

Relationships Between Morphological and Anatomical Characteristics of Durum Wheat (*Triticum Durum* Desf.) Awns and Yield Under Water Constraint

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Received: Nov. 27, 2024

Accepted: Jan 09, 2025

Published: Jan 21, 2025

Abstract:

There is no doubt that every part of the durum wheat plant (*Triticum durum* Desf.) has significantly a role in the contribution of grain yield as well as in the tolerance to drought. The aim of this work was to study awns' anatomical and morphological characteristics to analyze their role in yield. Three varieties (INRAT 69, Razzak, Duriac) were studied in an experiment field under irrigated and no-irrigated conditions. At the beginning of the heading stage, three treatments were applied: control, removal of all leaves, and removal of all leaves and awns. Excision of awns showed that these organs play an important role in the elaboration of yield, particularly in water deficit conditions. The role of this organ was more important in the determination of the weight of grains by ear (15.67%) and the thousand grains weight (15.94%) than in the elaboration of grains by ear (4.06%). The anatomical study showed the presence of stomata and three vascular bundles in each awns element. Thus, awns photosynthates will be transferred easily to grains. For this, we noted the importance of this organ in the contribution of yield and the interest in the protection of the cereal culture against diseases that can attack awns at the end of the development cycle.

Keywords: anatomy, awns, durum wheat, grains yield, water deficit

العلاقة بين الخصائص المورفولوجية والتشريحية لسفا السنبلة والإنتاجية للقمح الصلب (*Triticum durum* Desf.) تحت تأثير الإجهاد المائي

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استلمت: 27 نوفمبر 2024	قبلت: 09 يناير 2025	نشرت: 21 يناير 2025
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الملخص:

لا شك أن كل جزء من نبات القمح الصلب (*Triticum durum* Desf.) له دور كبير في المساهمة في إنتاج الحبوب وكذلك في تحمل الجفاف. إن الهدف من هذا العمل هو دراسة الخصائص التشريحية والمورفولوجية لسفاف السنبلة لتحليل دورها في الإنتاجية. تمت دراسة ثلاثة أصناف: إنرات 69، رزاق ودريك (69 INRAT، Razzak، Duriac) في حقل تجريبي في ظل ظروف مروية وغير مروية. في بداية مرحلة التسبيل، تم تطبيق ثلاث معاملات (1) الشاهد، (2) إزالة جميع الأوراق، (3) إزالة جميع الأوراق و سفاف السنبلة. أظهرت إزالة سفاف السنبلة أن هذه الأعضاء تلعب دوراً مهماً في إنتاجية القمح، وخاصة في ظروف نقص المياه. كان دور هذه الأعضاء أكثر أهمية في تحديد وزن الحبوب بالسنبلة (15.67%) ووزن ألف حبة (15.94%) مقارنة بإنتاج عدد الحبات بالسنبلة (4.06%). وقد أظهرت الدراسة التشريحية وجود ثغور وثلاث حزم وعائية في كل عنصر من عناصر السنبلة، وبالتالي تنتقل عملية التمثيل الضوئي والمواد العضوية المنتجة في السنبلة بسهولة إلى الحبوب، لذلك يجب التأكيد على أهمية هذه الأعضاء في المساهمة في زيادة الإنتاجية ودورها في حماية الحبوب من الأمراض التي يمكن أن تؤثر سلباً على السنبلة في نهاية دورة النمو لدى القمح.

الكلمات المفتاحية: التشريح، سفاف السنبلة، القمح الصلب، إنتاج الحبوب، الإجهاد المائي.

1. Introduction

Cereals are important for worldwide food security, particularly in developed countries [1]. It constitutes a significant source of human and animal nutrition[2]. Among the cereal species, durum wheat (*Triticum durum* Desf.) is a staple food cereal crop, playing a major role in strengthening for escalating global population [3]. However, this sector remains highly dependent on climatic conditions such as drought, which is considered the

most important factor in limiting its production. Water constraint is one of the yields threatening stress in wheat crops and alarming for food security [4]. This situation will become more critical against the background of a changing climate, which already impacts agricultural production around the globe [5] and poses a serious threat to global food security [6] Therefore, it is necessary to identify drought resistance mechanisms and the contribution of plant organs to grain yield, particularly at the end of the development cycle.

Thus, every organ of the durum wheat (*Triticum durum* Desf.) plant undoubtedly has a role in elaborating grain yield and biomass as well as in the resistance to drought. The study of the role of durum wheat organs was limited in most cases to roots, leaves, and tillers. However, the maximization of grain yield doesn't depend only on these factors in water deficit conditions. In fact, nutritive assimilation, that is, until the heading stage in favor of development and vegetative growth, turns after this stage in favor of the reproductive part represented by the ear and vegetative organs that are again in development (awns and flag leaf). The post-anthesis stage in cereals is often associated with severe water deficit conditions, leading to reduced yield; in these conditions, the ear possesses an elevated drought tolerance when compared with the flag leaf [7]. In this stage, the two organs are presented as "sources and sink" organs. The passage of the pre-anthesis situation (limited sink) to the post-anthesis situation (limited sources) requires a better understanding of the relationships between source-sink. The possible advantage of the ear as a photosynthetic (source) organ may be explained by its proximity to the grains, which are the final sinks [8]. Since the translocation pathway from the awn to the grain is short, awns can easily improve the photosynthetic capacity of the inflorescence [9]. Many studies demonstrate that flowers, fruits, and seeds are photosynthetically active

[10]. One important consideration of awns is that these organs often remain photosynthetically active when leaves have started to senesce [11] and contribute to photosynthesis, particularly under water-limited conditions when canopy assimilation is restricted [12]. Ear photosynthesis is quantitatively important to grain filling, particularly in dry areas where the source (assimilate) limitations can occur [13]. Awn plays a dominant role as an important transpiration and photosynthetic organ. It possesses a large surface area and can exceed the flag leaf blade [9], especially under drought conditions where the ear may become the main photosynthetic contributor to grain filling [14]. In durum wheat, the presence of awns doubled the total ear surface area and, thereby, light interception and can provide a potentially large photosynthetic surface comprising up to 60% of the entire ear surface area [15].

The most cultivated cereals (wheat, barley, oat, and rye) are awned [16], and some studies on wheat showed that awns might have a useful effect on yield, especially under drought stress [17]. Spike and awn colors are important for farmers. For example, Tunisian farmers associate the black color of awns with the Mahmoudi landrace, distinguished for its higher quality semolina and bread bakery [18]. These findings are consistent with previous studies showing that awn color was often among the most diversified traits in Tunisian landraces [19]. Despite the role that awns can play in developing grain yields, works that are interested in this subject and the effect of environmental conditions on this organ are not numerous. Overall, little is known about the elusive role of awns [20].

The aim of the study was to investigate awns' anatomical and morphological characteristics to analyze the relationships between awns structure and grain yield in durum wheat.

2. Material and Methods

2.1 Plant material

Three varieties of durum wheat (*Triticum durum* Desf.) were studied: INRAT 69: local Tunisian variety obtained by crossing *Kyperounda* x *Mahmoudi* 981 (lineage 58-25) in the INRAT; Razzak: ameliorated variety obtained by crossing *Karim* x *lined DM* x 69-331: AA S (LAKE - LD 390) Ch 67 in the INRAT; Duriac: is a French variety provided by Plants Amelioration Laboratory of Montpellier INRA/ENSA.

2.2 Experimental conditions

This study was carried out on a surface of 150 m² in an experimental parcel of the National Institute of Agronomic Research of Tunis (INRAT). The experimental culture was conducted firstly under complement irrigation and in pluvial conditions. At the tillering stage, the parcel, which was conducted in a pluvial, was protected by transparent plastic. When the soil humidity, at the 30 cm depth, becomes under 70% and 20% of the field capacity in the irrigated and the stressed parcels, respectively, irrigation was provided. Three replications of five lines of 2.5 m were used for each treatment.

2.3 Removal of awns and leaves

Three awns and leaves excision treatments were effectuated at the beginning of the heading stage for all varieties. Each one effectuated on 15 plants by replication (3 replications). T1: Check. All leaves and awns are maintained intact; T2: excision of all leaves whereas awns maintained intact; T3: excision of all leaves and awns.

2.4 Total length of awn

The total length and the total area of the awn were measured at three stages (S1: 15 days after the heading, S2: 30 days after the heading, and S3: 45 days after the heading). Each value represents the average of fifteen measurements (15 ears: 5 by repetition in the field). The total length of awns (TLA) was calculated according to the following formula:

2.5 Estimation of the total area of awn

The awn is constituted by n strands with three sides; each one is an isosceles triangle **Fig. 1**.



Fig. 1. Representation of the awn strand

The area of each side was calculated according to the following formula:

(h : length of the strand, d : base of the strand).

(n : total number of strands, TLA: total length of the awn).

2.6 Anatomical study

The longitudinal section of the awn strand was effectuated to determine stomatal density in the full heading stage. This parameter was determined by a micrometer localized in an optical microscope eyepiece (Olympus). Measurements were made on a single side of the strand at the base, the middle, and the top. Six replications were applied for the anatomical parameters (2 by replication in the field). The cross-section was released to study awns histology.

2.7 Determination of chlorophyll content

The chlorophyll content was performed at two stages (S1, S2): 15 and 36 days after heading. Each value represents the average of four measurements. Chlorophyll was determined by the McKinney-Arnon method. One ml of the extract was taken for the chlorophyll assay, to which 9 ml of 80% acetone was added. The chlorophyll content ($\mu\text{g/g}^{-1}$ dry matter) was measured successively at the absorption of 645 and 663 nm.

2.8 Yield components

Yield components, the number of grains by ear (NGE), the weight of grains by ear (WGE), and thousand grains weight (WTG) for each treatment (T1 to T3) were determined. 15 ears by replication for the 2 water treatments were used (15 ears x 3 treatments of awns removal x 2 water treatments x 3 varieties x 3 replications = 810 ears).

2.9 Statistical analysis

Statistical analysis was made with STATITCF software. Averages are compared by the least significant difference (LSD), given by the Bonferonni test (5%).

3. Results

3.1 The total length of awn strands (TLAS)

The total length of each awn is the length sum of all strands. The ANOVA showed that the variety, the treatment, and the stage effects were highly significant (Table 1). The total length of the strands of INRAT69 awns was the highest in all cases and reached 970.35 cm at S3. This parameter was lower in the variety Razzak for both treatments and at all stages. Water stress induced a reduction of TLAS. The most sensitive variety was the Duriac variety, with a reduction of 26.87% against 20.29% for Razzak and 19.16% for INRAT69.

Over 90% of awn length growth occurred before the second week of heading. This showed that the awn had already completed its growth during the grain-filling period (between 15 and 45 days after the heading). The evolution of awn growth showed in all varieties, under the two water treatments, that TLAS represents, 15 days after heading, more than 60% of the final length (Table 2). In irrigated conditions, it reached 80% at Razzak and 89.54% at Duriac. One month after the heading, the TLAS represents more than 70% of the final length. It reached 97.46% at Duriac and 93.27% at INRAT69 in irrigated conditions. Thus, the awn reached its peak growth 30 days after heading.

Table 1. Variation of the total length of durum wheat awn strands according to the variety (V), the water regime (WR) (I: irrigated, NI: not irrigated), and the development stages (S) expressed in cm

		S1	S2	S3	Average	
INRAT69	I	668.98	905.08	970.35	848.13	766.85
	NI	565.63	617.32	873.78	685.57	
Razzak	I	671.73	685.33	839.43	732.16	657.88
	NI	478.1	585.5	687.2	583.6	
Duriac	I	747.68	834.95	856.65	813.09	703.84
	NI	496.63	539.48	747.68	594.59	
Average	I	696.13	808.45	888.81	797.79	709.52
	NI	513.45	580.76	769.55	621.25	

LSD: least significant difference; LSD (V)= 71.42 LSD (WR)= 47.13 LSD (S)=71.42; LSD (V x S) =171.78 LSD (WR x S) = 126.91 LSD (V x WR x S) =279.7; S1 – 15 days after the heading, S2 – 30 days after the heading, S3 – 45 days after the heading

Table 2. The total length of durum wheat awn strands expressed in % relative to the length obtained on the 45th day after the heading (S3)

	INRAT69			Razzak			Duriac		
	I	NI	Average	I	NI	Average	I	NI	Average
S1	68.94	64.73	66.83	80.02	69.57	74.79	89.54	66.42	77.98
S2	93.27	70.65	81.96	81.16	85.20	83.18	97.46	72.15	84.80

S1: 15 days after the heading, S2: 30 days after the heading, I: irrigated, NI: not irrigated

3.2 Variation of the awns area

Independently of the stages (Table 3), the awns area of the variety INRAT69 is the highest in both irrigated and stress conditions. However, the awns area of the other varieties depends on the water regime. It was higher in the Duriac variety in irrigated and in the Razzak variety in water deficit

conditions. The water stress decreased the awns area in all varieties. This reduction was 19.17, 20.43 and 35.72% at INRAT69, Razzak, and Duriac, respectively. The awns growth represented, at 15 days after heading, more than 64% of its final surface (Table 4). It reached 97.47% and 91.17%, respectively, for Duriac under irrigation and under water deficit conditions. Thus, maximum awns growth was completed before the second week of heading.

Table 3. Variation of the durum wheat awn surface according to the varieties (V), the water regime (WR) (I: irrigated, NI: not irrigated), and the stages (S) of development expressed in cm²

		S1	S2	S3	Average		
INRAT69	I	67.88	72.77	50.17	63.61	57.51	
	NI	42.41	65.52	46.3	51.41		
Razzak	I	51.39	62.95	50.38	54.91	49.34	
	NI	43.91	51.54	35.85	43.77		
Duriac	I	62.62	64.24	56.07	60.98	50.08	
	NI	37.13	40.46	39.98	39.19		
Average	I	60.63	66.65	52.20	52.30		
	NI	41.15	52.50	40.71			

LSD: least significant difference; LSD (V) = 6.82 LSD (WR) = 4.50; LSD (S)= 6.82 LSD (V x WR x S) =26.72; S1 – 15 days after heading, S2 – 30 days after heading, S3 – 45 days after heading

Table 4. Area of the awn at 15 days after heading expressed in % relative to the final area

	INRAT69	Razzak	Duriac
I	93.28	81.63	97.47
NI	64.72	85.19	91.17
Average	79	83.41	94.32

I: irrigated, NI: not irrigated

3.3 Variation of chlorophyll content in awns

The highest value of total chlorophyll content was recorded in the awns of the Razzak variety. However, the lowest entire chlorophyll content was observed in those of the variety INRAT69 (Figure 2). This figure also shows that the total chlorophyll content was significantly reduced three weeks after the first stage. On average, this decrease was 41.33%. The water deficit was accompanied in all cases by a significant reduction in the total chlorophyll

content. This reduction varied according to the varieties and development stages.

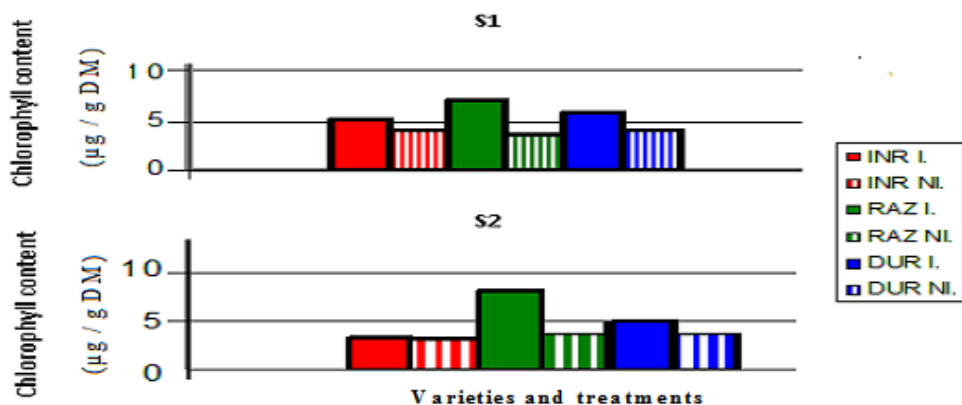


Fig. 2. Variation of the durum wheat total chlorophyll content ($\mu\text{g/g}^{-1}\text{ DM}$) according to varieties (V), water regime (WR) (I: irrigated, NI: not irrigated), and development stages (S)

LSD: least significant difference; LSD (V)= 0.9; LSD (WR)= 0.54; LSD (S)= 0.54; LSD (V x WR) = 1.85; S1 – 15 days after heading, S2 – 36 days after heading

3.4 Variation of stomatal density in awns

Stomata were arranged in two lines in each strand (Figure 3). Stomatal density varied according to variety, water treatment, and position on the strand (Figure 4). The stomatal density was much greater in the middle of the strand in the two Tunisian varieties. However, in the Duriac variety, the stomatal density was constant along the strand except in the middle in the irrigated conditions. Water deficit increased the stomatal density of awns in most cases. This increase was more important at the top for the variety INRAT69 and in the middle for the Razzak and Duriac varieties.



Fig. 3. Longitudinal section of durum wheat awns

On average, the Stomatal density in awns was 43.8 st/mm² Table 5. Razzak kept the first position. However, the smallest density was observed in the INRAT 69 variety. Water deficit increased, in most cases, the stomatal density. A raise of 7.01 and 8.39 stomata/mm² were recorded, respectively, for INRAT69 and Razzak. However, a weak increase in stomatal density was observed in the French variety (+ 4 stomata /mm²).

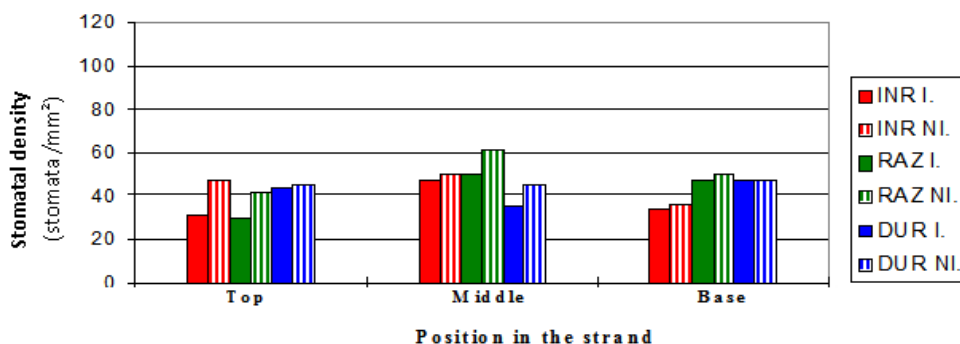


Fig. 4. Variation of the durum wheat stomatal density in the awns strand according to the varieties (V), the water regime (WR), and the position (P) on the strand (top, middle, base)

LSD (V) = 4.17; LSD (WR) = 2.75; LSD (P) = 4.17; LSD (V x P) = 10.02; LSD (WR x P) = 7.41; I – irrigated, NI – not irrigated; LSD – least significant difference

Table 5. Variation of durum wheat stomatal density according to the varieties and the water regime (stomata / mm²)

	INRAT69	Razzak	Duriac
stomatal density in irrigated conditions	37.46	42.33	41.91
stomatal density in stressed conditions	44.47	50.72	45.91
Average	40.96	46.52	43.91
General Average	43.8		

3.5 Anatomy of durum wheat awns

The cross-section of the awns strand showed different tissues Fig. 5. The epidermis was a protective tissue, and the parenchyma and chlorenchyma a reserve and photosynthetic tissues. The cross-section also showed three vascular bundles arranged by primary xylem (on the inside) and primary phloem (on the outside). In the epidermis, some cells give out some elongations toward the outside. These elongations are a protector hears that

intervene in the regulation of transpiration, which provided the xerophytic character of awns Fig. 5.

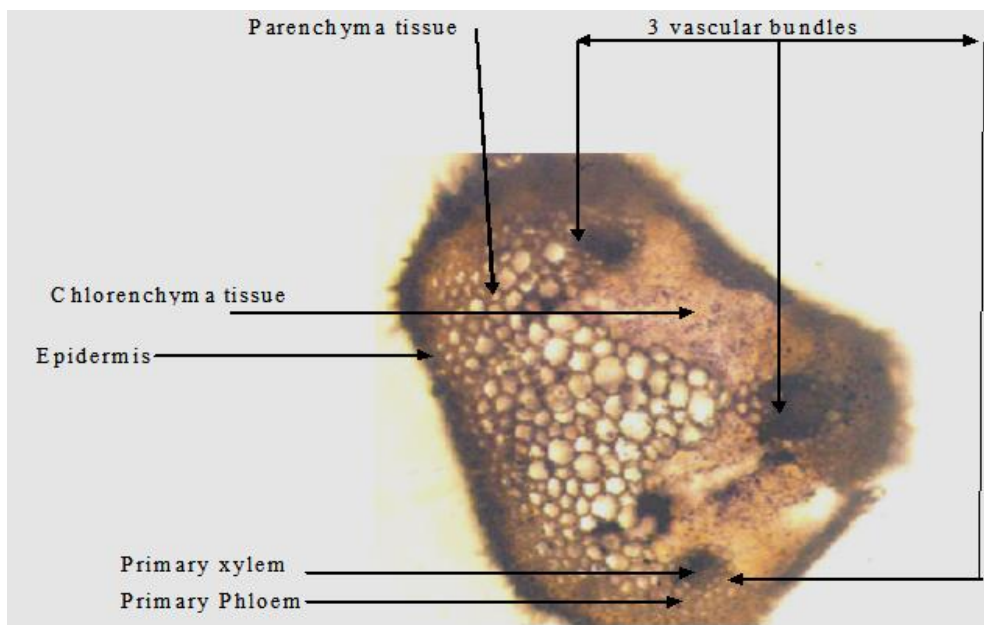


Fig. 5. Transverse section of durum wheat awns

With a high number of strands by awns (on average, 60 strands), the number of conductor elements reaches 180 or more by awn. This tissue could play a major role in the photosynthetic activity after the heading stage.

3.6 Grains yield and its components

Yield components such as the number of grains by ear (NGE), the grains weight by ear (WGE), and the thousand-grain weight (WTG) largely determine the final grains yield. Results showed that the two Tunisian varieties, particularly Razzak, give the most elevated yield in irrigated and water deficit conditions Table 6.

Table 6. Durum wheat yield and its components variation according to varieties (V) and water regime (WR) under control treatment T1 (all leaves and awns maintained intact)

	INRAT 69		Razzak		Duriac	
	I	NI	I	NI	I	NI
NGE	40.799	31.964	41.466	33.532	45.644	42.714

WGE (g)	2.2586	1.506	2.6803	1.9451	2.1556	1.666
WTG (g)	54.9519	48.014	58.1767	51.6477	50.3023	44.224
Yield: kg/m	0.758	0.492	1.142	0.643	0.698	0.465

I: irrigated, NI: not irrigated, LSD: the least significant difference. LSD (V) NGE = 2.10; LSD (T1) WGE = 0.36; LSD (V) WTG = 2.11; LSD (T1) WTG = 1.04; LSD (V) Yield = 0.25; LSD (T1) Yield = 0.36

This study showed that the French variety was characterized by the most elevated NGE in the different culture conditions but with small grains.

The grain weight by ear (WGE) and the thousand-grain weight (WTG) of the Razzak variety were superior to the other varieties in different water conditions. Producing the most voluminous grains, this variety gave the most elevated yield despite the weakest NGE. The transfer of assimilating and grain filling seems to be more efficient for this variety in irrigated and underwater constraints.

3.7 Effect of awns removal on yield components

Treatments T2 and T3 were applied to avoid compensation by the leaves of the yield decrease due to the absence of awns. Results of awns removal are presented in Table 7. Despite the weak role of these organs in the determination of NGE, their role was more important in water deficit conditions than in irrigation conditions, especially for the two varieties INRAT69 and Duriac.

Table 7. Yield components reduction in % in the absence of awns (Difference between T2 and T3)

	INRAT69		Razzak		Duriac		Average
	I	NI	I	NI	I	NI	
NGE	3.65	6.47	1.83	3.79	2.47	3.39	4.06
WGE	9.73	14.65	19.38	21.15	9.75	19.41	15.67
WTG	12.32	13.10	13.5	19.93	15.48	21.36	15.94

I: irrigated; NI: not irrigated; T2: excision of all leaves whereas awns maintained intact; T3: excision of all leaves and awns. NGE: number of grains by ear, WGE: grains weight by ear, WTG: thousand-grain weight

4. Discussion

Results showed that yield components varied from one variety to another and between water treatments. How to explain this variation in relation to awns, and what is the role of this organ in the resistance to water constraint? The durum wheat awn is a fibrous extension of the lemma of the florets which contributes to grain dispersal and burial and fends off animal predators [20]. Awns also play a dominant role as important transpiration and photosynthetic organs in the ear [21]. It is important to indicate that works interesting in awns, particularly anatomical studies, were not numerous. The ear of cereals makes an important contribution to grain yield, but the mechanisms ensuring this phenomenon are not completely elucidated [22]. In different wheat varieties, awns have up to 50% of the total stomata in the spike [23]. Our study showed that water constraint increased awns' stomatal density. This increase was due to a reduction of epidermal cell volume and/or to the elevation of stomata number and the reduction of their size. However, an increase in stomata number by area unit could be considered an excellent factor of tolerance to water deficit if it was related to a good physiological activity. The raise of stomatal density can improve CO₂ assimilation and decrease water loss. Indeed, an elevated number of stomata can generate small-size stomata with a fast closing. Because awns are located at the top of the canopy where light is abundant, they are suitable for light interception and CO₂ uptake [16] and they can intercept up to a third of incident light [24]. So, awns could improve yield in drought conditions by increasing the photosynthetic area of the ear. This could explain the high yield and the voluminous grains obtained in the two Tunisian varieties, particularly the Razzak variety, which had the most elevated stomatal density.

The anatomical study also showed that the structure of the awn blade is similar to that of the stem: reduced cortex, developed pith xylem, and phloem superimposed. Belonging to the class of Liliopsidae (monocotyledons), the structure of the awn blade is similar to that of a Magnoliopsidae stem (dicot): the vascular bundles are in small numbers and arranged in one circle: monocyclic (polycyclic arrangement for monocot stem). Awn wheat possesses xeromorphic features, such as a thick epidermis, cuticles, and high conductive tissues, providing water-use efficiency, especially under water shortage [25].

Our results showed the presence of three conducting elements in every awns element. These results permitted us to examine the relationship between awns and grains. Thus, photosynthate produced in awns will be transferred easily toward grains. The direct vascular linkage between the awns and the lemma should permit direct carbon movement to the developing grain [9]. Because the awn is the nearest source of assimilates to grains and due to the high number of strands (50 to 70 strands/ear) and the presence of stomata, the conducting tissue of the awn can play an important role in supplying assimilates to grains. With a higher photosynthetic contribution, awns play a major role in providing assimilates for grain filling in wheat [26]. Thus, these hypotheses could explain the importance of awns at the awned wheat species in the regions characterized by elevated temperatures and weak precipitation. On the contrary, awnless wheat produced significantly more grains per unit area and per spike, resulting in a significant reduction in grain size [27]. In some conditions, the leaves are already senescent or heavily shaded, particularly the flag leaf; the awn can contribute significantly to photosynthesis. The quantity and duration of green biomass at the end of the culture stage, such as ear and flag leaf, contributed to grain filling [28]. Compared to the flag leaf, ear photosynthesis exhibits higher

water stress tolerance [13]. This organ is an important photosynthetic organ on spike [29], and it can improve grain yield in drought conditions by increasing the photosynthetic ear area. Sanchez-Bragado et al. [30] showed that the rate of photosynthesis decreased much earlier in flag leaves than in awns, and the activity of the PEP Case was much higher in awns than in flag leaves, particularly at the late stages of grain filling.

The presence of hairs on the awns can play an important role in the water supply of the grains from atmospheric humidity. These hairs can protect the awns by reducing water loss caused by wind and high temperatures. We also know that the period between March and May is characterized by high atmospheric humidity at night and low humidity and high temperature during the day. Thus, hair could play two roles: absorbing water at night and protecting against water loss during the day. Awns can help the ear maintain high water use efficiency during the grain filling period. They potentially impact plant performance through carbon accumulation and remobilization and improved water-use efficiency [31]. This organ shows higher relative water content and better osmotic adjustment under water stress compared to the flag leaf [13].

The total length of the strands, 15 days after heading, represented between 60% and 98.54% of the final length. The awn growth reached its peak before the grain-filling period. The maximum growth of the root system (at the heading stage) and those of awns (before the grain filling stage) permitted an excellent orientation of the photosynthate towards the grains. Long awns are considered to be an important component trait of the high-yielding wheat ideotype, particularly for wheat grown under water-limited conditions [32]. Studies of the locus linked to the awns length QTL revealed the role of the awn and its chloroplasts in grain filling during abiotic stress [17].

For the most part, grain yield is determined by grain number and weight [33]. Our results showed that the Razzak variety, giving the highest yield and the most voluminous grains, occupied the first place regarding chlorophyll content in awns. It was also found that the highest stomatal density characterizes this variety with the highest yield, WGE, and WTG. Water stress increased the stomatal density in the two Tunisian varieties, particularly in Razzak. Salma et al. [34] demonstrated that varieties with high stomatal density were more drought-resistant, giving the highest grain yield. The variation in yield component between varieties may be due to a genotypic variation in ear morphology linked to differences in photosynthetic potential [12].

Kolupaev et al. [13] showed that the contribution of the ear to the grain yield is unclear. However, our work showed that awns contributed weakly to determining the ear number grains (4.06%) since this component is determined between the end of the tillering and the beginning of the elongation stage. Meanwhile, the role of awns was more critical in grain filling and contributed to 15.67% of the ear-weight grains and 15.94% of the thousand grains weight. So, awn could be represented as a major contributor to grain filling in durum wheat. Awn cells are responsible for several functions, such as developing the seed grain [16]. Otherwise, the reduction of WGE and WTG in the absence of awns was more accentuated in water-limited conditions than in favorable conditions. So, awns play a more important role in grains filling in the presence of water deficit. These results denote the importance of awns in the presence of drought. Ear photosynthesis is less affected by water deficit than assimilation in the flag leaves [8]. Awns' better performance under water stress than leaves was due to good water status and higher expression of key genes for drought-stress responses [35]. Because of their xerophytic character, this result can be

explained by the better resistance to drying of chlorophyllin awns part. A more important role of the ear can be explained by the fact that the flag leaf becomes more quickly senescent, the remobilization of assimilates, and the stem photosynthesis becomes weak [36]. Tambussi et al. [37] showed a significant reduction of stomatal conductance of flag leaf at the post-anthesis stage compared to the earlier developmental stages. The spike exhibited a stable net photosynthetic rate and chlorophyll content, a lower accumulation of reactive oxygen species, and more enhanced percentages of antioxidant enzyme activities [38].

The results obtained in our work illustrate the important role played by awns in the elaboration of grain yield. These results are in accordance with those of [12], which demonstrated that the awned phenotype contributes to slightly greater economic or harvestable yield through larger kernels and improved grain quality. Awns are mainly useful under terminal drought conditions, owing to their elevated water stress tolerance that facilitates the maintenance of grain weight and a reduced number of shriveled grains compared with awnless lines [7]. It is to be noted that this organ can escape some cryptogamic diseases that attack durum wheat culture. In the case of the flag leaf being affected by yellowing produced by rust (*Puccinia triticina*), the presence of awns partially compensated for the loss of grain yield [39].

5. Conclusions

The study aimed to investigate the role of awns of the durum wheat (*Triticum durum* Desf.) plant in the yield contribution. We have demonstrated that:

1. Awns play a significant role in elaborating grain yield in durum wheat, mainly underwater constraints. This part of the durum wheat plant

- significantly increased grain weight (grain filling) more than the number of grains.
2. Awned varieties are more suitable in water deficit conditions than awnless ones.
 3. Awns strand presented stomata and vascular bundles, indicating that awns photosynthates will be transferred easily and rapidly to grains compared to leaves.
 4. The highest grain yield was obtained in the variety that had good awns features (the most developed awns area, the high stomata density, and the high chlorophyll content), principally under deficit water conditions.
 5. Thus, this study accentuated the protection interest of durum wheat culture against the end-cycle diseases that can attack awns and flag leaves.
 6. It is important to identify QTLs associated with the weight grain in durum wheat awns to improve grain yield under water constraints and to select genes that control this organ's development in awnless species' breeding programs.

Acknowledgment

The authors thank all staff of the Plant Physiology Laboratory of INRAT.

Conflict of interest

The authors declare no conflict of interest.

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