		Spike	1.3	-0.4	40.0	-0.7	32.9	-20.9
	Awns	1.8	-0.2	36.0	-9.0	44.5	-6.8	Bou/Ofanto	C	3.0	0.0	54.3	0.0	54.5	0.0
	Leaf	1.6	-0.4	38.0	-7.0	42.7	-8.7		Awns	2.1	-0.8	49.0	-5.3	43.2	-11.3
	Spike	1.6	-0.4	39.0	-6.0	42.0	-9.3		Leaf	1.8	-1.1	43.0	-11.3	42.4	-12.0
Bousselam	C	2.3	0.0	47.3	0.0	49.0	0.0		Spike	1.8	-1.2	42.0	-12.3	41.9	-12.6
	Awns	1.8	-0.6	37.3	-10.0	47.1	-1.8	Ofanto	C	3.0	0.0	52.0	0.0	57.3	0.0
	Leaf	1.9	-0.4	39.0	-8.3	47.9	-1.1		Awns	1.6	-1.3	37.3	-14.7	43.7	-13.6
	Spike	1.8	-0.5	41.0	-6.3	43.7	-5.3		Leaf	2.0	-1.0	41.7	-10.3	47.9	-9.4
Setifis	C	2.2	0.0	41.0	0.0	45.8	0.0		Spike	1.9	-1.1	38.0	-14.0	49.5	-7.8
	Awns	1.9	-0.3	43.3	2.3	44.5	-1.3	MBB/Ofanto	C	2.2	0.0	42.0	0.0	51.4	0.0
	Leaf	1.8	-0.4	40.5	-0.5	43.3	-2.5		Awns	1.7	-0.4	38.7	-3.3	45.1	-6.2
	Spike	1.7	-0.6	41.5	0.5	41.0	-4.8		Leaf	2.0	-0.2	40.0	-2.0	49.8	-1.6
Badre	C	2.8	0.0	49.0	0.0	56.6	0.0		Spike	1.2	-0.9	37.3	-4.7	33.3	-18.0
	Awns	2.4	-0.4	41.0	-8.0	49.0	-7.6	Essalem	C	2.0	0.0	49.7	0.0	48.9	0.0
	Leaf	2.3	-0.5	42.0	-7.0	49.8	-6.8		Awns	1.5	-0.5	31.0	-18.7	40.9	-8.0
	Spike	2.0	-0.8	46.3	-2.7	51.5	-5.1		Leaf	1.5	-0.5	40.7	-9.0	37.2	-11.7
Megress-1	C	2.6	0.0	45.0	0.0	58.8	0.0		Spike	1.0	-1.0	31.7	-18.0	32.8	-16.1
	Awns	2.0	-0.6	41.0	-4.0	49.6	-9.2	Megress-3	C	1.9	0.0	44.7	0.0	45.5	0.0
	Leaf	2.0	-0.7	41.5	-3.5	47.4	-11.4		Awns	1.3	-0.5	29.7	-15.0	41.2	-4.3
	Spike	2.4	-0.3	46.0	1.0	51.6	-7.1		Leaf	1.2	-0.7	28.3	-16.3	43.0	-2.5
Benzitouni	C	2.7	0.0	52.3	0.0	54.2	0.0		Spike	1.1	-0.8	28.7	-16.0	38.1	-7.4
	Awns	2.0	-0.7	42.7	-9.7	45.8	-8.4								
	Leaf	1.9	-0.8	34.3	-18.0	46.8	-7.4	Lsd5%		0.3	0.3	5.1	5.1	6.3	6.3

Δ = reduction relatively to the control value, $\bar{Y}$ = mean value

In general, the number of grains/spike of Waha, Megress-1, Setifis and MBB/Ofanto was less affected by the removal-shading treatments compared to Essalem, Megress-3, Ofanto and Benzitouni, which expressed high % reductions. The number of grains/spike of Megress-1 (-7.8%), Setifis (-1.2%), and MBB/Ofanto (-4.8%) was less affected by leaf ablation compared to the decline of the mean value of this trait expressed by Benzitouni (-34.4%) and Megress-3 (-36.6%).

The effect of awns ablation, on the number of kernels per spike, was smaller in Setifis (+5.7%), Waha (-7.5%), Megres-1(-8.9%) and MBB/Ofanto (-7.9%) and larger in Megres-2 (-32.0%), Essalem (-37.6%) and Megress-3 (-33.6%). Spike shading effect was smaller on the number of kernels/spike of Badre (-5.1%), Megress-2 (-1.6%), MBB/Ofanto (-11.1%) compared to the effect of the same treatment on the same trait of Bousselam/Ofanto (-22.7%), Essalem (-36.2%) and Megress-3 (-35.8%). Setifis and Megress-3 expressed a completely opposite behavior to the removal-shading treatments. Setifis showed an inherent capacity to minimize the decline induced by the removal-shading treatments, while this ability seems to be missing in Megress-3 (Figure 1B).

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The general pattern of variation shown by kernel weight in response to the removal-shading treatments indicated that Bousselam and Setifis were the least affected, compared to Megres-2 and Essalem, which exhibited larger declines. Bousselam (-3.8%) and Setifis (-2.8%) kernel weight showed small declines, due to awns ablation, compared to Ofanto (-23.7%) and Bousselam/Ofanto (-20.7%). Similarly, the response of this trait to leaf ablation was smaller in Bousselam (-2.2%) and MBB/Ofanto (-3.2%) and larger in Megres-2 (-26.3) and Essalem (-23.9%). Kernel weight of Badre (-9.0%) and Waha (-10.2%) was less affected by spike shading than Megress-2 (-38.8%) and MBB/Ofanto (-35.1%) (Figure 1C).

Pattern of the variability of responses to removal-shading treatments:

The pattern of the variation in the response of the genotypes to organs removal or shading and relationships with grain yield and yield component, determined on a ground area basis, were investigated through clustering and principal components analysis (PCA). To get a simplified picture in the pattern of variation of the responses to source limitation, the tested genotypes were clustered on the basis of the values of the declines induced by the treatment to the measured traits. Cluster analysis gave four groups, including 5 (G1), 5 (G2), 2 (G3) and 1 (Megress-2) entries each. The mean values of the measured traits were over average genotypes per group and subjected to a principal components analysis, along with the yield and yield components, determined on an area basis. The first two axes of the PCA explained 90.9% (46.7 and 44.2%, respectively) of the variability submitted to the analysis. Spike number (SN), spike grain yield declines, induced by flag leaf ablation (SGYL), awns removal (SGYA), and spike shading (SGYS), kernels/spike declines, induced by flag leaf ablation (KSL) and spike shading (KSS) were positively correlated with PCA1. PCA1 represents, then, spike number/m² and the responses of spike grain yield and kernels/spike to defoliation and shading. Kernel weight declines due to leaf ablation (KWL), awns removal (KWA) and spike shading (KWS) were positively correlated to PCA2, while kernels/spike, thousand-kernel weight and grain yield were negatively correlated with this axis (Figure 2).

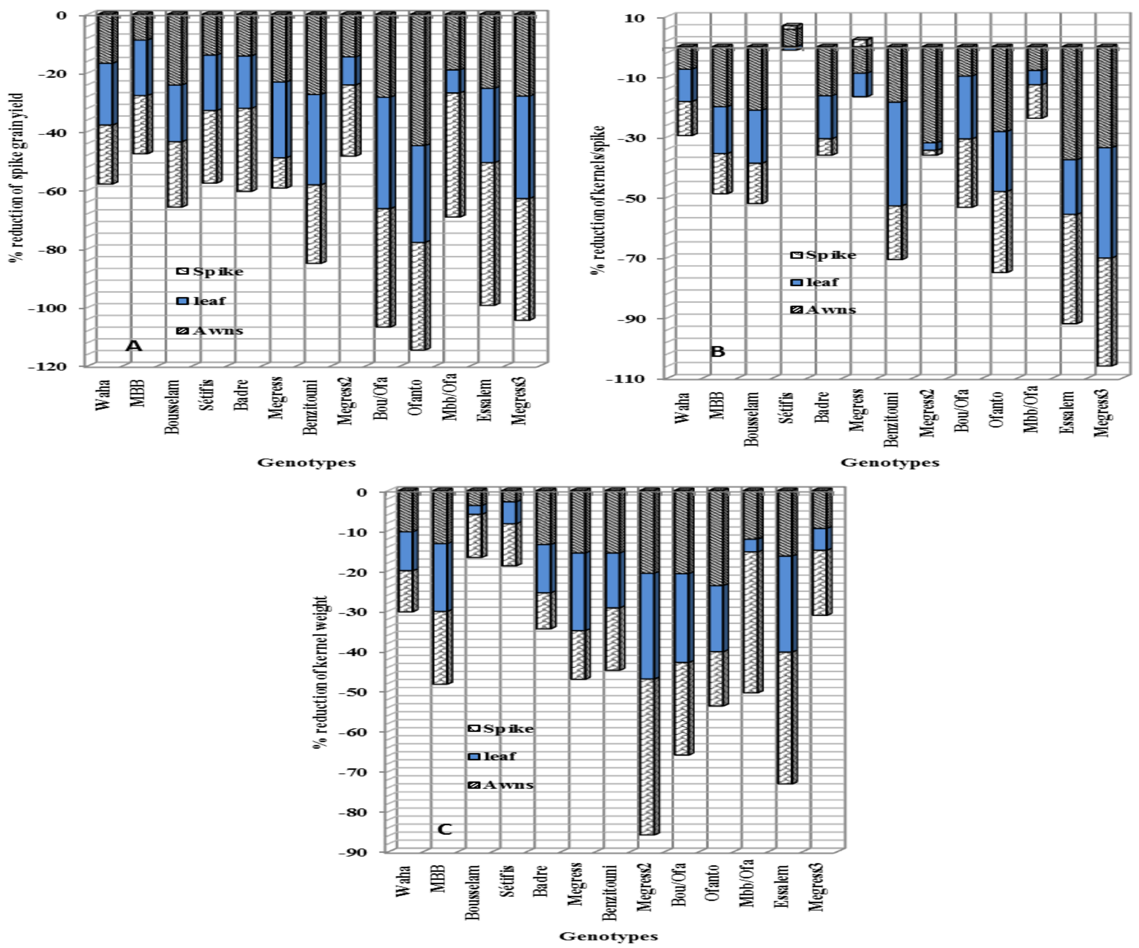

Fig. 1: Variation, among genotypes, of the reduction (%) of spike grain yield (A), kernels/spike (B) and kernel weight (C) caused by the removal-shading treatments.

G1 and G2 groups of varieties were opposed along PCA1, suggesting that genotypes, belonging to G1, tented to have a high spike number per m², associated with small declines in spike grain yield induced by ablation of flag leaf, awns and spike shading, and with small declines in kernels/spike due to flag leaf and spike shading. Taking the opposite position, along PCA1, the genotypes belonging to G2 are characterized by low spike number per m², and large declines in spike grains yield and kernels/spike induced by organs removal and shading (Table 6, Figure 2). These results suggested that genotypes of G1 group, bearing high number of fertile tillers per m² (high source capacity per unit area), are less sensitive to source limitation effects on spike grain yield and kernels/spike, than those of G2 group which producing less spikes/m². Therefore G1 group maintained high grain yield compared to G2 varieties under stressful conditions (Table 6, Figure 2).

The position of Megress-2 along the axis 2 indicated that this genotype had high grain yield, a high number of kernels/spike and high thousand kernel weight, associated large declines induced by organs removal and shading to kernel weight. G3 group of genotypes which occupied the opposite position to Megress-2, had low grain yield /m², low kernels/spike, low thousand kernel weight, and low declines in kernel weight, induced by removal and shading of the plant organs (Table 6, Figure 2). Despite their ability to minimize the effect of the source limitation on kernel weight, G3 group of genotypes could not maintain a high grain yield, essentially because of their inherent low thousand kernel weight and low kernels per spike which classified them as low yielding genotypes (Table 6, Figure 2).

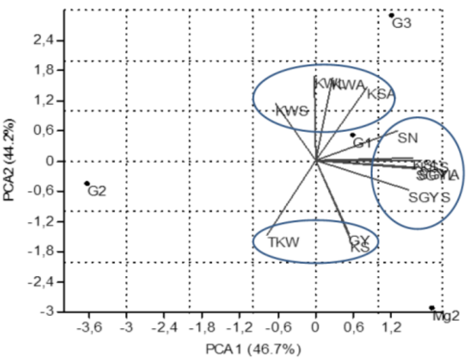

Fig. 2: Principal component analysis projections on axes 1 and 2 (GY = grain yield g/m², SN = number of spikes /m², KS= kernels/spike, TKW = thousand-kernel weight, SGYA, SGYL, SGYS = spike grain yield declines induced by awn removal, leaf removal and spike shading, respectively; KSA, KSL, KSS = Kernels/spike declines induced by awn removal, leaf removal and spike shading, respectively; KWA, KWL, KWS= kernel weight declines induced by awn removal, leaf removal and spike shading, respectively).

Table 5: Means of the declines induced by the source limitation treatments to the variables measured, averaged per group of varieties.

	SGYA	SGYL	SGYS	KSL	KSA	KSS	KWA	KWL	KWS	SN	KS	GY	TKW
G1	-0.4	-0.5	-0.5	-6.3	-7.0	-4.0	-6.0	-6.5	-6.3	362.9	44.0	688.5	43.2
G2	-0.8	-0.8	-1.0	-11.3	-14.3	-13.9	-8.9	-8.8	-10.4	299.8	41.6	577.9	46.7
Mg-2	-0.3	-0.2	-0.4	-1.0	-13.0	-0.7	-11.1	-14.2	-20.9	334.4	49.5	757.8	45.9
G3	-0.4	-0.3	-0.7	-1.3	-0.5	-2.1	-3.8	-2.1	-11.4	348.0	38.1	482.9	37.4

SGYA, SGYL, SGYS= spike grain yield declines (g/spike) induced by awns removal, leaf removal and by spike shading, respectively; KSA, KSL, KSS= Kernels/spike declines (grains/spike) induced by awns removal, leaf removal and by spike shading, respectively; KWA, KWL, KWS = Kernel weight declines (mg/kernel) induced by awns removal, leaf removal and by spike shading, respectively; G1 = Badre, Megress-1, Waha, Bousselam, MBB, G2= Benzitouni, Ofanto, Essalem, Megress-3, Bousselam/Ofanto; G3= Setifis, MBB/Ofanto.

Discussion:

The present investigation revealed significant divergence among varieties, removal-shading treatments and varieties × treatment interaction, suggesting that flag leaf, awns and spike affected significantly the measured traits in the post anthesis growth stage. Flag leaf and awns removal, as well as spike shading, induced substantial reduction in spike grain yield, number of kernels/spike and kernel weight. On the average, over the thirteen studied varieties, spike shading induced greater decline in spike grain yield, kernels/spike and kernel weight (-26.1, -12.6 and 13.5%) followed by awns ablation (-21.7, -17.1 and -6.1%) and leaf ablation has the lowest effect (-21.7, -14.1 and -4.1%). In over averaged source limitation treatments, the means were -21.7, -14.7 and -8.0, respectively. These results are in agreement with those of Mahmood and Chowdhry [14] and Khaliq *et al.* [15] who reported 34.5% and 18.32% decrease in yield due to flag leaf blade ablation. Alam *et al.*, [7] reported that flag leaf ablation induced a decline of 9.9%, 7.6% and 16.8%, in the number of grains per spike, kernel weight and spike grain yield, respectively. The results of this study, about awns removal effect, are in accordance with those of Radmehr *et al.*, [16] who mentioned that awns removal affected the number of grains/spike, grain weight/spike and thousand-kernel weight. In this context, Aranjuelo *et al.*, [4] mentioned that ear contribution to grain filling varied widely, from 10 to 76%, due to genetic diversity and growing conditions. Maydup *et al.*, [8] found that ear photosynthesis makes a sizeable contribution to grain yield, ranging from 22% to 45%, under stress conditions. Abdoli *et al.,* [17] noted that flag leaf removal affected spike grain yield, kernel weight, grain number per spike, and that the effect varied among the assessed genotypes, which is in accordance with the results of the present study. The observed declines in the measured traits after removal or shading suggested the importance of photosynthesis of these plant organs during grain filling and/or the importance of the reserves mobilized from them. In fact, according to Li *et al.*, [18], the presence of awns facilitates more CO_2 fixation in the plants. Saeidi *et al.*, [5] mentioned that the inhibition of spike photosynthesis significantly decreased grain yield, thousand kernel weight, grains/spike and peduncle specific weight. Xu *et al.,* [9] mentioned that, compared with flag leaf blade, spike photosynthesis possesses higher stress tolerance, and proposed to select for higher ear photosynthesis to improve yield potential and adaptation to less favorable environments. The results of this study showed differential responses of the tested genotypes to the source limitation treatments. Similar genotypic behaviors were observed by Abdoli *et al.,* [17]. Minimization of the decline induced by removal of plant photosynthetic organs could be explained by the fact that removal stimulates the appeal of assimilates stored elsewhere in the plant to compensate for the deficiency of the photosynthetic contribution arising from the removed plant organ and thereby avoiding a sizeable decrease in the achieved mean of the measured trait.

The analysis of the relationships between variables measured on main stem spike and yield and yield component, measured on an area basis, indicated that genotypes, having high number of spikes per m², are more tolerant to source limitation, than those having fewer fertile tillers per m². The results indicated also that genotypes having low thousand kernel weight and low kernels/spike are more tolerant to source limitation, even though they are less desirable in selection due to their inherent low yielding capacity. The results indicated also that Megress-2 seemed to be sensitive to source limitation, but due to its high thousand kernel weight and high kernels per spike, it achieved a high grain yield under the experienced growth conditions of this study. Modern durum wheat varieties resulting from the green revolution are high yielding due to the reduced height and high spikes /m², compared with ancient varieties [19]. The increased yield of this plant material was due to the increased number of kernels/m² and to the shift in the way assimilates stored in the stem are partitioned. Producing more fertile tillers (more storage capacity par unit area), these varieties store excess carbohydrates in stem tissues and remobilize it to the grain to minimize yield and yield components declines under varying environmental conditions. These hypotheses are in agreement with findings of Asseng and Herwaarden [20] who observed a relationship between stem carbohydrate storage and the genotype ability to maintain high yield stability under stressful conditions. However, in the present study, genotypes with high kernel weight, which tolerate source limitation treatments, were not identified among the tested entries. One entry, exhibiting sensitivity to source limitation treatments, was identified, but this genotype had a high grain yield due to a high kernels/spike and high thousand kernel weight. This finding contrasts with what has been reported by Rebetzke *et al.*, [19] who mentioned that genotypes, with few fertile tillers per unit area, produced grains with high dry mass but this is done at the expense of the number of grains per m² which is reduced. The increase in the grain mass in these lines appears to compensate for the lower grain number set, to minimize yield decline.

Conclusion:

The results of this study indicate the possibilities to improve stress tolerance and yield stability in durum wheat, through the ability to minimize the effects of source limitation during the grain filling period. Varieties with high number of fertile tillers seem to possess this ability. This type of plant material had a high assimilate on storage capacity which is used under stressful conditions to minimize the effect of source limitation on grain yield. Such genotypes show improved floret fertility, grain filling, and yield under stress due to compensation by an increase in assimilate remobilization from the stem.

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