Assessment of biological and agronomic diversity of seven durum wheat varieties cultivated in the Northeastern region of Algeria

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Abstract. Boudersa N, Chaib G, Atoui A, Cherfia R, Bouderbane H, Boudour L. 2021. Assessment of biological and agronomic diversity of seven durum wheat varieties cultivated in the Northeastern region of Algeria. Biodiversitas 22: 1025-1036. The present work was carried out during the 2017/2018 agricultural season, at the experimental station of the ‘Institut Technique des Grandes Cultures’ (ITGC) – El Khroub, Constantine, Algeria. The main objective of this study was the evaluation and the characterization of seven varieties of durum wheat (Triticum durum Desf.) in terms of their behavior and yield. For these reasons, several phenological, morpho-physiological, and biochemical traits, as well as the yield with its components were studied. The obtained results showed a significant variety effect, in particular, for the variables corresponding to the production and to the tolerance. The analysis of the correlation coefficients indicated that the number of spikes per m², the number of grains spike−1, and the rate of chlorophyll pigments in the leaves were the most related characteristics to grain yield. Indirect selection for breeding productivity through these traits could prove to be effective. Besides, it revealed that tall varieties displayed better resistance to possible hazards; had high relative water content (RWC), accumulated more soluble sugars and proline, as well as, they showed a low level of Malondialdehyde (MDA) compared to other varieties. In addition, this study allowed us to determine many relationships between the studied parameters, that can make a contribution in both the productivity and the adaptation improvement programs of the durum wheat.

Keywords: Characterization, correlation, diversity, productivity and adaptability, Triticum durum

INTRODUCTION

Triticum durum Desf. is one of the most essential cereals that are cultivated worldwide on almost 17 million hectares (ha), with a global production of 38.1 million tonnes in 2019 (Xynias et al. 2020). In Algeria, durum wheat is the first cultivated cereal; it occupies 45% of the area designated for cereals, or 1.6 Mha (ONFA 2017). However, its production is still insignificant, it covers only 20 to 25% of the needs of an increasingly growing population, and the rest being imported (Chehili et al. 2017). This low production is often explained by the fact that the majority of the area sown to durum wheat is located on the high plains, where the rainfall and the temperatures are subjected to large intra and inter-annual variations, often combined with frequent spring frosts and the appearance of sirocco at the grain filling stage; which seriously affect the yields (Benniou et al. 2018). Indeed, this situation can only be unblocked by a real and an effective increase in yields through the application of better management of both adapted technical pathways (soil preparation, date and dose of sowing, irrigation, fertilization, weed control, and disease control), and genetic improvement allowing to create adapted varieties to environmental conditions of cultivation.

The goal of genetic improvement in wheat has always been to increase productivity. Whereby, the success of this strategy is linked to the existence of favorable environmental conditions, which allow the expression of the different factors of the yield (Ghennai et al. 2017). For this reason, the study and the characterization of genetic resources to create new varieties with good quality, high yield, adapted to climatic variations, and resistance to diseases are essential (Amallah et al. 2016). Besides, these steps also make it possible to estimate the existing diversity in the studied material, and they are considered as a starting point for their use in breeding programs (Khennaoui 2018). Thus, this research requires studying, identifying, and verifying the phenological, morpho-physiological, and biochemical characteristics related to the yield. Therefore, a good understanding of all of these aspects during the life cycle of the plant and a well comprehension of the main links between the grain yield and these components can be useful in the identification and the selection of the interest traits. Indeed, several agricultural studies have confirmed that this information is used to guide the selection process in order to improve the characteristics capable of obtaining better performance (Aghaee et al. 2010; Zarkti et al. 2012; Sahri et al. 2014).

The current study had two main objectives: (i) Evaluation of the variability of seven varieties of durum wheat, using measurements of agro-morpho-physiological and biochemical characters. (ii) Analyzing and highlighting the different links recorded between the studied parameters...
in order to improve our knowledge about the extraction of the most discriminating and important traits that may be useful for the classification and the characterization of durum wheat varieties. This study, also, allowed us to identify the most interesting and relevant varieties that would largely be behind the choice of adapted genotypes to the unfortunate conditions.

**MATERIALS AND METHODS**

**Plant material**

This study has focused on seven varieties of durum wheat (*Triticum durum* Desf.) mostly cultivated in the region of northeastern Algeria. The grains were supplied by the ‘Institut Technique des Grandes Cultures’ (ITGC) of Constantine, Algeria. The name, the pedigree, and the origin of the varieties are shown in Table 1.

**Location of the experiment**

The experiment was conducted on the ITGC site of El Khroub, Constantine, Algeria at an altitude of 640 m, a latitude of 36.25° North and a longitude of 6.67° East (Figure 1). The site soil has a slimy-clayey texture, with a dry condition, a depth of 120 cm, and a flat topography. The bioclimatic stage of the site is semi-arid, characterized by a Mediterranean climate and an average annual rainfall of 450 mm over 25 years.

**Physicochemical characteristics of the soil in the experimental area**

Soil analysis was regularly carried out by the ITGC laboratory. The results are shown in Table 2.

**Test setting up**

The test was carried out during the 2017/2018 agricultural campaign. The sowing was carried out on January 03rd, 2018. A manual sowing was carried out at a regular depth of 4 ± 1 cm by distributing the grains in a regular manner along parallels lines.

The adopted experimental device is a simple device, which consists in distributing the plots CÔTE to CÔTE. Each five meters long by 1.2 meters wide and comprising six lines 20 cm apart from each other; i.e. an area of 6 m², the distance between plots is 50 cm. Each elementary plot receives a unique treatment at a density of 250 seeds/m² (Table 3).

**Climatic characteristics of the experimental site**

The observed characteristics in the region are notably the rainfall and the temperature (Table 4). These two factors have an important effect on the development of cereals. According to Table 4, the cumulative rainfall was generally good with an annual cumulative rainfall of 550 mm. This year was characterized by fairly rainy autumn which allows adequate preparation of the seedbeds. The winter period was marked by relatively average rainfall, which allowed a good start to the crop. The spring was fairly well moist with a suitable beneficial distribution for the development and the formation of crop yield components. Temperatures were mild during this campaign.

**Table 1. Name, pedigree, and origin of the used varieties**

| Variety | Pedigree | Origin |
|---------|----------|--------|
| Waha    | Plc/Ruff/Gta’s/3/Rolette CM 17904 | Syria, Algeria |
| Cirta   | KB214-0KB-20KB-OKB-1KB-0KB | Algeria |
| Wahbi   | KB86022-1KB0KB-2KB-2KB0KB | Algeria |
| Bousslem| Heider/Martes/Huevos d’Oro. ICD-414 | Algeria |
| Semito  | Capeiti8/Valvona | Italy |
| GTA dur | Crane4/PolonicumPI185309/T.glutin en/2* Tc60/3/Gli | Mexico, Algeria |
| Vitron  | Turkey77/3/Jori/Anhinga/Flamingo | Spain |

Figure 1. Geographical location of the study area
Table 2. Physicochemical characteristics of the soil

| Characteristic             | Depth (cm) | 0-30 | 30-60 | 60-90 |
|----------------------------|------------|------|-------|-------|
| Clay (%)                   |            | 55   | 44    | 60    |
| Fine silt (%)              |            | 29   | 3     | 6     |
| Coarse silt (%)            |            | 1    | 3     | 4     |
| Fine sand (%)              |            | 11   | 11    | 18    |
| Coarse sand (%)            |            | 3    | 3     | 13    |
| Organic matter (%)         |            | 1.49 | 1.45  | 1.37  |
| pH                         |            | 7.6  | 7.6   | 7.9   |
| Electrical conductivity (mS/cm) |          | 0.5  | 1.7   | 0.6   |
| Real density (g/cm³)       |            | 2.2  | 2.2   | 2.2   |

Table 3. Main characteristics of the test during the campaign

| Characteristics of the tests | Dates, tools, and used doses |
|------------------------------|------------------------------|
| Previous cultivation         | Lentil cultivation.          |
| Plowing                      | Carried out at the end of September at a depth of 35 cm with a plowshare. |
| Cross-crossing               | 1st passway October 15th, 2017; 2nd passway October 22nd, 2017 with a Cover crop. |
| In-depth fertilization       | 100 kg ha⁻¹ of MAP (12% N, 52% P) on 21/11/2017 and the 3rd Cover crop pass way on 12/11/2017. |
| Installation date of the sowing | On 03/01/2018. |
| Seeding rate (Dose)          | 250 seeds/m². |
| Nitrogen fertilization       | 1st dose: Urea 46% dose 0.7 Qt/ha on 02/28/2018. |
|                              | 2nd dose: Urea 46% dose 0.7 Qt/ha on 04/04/2018. |
| Chemical weed control        | Zoom (anti dicotyledon) and Akopik (anti Gramineae) on 03/05/2018; |
|                              | Dose : 0.25 L ha⁻¹ Akopik + 120 g ha⁻¹ zoom. |

Measured parameters

Several agro-morphological, physiological and biochemical parameters were evaluated: the duration of heading (DH) expressed in days from the sowing to the stage of the appearance of the outlines of the spikes. To determine the period of heading, it should be mentioned the date when 50% of the spikes of the elementary plot emerged from the sheath of the last leaf. The height of the plant (HP, cm), the area of flag leaf (AFL, cm²), the length of the spike (LS, cm), beards not included, the length of the spike peduncle (LSP, cm), the length of beards (LB, cm), the number of herbaceous tillers (Nb HT), the number of spike tillers (Nb ST), the grain yield (GY, t ha⁻¹); and these components including the number of spikes per square meter (Nb S/m²), the number of grains per spike (Nb G/S) and the weight of thousand grains (WTG, g). The relative water content (RWC, %) was determined by the method of Barrs (1968), the determination of chlorophyllian and carotenoid pigments Chl (a), Chl (b), Chl (t), Car (μg.ml⁻¹/FM) was established according to the method of Lichtenhaler (1987). The determination of proline (Pro, mg g⁻¹ FM) was carried out according to Troll and Lindsey (1955), the determination of soluble sugars (Ss, mg g⁻¹ FM) was performed by the method of (Dubois et al. 1956), and the determination of malondialdehyde (MDA, nmol g⁻¹ FM) was realized according to the method of (Ksouri et al. 2007).

Data processing

The obtained results were analyzed using the statistical program SPSS v.25. Statistical treatments included the correlations, the analysis of variance, the principal component analysis (PCA), as well as the ascending hierarchical classification (AHC).

RESULTS AND DISCUSSION

Results analysis

In light of the results presented in Table 5, the heading duration recorded for each variety, Wahbi and Vitron were characterized by a short duration of 118 days. Wahbi, Semito, and GTA dur recorded a two-day longer period (+2 days) than the two previous varieties (120 days). Bousselem was characterized by duration of 122 days, while Cirta was distinguished by the longest heading duration, 124 days.

For the yields (Y) results, they varied between 3.32 ± 0.16 and 5.46 ± 0.2 t ha⁻¹, the maximum value of 5.46 ± 0.22 t ha⁻¹ was observed in GTA dur, while the minimum value of 3.32 ± 0.16 t ha⁻¹ was noted in Wahbi.

The values of the WTG ranged between 40.61 ± 0.51 and 47.33 ± 0.20 g. The highest value of 47.33 ± 0.20 g was obtained in Cirta, whilst, the low value of 40.61 ± 0.51 g was recorded in the Wahbi variety.

The Nb S/m² was very variable, The highest value of 265.00 ± 1.73 S/m² was observed in GTA dur. However, the lowest value of 200.00 ± 5.29 S/m² has been observed in Wahbi.

Table 4. Climatic data recorded during the campaign

| Month factors       | Sep | Oct | Nov | Dec | Jan | Fab | Mar | Apr | May | Jun | Total |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Precipitation (mm)  | 33  | 18.5| 120.70| 62.50| 28.40| 45.00| 115.60| 54.30| 59.10| 12.90| 550   |
| Temperature average (°C) | 24.35| 18.79| 12.40| 09.21| 07.49| 07.40| 09.71| 11.15| 13.53| 17.72| -     |
For the Nb G/S, the greatest value 44.40 ± 1.44 G/S has been registered by GTA dur. While the lower value of 36.00 ± 1.00 G/S was showed in Cirta variety. The Nb ST, it was found that the highest value of 3.200 ± 0.26 tillers plant⁻¹ was observed in the variety GTA dur and the lowest value 2.00 ± 0.72 tillers plant⁻¹ was detected in the variety Wahbi. Furthermore, a similarity for the Nb HT equal to 4.00 ± 1.00 cm was detected in the variety Bousselem variety whereas, the lowest estimated value of 1.54 ± 0.08 cm was obtained in GTA dur. While the longest beard 17.50 ± 0.20 cm ranged between 13.80 ± 0.20 and 17.50 ± 0.20 cm, the lowest height equal to 81.40 ± 1.15 cm was recorded in the variety Vitron, however, the highest height 92.50 ± 0.44 cm was noted in the variety Wahbi. The lowest height equal to 81.40 ± 1.15 and 92.50 ± 0.44 cm. The highest height varies depending on the variety.

Regarding the morphological traits assessed, the HP varied depending on the variety. It fluctuates between 29.14 ± 2.85 and 38.55 ± 0.21 cm². The largest area 38.55 ± 0.21 cm² was showed in GTA dur, while the smallest area of 29.14 ± 2.85 cm² was recorded in Vitron variety.

The obtained results of the LSP showed that the longest peduncle 35.60 ± 0.36 cm was recorded in the variety Bossemle while the shortest was observed in the variety Waha with 17.00 ± 0.30 cm. For the LB, the values recorded for this parameter ranged between 13.80 ± 0.20 and 17.50 ± 0.20 cm, the longest beard 17.50 ± 0.20 cm distinguished the GTA dur variety while the shortest beard was recorded by Waha 13.80 ± 0.20 cm.

The LS values varied from 5.50 ± 0.44 and 7.00 ± 0.30 cm, the longest spike 7.00 ± 0.30 cm was obtained in GTA dur variety, however, the shortest estimated at 5.50 ± 0.44 cm was detected in Bossemle.

At the physiological level, the RWC oscillated between 62.34 ± 8.63 and 93.88 ± 4.16%. The maximum value was recorded in Waha, in contrast, the minimum value was noted in Cirta. For the chlorophyll pigments; Chl (a), Chl (b), Chl (t) and Car; GTA dur recorded the best performing values (169.94 ± 14.99; 92.27 ± 4.57; 262.22 ± 19.45 and 52.33 ± 2.53 μg ml⁻¹/FM) unlike, Cirta revealed the lowest values (115.43 ± 3.48; 90.23 ± 2.61; 205.66 ± 5.92 and 23.84 ± 5.75 μg ml⁻¹/FM).

The determination of the Ss revealed that Wahbi has accumulated greatest amount 0.87 ± 0.04 mg g⁻¹ FM while the lowest concentration 0.25 ± 0.07 mg g⁻¹ FM was recorded in Cirta leaves.

Table 5. Variables average values measured in the studied varieties (n = 3)

| Varieties parameters | Waha  | Cirta  | Wahbi  | Bossemle | Semito  | GTA dur | Vitron  |
|----------------------|-------|-------|--------|----------|---------|---------|---------|
| RWC                  | 79.88±4.61 | 62.34±8.63 | 93.88±4.16 | 69.90±2.16 | 87.42±3.87 | 71.02±0.22 | 83.04±5.70 |
| Chl a                | 119.37±7.64 | 115.43±3.48 | 69.69±1.85 | 137.58±2.94 | 135.46±10.67 | 169.94±14.99 | 132.90±5.34 |
| Chl b                | 90.78±2.19 | 90.23±2.61 | 90.70±0.32 | 91.84±9.56 | 91.79±0.14 | 92.27±4.57 | 90.92±4.29 |
| Chl t                | 210.15±9.69 | 205.66±5.92 | 209.40±8.69 | 229.42±10.50 | 227.25±9.65 | 262.22±19.45 | 223.82±5.08 |
| Car                  | 40.06±3.11 | 23.84±5.75 | 40.02±1.84 | 50.91±4.23 | 44.23±1.93 | 52.33±2.53 | 42.12±5.50 |
| Pro                  | 0.49±0.13 | 0.25±0.07 | 0.97±0.06 | 0.36±0.02 | 0.75±0.04 | 0.44±0.07 | 0.53±0.05 |
| Ss                   | 0.65±0.06 | 0.54±0.03 | 0.87±0.04 | 0.87±0.01 | 0.73±0.01 | 0.42±0.09 | 0.49±0.03 |
| MDA                  | 1.82±0.01 | 2.46±0.23 | 1.74±0.07 | 1.85±0.01 | 1.78±0.02 | 1.54±0.08 | 1.81±0.06 |
| AFL                  | 35.36±0.59 | 31.56±0.90 | 31.30±0.76 | 36.77±0.37 | 31.40±0.49 | 38.55±0.21 | 29.14±2.85 |
| PH                   | 90.80±0.44 | 81.40±1.15 | 92.50±0.44 | 86.00±1.32 | 92.30±2.35 | 81.44±0.59 | 91.77±1.70 |
| Nb HT                 | 4.00±1.00 | 4.00±1.00 | 4.00±1.00 | 5.00±0.00 | 4.00±0.00 | 4.00±1.00 | 4.00±1.00 |
| Nb ST                 | 2.90±0.17 | 2.40±0.10 | 2.20±0.72 | 3.00±0.00 | 2.90±0.10 | 3.20±0.26 | 3.10±0.17 |
| LS                   | 6.80±0.26 | 6.30±0.35 | 6.20±0.26 | 5.50±0.44 | 5.80±0.72 | 7.00±0.30 | 6.50±0.70 |
| LSP                  | 17.00±0.30 | 24.00±2.00 | 17.50±0.50 | 35.60±0.36 | 20.00±1.80 | 30.33±0.21 | 23.10±1.05 |
| LB                   | 13.80±0.20 | 15.37±0.25 | 14.16±0.31 | 16.20±0.26 | 14.20±0.44 | 17.50±0.20 | 14.20±0.36 |
| Nb G/S               | 41.40±1.97 | 36.00±1.00 | 39.40±1.22 | 42.30±2.07 | 40.10±2.15 | 44.40±1.44 | 43.40±1.44 |
| Nb S/m²              | 239.33±2.00 | 220.00±5.29 | 200.00±2.00 | 237.00±6.24 | 230.00±2.00 | 265.00±1.73 | 240.00±2.00 |
| WTG                  | 40.61±0.51 | 47.33±0.20 | 42.18±0.38 | 45.27±0.43 | 43.97±0.09 | 45.48±0.22 | 45.17±0.11 |
| HD                   | 118.00 | 124.00 | 120.00 | 122.00 | 120.00 | 120.00 | 118.00 |
| GY                   | 4.02±0.14 | 3.74±0.08 | 3.32±0.16 | 4.53±0.20 | 4.05±0.23 | 5.46±0.22 | 4.70±0.14 |
Axis 02 (vertical axis) is denoted by the strong contribution of DH and MDA on the negative side; while on the positive side of this axis the HP, RWC, and Pro are found at the same time. This axis can be qualified as a component of precocity, at heading stage, and of tolerance.

The graphical representation of the seven varieties (Figure 3) makes it possible to distinguish that: GTA dur was characterized by high values of the following variables: GY, Nb S/m², Nb ST, Nb G/S, Chl (a), Chl (t), Car, AFL, LS, and LB. However, this variety is distinguished by a short straw and a slight build-up of Pro, Ss, and MDA. In contrast, on the negative side, is Wahbi, which performed less well on the previous variables, this variety stands out for a higher HP, a high RWC and a strong accumulation of Pro and Ss. The variety Cirta was characterized by the lowest average values of all of the following variables: the content of chlorophyll pigments, HP, RWC and Pro and a late heading, while it has accumulated the greatest amount of MDA and it has the highest WTG. Bousselem was characterized by a dense herbaceous tillering, a short spike with a long peduncle, and also a relatively late heading. Moreover, Waha was distinguished by an early heading, a short peduncle and a barbecue and the lowest WTG. Vitron was distinguished by its narrowest AFL, short duration of heading. For Semito, this variety includes average values of all the studied variables.

PCA made it possible to organize phenotypic diversity among our seven varieties into four distinct groups according to the productivity, which proves that the studied varieties did not behave in the same way according to the climatic conditions of the agricultural year 2017/2018, which were more or less favorable to good agriculture.

Group 1 = GTA dur.
Group 2 = Vitron and Bousselem.
Group 3 = Cirta, Waha and Semito.
Group 4 = Wahbi.

Figure 2. Correlations graph of 20 analyzed parameters

Figure 3. Distribution of varieties in function of two principal components
To corroborate these results, a one-factor ANOVA analysis was carried out (Table 6). This test is limited to the parameter which discriminates the best-studied varieties, namely the GY (see Table 8). The test of homogeneity of the variances gave a Levene statistic of 0.449 (Sig. = 0.834) which expresses equality of the seven varieties variances.

The observed F value of 46.764 (Sig. = 0.000) indicates that the seven varieties do not have the same behavior in terms of production. The post hoc test of Newman-keuls revealed the existence of four groups (Table 6): the $1^{st}$ group consisted of the variety GTA dur, the $2^{nd}$ group was formed by the grouping of the three varieties Cirta, Waha and Semito, the $3^{rd}$ group included the two varieties Bousselem and Vitron, as well as the $4^{th}$ group consisted of the variety Wahbi.

Figure 4 shows that the distribution of varieties differs significantly in terms of productivity. Indeed, GTA dur was characterized by the highest average yield with $5.46 \pm 0.22$ t ha$^{-1}$, followed by the $2^{nd}$ group that made up of two varieties Vitron and Bousselem which stood out with average yields of $4.70 \pm 0.14$, and of $4.53 \pm 0.20$ t ha$^{-1}$, respectively. Semito, Waha and Cirta form the $3^{rd}$ group that was characterized by almost similar averages of $4.02 \pm 0.23$, of $4.05 \pm 0.14$ and of $3.74 \pm 0.08$ t ha$^{-1}$, consecutively. Besides, Wahbi variety comes in the bottom of the classification with the lowest grain yield of $3.32 \pm 0.16$ t ha$^{-1}$.

**Cluster analysis**

The analysis of the hierarchical classification results made it possible to clarify the differences that exist between the different varieties based on the measured parameters (Figure 5).

The first group is represented by GTA dur and Bousselem varieties. They are the most profitable varieties given the higher or lower values of the yield and its components. These varieties seem to be well adapted to the environmental conditions, recording the highest values in terms of chlorophyll pigment content in the leaves, a large AFL and a long spike peduncle.

The second group includes the varieties Waha, Cirta, Semito and Vitron that showed average values of the different studied parameters. The third group is formed by the only Wahbi variety that presents a certain dissimilarity compared to the other varieties. It is distinguished by the least efficient production characters, as it is tolerant giving the high values of HP, RWC and of the rate of osmo-regulators that it has displayed.

### Table 6. Homogeneous groups according to the Student-Newman-Keuls test

| Varieties | Sub-division for $\alpha = 0.05$ |
|-----------|----------------------------------|
|           |                                 |
| Wahbi     |                                 |
| Cirta     |                   33.245$a$        |
| Waha      |                   37.481$b$        |
| Semito    |                   40.228$b$        |
| Bousselem |                   40.563$b$        |
| Vitron    |                   45.370$c$        |
| GTA dur   |                   47.052$c$        |
| Signification |               0.122        |
|           |                                |
|           |                                |

Note: a, b, c and d indicate the homogeneous groups

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**Figure 4**. Graphical comparison of grain yield (GY) averages
Discussion

In the present work, seven varieties of durum wheat were evaluated on the basis of numerous agromorphological, physiological and biochemical traits in order to extract the most useful traits that can be used by breeders in a breeding program. The results showed an important diversity between the studied varieties which would be attributed to the genetic heritage of each variety as well as to the environment in which they were regenerated.

The phenological monitoring results revealed that the duration between the sowing and the heading of the different studied varieties varied from 118 to 124 days. Couvreur (1985) reported that the earliness of a variety is determined from the duration length of the development cycle from the sowing to the heading stage. According to this author, a variety is considered early if the duration is less than 100 days; it is semi-early if the duration is between 100 and 120 days, and tardy if this duration exceeds 120 days. On this basis, our varieties can be classified into two groups: the semi-early group including Waha, Vitron, Wahbi, Semito, as well GTA and the 2nd is tardy group comprising the two varieties Bousselem, and Cirta. On the other hand, it appears that the GY has represented the most discriminating characteristic between the studied varieties.

According to Kara and Bellkhiri (2011) annual variations in climatic conditions make the selection based solely on the yield is difficult. The results of several studies exhibited that the grain yield is very variable, polygenic and the most often subject to strong genotype by environment (G × E) interactions (Bennahammed et al. 2010; Sanchez-Garcia et al. 2012; Semcheddine et al. 2017). For this reason, breeders often use the indirect selection and the traits that are well correlated with the yield to improve grain yields in dry environments (Sallam et al. 2014). However, the principal components analysis (PCA) makes it possible to highlight the different correlations between the measured variables, ranging from a weak to a strong correlation. The study of these relations and their good understanding are interesting for the breeder who seeks to identify the effect of the characters, easily measurable very early in the development cycle of the plant (DH, HP, AFL, LSP, LB, LS, RWC, Pro, Ss, MDA, etc.), on more complex characteristics such as Nb G/S, WTG, and Yield, that are measured at the harvesting stage by destructive and relatively less precise methods (Kirouan et al. 2019). The correlation matrix (Table 7) displays that the DH is negatively correlated with the Nb S/m² (r = -0.276), the Nb G/S (r = -0.637), and the Yield (r = -0.213). This means that more or less early growth gives a high Nb S/m² as well as a big Nb G/S; which leads to a gain in grain yield of durum wheat. These results are in agreement with those observed by Mansouri et al. (2018). Similarly, Chennafi et al. (2010) found in their work that cultivars with early headings are more productive than those characterized by tardy heading. Chentoufi et al. (2014) considered that the earliness at the heading stage and that at maturity as important selection criteria, are parameters of tolerance and adaptation to climatic constraints.

Considering the random distribution of precipitation in arid to semi-arid regions, the adoption of relatively short-cycle varieties is necessary, this biological mechanism is a desirable feature and could be quantified as evasion since early genotypes can accomplish their cycle through avoiding also terminal drought (Megherbi et al. 2012). Nevertheless, the increase in the earliness of cereals, although it has given undeniable results, is not without drawbacks, it contributes, among other things, to the reduction of productivity and is only suitable for late drought and short duration (Melki and Dahmane 2008). Slafer et al. (2005) demonstrated that, in the absence of stress, the late genotypes are generally more productive than early ones. This is due to the fact that the early genotypes make less use of the availabilities offered by the production medium.

Figure 5. Ascending hierarchical classification (AHC) of studied durum wheat varieties based on the measured parameters.
### Table 7. Correlation coefficients matrix of the various analyzed variables

|       | RWC   | Chl a | Chl b | Chl T  | Car  | Pro  | Ss   | MDA  | AFL  | PH   | Nb HT | Nb ST | LS   | LSP  | LB   | Nb G/S | Nb S/m² | WTG  | D H  | GY  |
|-------|-------|-------|-------|--------|------|------|------|------|------|------|-------|-------|------|------|------|--------|---------|------|------|-----|
| RWC   | 1.000 |       |       |        |      |      |      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Chl a | -0.202| 1.000 |       |        |      |      |      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Chl b | -0.042| 0.884 | 1.000 |        |      |      |      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Chl T | -0.197| 1.000 | 0.893 | 1.000  |      |      |      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Car   | 0.205 | 0.762 | 0.891 | 0.771 | 1.000|      |      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Pro   | 0.952 | -0.164| -0.008| -0.159| 0.174| 1.000|      |      |      |      |       |       |      |      |      |        |         |      |      |     |
| Ss    | 0.420 | -0.427| -0.029| -0.413| 0.123| 0.496| 1.000|      |      |      |       |       |      |      |      |        |         |      |      |     |
| MDA   | -0.536| -0.634| -0.693| -0.639| -0.881| -0.498| -0.062| 1.000|      |      |       |       |      |      |      |        |         |      |      |     |
| AFL   | -0.457| 0.612 | 0.627 | 0.615 | 0.576| -0.384| -0.053| -0.379| 1.000|      |       |       |      |      |      |        |         |      |      |     |
| HP    | 0.908 | -0.405| -0.172| -0.398| 0.106| 0.764 | 0.467 | -0.354| -0.548| 1.000|       |       |      |      |      |        |         |      |      |     |
| Nb HT | -0.333| 0.114 | 0.366 | 0.124 | 0.422| -0.321| 0.529 | -0.011| 0.425 | -0.178| 1.000 |      |      |      |      |        |         |      |      |     |
| Nb ST | -0.205| 0.725 | 0.706 | 0.728 | 0.69 | -0.375| -0.446| -0.507| 0.447 | -0.111| 0.220| 1.000|      |      |      |      |        |         |      |      |     |
| LS    | -0.079| 0.263 | -0.113| 0.249 | -0.059| -0.133| -0.755| -0.214| 0.205 | -0.215| -0.667| 0.203| 1.000|      |      |      |      |        |         |      |      |     |
| LSP   | -0.653| 0.606 | 0.594 | 0.608 | 0.481| -0.597| -0.074| -0.058| 0.586 | -0.648| 0.75 | 0.483 | -0.27| 1.000|      |      |      |      |        |         |      |      |     |
| LB    | -0.666| 0.769 | 0.612 | 0.766 | 0.413| -0.52 | -0.324| -0.14 | 0.727 | -0.846| 0.367| 0.375 | 0.118| 0.844| 1.000|      |      |      |      |        |         |      |      |     |
| Nb G/S| 0.124 | 0.743 | 0.694 | 0.745 | 0.872| -0.009| -0.255| -0.823| 0.459 | 0.085 | 0.204| 0.836 | 0.294| 0.394| 0.339| 1.000|      |      |      |      |        |         |      |      |     |
| Nb S/m²| -0.422| 0.807 | 0.666 | 0.805 | 0.577| -0.525| -0.640| -0.420| 0.628 | -0.414| 0.087| 0.921 | 0.45 | 0.516| 0.589| 0.752| 1.000|      |      |      |      |        |         |      |      |     |
| WTG   | -0.702| 0.418 | 0.202 | 0.412 | -0.100| -0.608| -0.491| 0.376 | 0.060 | -0.758| 0.157| 0.183 | -0.074| 0.668| 0.690 | -0.056| 0.308| 1.000|      |      |      |      |        |         |      |      |     |
| DH    | -0.659| -0.139| -0.13 | -0.139| -0.424| -0.452| 0.138 | 0.702 | 0.088 | -0.677| 0.354| -0.426| -0.442| 0.444| 0.443 | -0.637| -0.276| 0.640| 1.000|      |      |      |      |        |         |      |      |     |
| GY    | -0.379| 0.901 | 0.727 | 0.898 | 0.660| -0.449| -0.604| -0.478| 0.555 | -0.432| 0.17 | 0.889 | 0.354| 0.657| 0.698 | 0.815| 0.943| 0.464 | -0.213| 1.000|      |      |      |     |

### Table 8. Components’ matrix

|       | GY    | Chl a | Chl T | Nb S/m² | LB   | Chl b | Nb ST | LSP   | Nb G/S | AFL  | Car  | Ss   | Nb HT | LS   | D H  | RWC  | MDA  | HP   | Pro  | WTG  |
|-------|-------|-------|-------|---------|------|-------|-------|-------|--------|------|------|------|-------|------|------|------|------|------|------|------|
| Axe 1 | **0.960** | 0.932 | 0.932 | 0.906   | 0.83 | 0.821 | 0.818 | 0.769 | 0.751  | 0.732 | 0.715 | -0.448 | 0.322 | 0.235 | -0.046 | -0.457 | -0.475 | -0.543 | -0.462 | 0.472 |
| Axe 2 | 0.084 | 0.186 | 0.192 | 0.091  | -0.409| 0.311 | 0.283 | -0.413| 0.581  | -0.059| 0.58  | 0.188 | -0.225| 0.161 | -0.898| 0.85  | -0.844 | 0.777 | 0.732  | -0.698 |
However, wheat is generally cultivated in rainy conditions in the Mediterranean region which often imposes a certain number of environmental constraints on tardy varieties. The varietal selection based on the earliness must favor obtaining varieties with an earliness date of Heading, which varies from one year to another, should coincide with the optimum heading period. Obtaining optimum and stable productivity depends on obtaining this type of variety. To achieve this goal, this selection should relate to both the thermo-periodic and the photo-periodic requirements of the plant (Mekhlouf et al. 2006).

DH also has shown a positive correlation with WTG ($r = 0.640$). According to Samira et al. (2011), developmental delay allows the plant to accumulate energy and resources to combat stress, before the imbalance between the inside and the outside of the body increased to threshold where the damage will be irreversible. The link is explained by a greater accumulation of reserves; consequently, the grains are well filled. Similar results have been obtained in the work of Al-Doss et al. (2010) ($r = 0.370$).

The GY presents positive correlations with the components: Nb S/m² ($r = 0.943$), Nb G/S ($r = 0.815$), and WTG ($r = 0.464$). The varieties Bousselem, Vitron, and GATA dur gave the highest values for these traits and, therefore, they displayed the highest yields. These results are in agreement with several studies that showed that the yield is the result of several characters that contribute to its achievement (Kahrizi et al. 2010; Lopes et al. 2012; Farshadfar et al. 2013). In the light of these results, the best yields were observed due to the high Nb S/m² and to the high Nb G/S which are in agreement with those obtained by several researchers (Mazouz and Bouzerzour 2017; Kizilgeci 2019). Fellahi et al. (2019) stated that the number of grains per spike and the number of ears per plant have high direct effects on yield. This does not exclude the important role of WTG in the expression of yield. Erchidi et al. (2000) reported that the indirect contribution of this component to yield, under variable climates, is greater via the number of grains per spike than their direct contribution. Furthermore, Whan et al. (2014) showed that seed size is a very important part of basic plant research, since, in plant reproduction, seed formation and development had significant effects, as well as cereal breeding, as a related trait yield and vigor. Grain size and shape are two among main targets in wheat breeding programs, due to their significant effect on grain weight and yield (Okamoto et al. 2013; Rasheed et al. 2014). Similar results of relationships between grain yield and WTG have been observed in previous studies (Ferdous et al. 2010; Khan et al. 2013; Zoghmar et al. 2016; Safarova et al. 2019).

In addition, the Yield is positively correlated with the Nb ST ($r = 0.889$). According to Khan and Naqvi (2011) tillering is a varietal character, which under favorable conditions, could provide information on the potential of varieties. He also noted that the number of tillers per plant has direct contribution towards grain yield. It means, as the number of productive tillers increases there will be simultaneous increase in yield. Our results agree with the observations made by Sang et al. (2014) who concluded that tiller formation affects grains number and grain weight, therefore it is closely related to yield, besides, Hazmoune and Benlaribi (2004) found that the ability of a plant to form a large number of tillers is very beneficial for increasing and stable yield in variable environments. Understanding this contribution can help in the selection of suitable and highly productive genotypes (Elhani et al. 2007).

From the results presented in Table 7, it emerges that the AFL has significant and positive correlations with the yield, the spike characteristics (LS, LSP and LB), as well as with all the chlorophyll pigments. Overall, these results are in agreement with those of Salmi et al. (2015) who reported that a flag leaf with large dimensions is certainly desirable in favorable environmental conditions, since this organ is the last, which remains inactive, with the spike and the ears. An increase in AFL induces an increase in the photosynthetic capacity for the synthesis of organic compounds that are favorable to a high yield. Since the productivity of a plant is linked to its growth capacities, in the event of stress causing the decrease in FLA as well as in the vegetative part of the plant and, therefore, in the photosynthesis, the priority of the plant is to preserve its ability to produce at least one viable seed. Thus, it, therefore, implements a process of abortion of seeds that cannot be filled for the lack of sufficient resources. Our results are also supported by other studies (Guendouz et al. 2012; Allam et al. 2015; Himani et al. 2018).

The HP showed negative and significant associations with the yield and their components (Table 7). These results mean that the varieties with short straws present the best values for the agronomic characteristics. Our results are in agreement with those of several studies showing that short plants are more productive than tall straw plants. Since the short ones have a significant tillering capacity, each tiller will lengthen and put an inflorescence which increases the spike stand, consequently, an increase in yield (Benniou et al. 2018). In the same context, Kirouani et al. (2019) obtained similar results to ours and they attributed the reason to the fact that tall varieties do not have the capacity to provide the energy and the assimilates necessary for the formation of spikes and the elongation of tillers at the same time. However the great length of the plant has many advantages such as adaptation to the lack of water at the end of the cycle, thus ensuring a good filling of the grain and the use of straw in animal feed breeding when the stem pith is absent or thin (Zerafa et al. 2017).

It is also important to note the positive correlation recorded between the characteristics of the spike (LS, LSP, and LB), and the yield and its components. This is corroborated with the hypothesis presented by Guo et al. (2018), who assumed that it was possible to maximize grain yield by manipulating and predicting wheat spike morphology. Kahali et al. (2016) explained the role of the peduncle by the quantity of photosynthetic assimilates stored in this part of the plant, which are likely to be transferred to the grains, while Kong et al. (2010) also felt that the peduncle contributes crucially during the final
stages of grain filling. Regarding to the LS, many authors have pointed out the important role of a long spike (Subhashchandra et al. 2009; Rebetzke et al. 2016) reported that the length of the spike has a positive and a high direct effect on the yield/plant. Likewise, Merah and Monneveux (2014) reported that beards play an important role in the stress tolerance and in the filling of grains by their developed surface, their upright port and their position in the immediate vicinity of the seed that promotes its formation, which would make a gain performance.

The mechanisms of adaptation and of tolerance to abiotic constraints are diverse. For example, the measurement of the relative water content (RWC) makes it possible to describe in a global way the water status of the plant, reflecting the metabolic activity of the tissues and used as the most significant index of tolerance to stress in particular dehydration Sallam et al. (2019). It has also been proposed as a useful trait for breeding stress-tolerant wheat varieties (Hasheminasab et al. 2012; Farshadfar et al. 2014). The obtained results showed that the RWC reveals a negative correlation with the yield. The varieties Wahbi, Waha, and Semito showing the highest RWCs, are relatively the least productive, with the exception of the variety Cirta, which seems to have little tolerance for the yield compared to other varieties. This is perfectly similar to the results obtained by Khennoufi et al. (2016) who recorded a negative relationship (R = -0.466) between RWC and Yield, and on the basis of previous studies, they have been concluded that genotypes tolerant to abiotic stress are less productive and lose less water leaf area per unit of time. In addition, the RWC shows negative correlations with the following parameters: AFL, LSP and LB this means that the narrow AFL, and the characteristics of a short spike contribute to a limitation of water losses. Similar results have been reported by other studies (Salmi 2015; Khennoufi et al. 2016). On the other hand, it appears that varieties with a high height have a high RWC; these results correspond to those obtained by Jatoi et al. (2011). Elevated RWC is a form of resistance which probably results from active osmoregulation, by a mechanism of stress tolerance, by osmotic adjustment which results in an increase in osmotic potential due to an accumulation of osmolytes in the cytoplasm such as proline and soluble sugars. Chaib et al. (2015) clarified the important role of these osmolytes in osmo-regulation in order to ensure the optimal physiological functioning of the cell, especially under stressful conditions. Positive correlations were observed in our study between RWC and Pro (r = 0.952) and Ss (r = 0.420). These results suggest that the varieties with the highest relative water content accumulate more Ss and Pro. These results are supported by the findings of Sassi et al. (2012). MDA is negatively correlated with RWC and chlorophyll pigments (Table 7). This suggests that the peroxidation of the membrane lipids would be associated with a malfunction and lead to the damage of the main cellular components, consequently, the membrane then loses its integrity by becoming permeable, plasmolysis and releases, towards the extracellular space, its contents, which seriously affects the productivity of the plant; in general. Similar results have been obtained in many species, such as (colza) (Brassica napus L.) (Toumi et al. 2014), soft wheat (Triticum aestivum) (Khalilzadeh et al. 2016), and durum wheat (Triticum durum) (Bouchemail et al. 2018). Besides, the presence of a negative correlation between Pro, Ss and MDA (Table 7) could be explained by the role of these compounds in the protection of cell membranes. Hacini and Brinis (2012) pointed out that osmo-protection is another trait for which researchers are unanimous in its participation in the tolerance of genotypes. The diversity of responses, even if basically, proteolysis necessarily leads to an accumulation of solutes such as proline and soluble sugars, proves that genotypes react differently depending on their genetic origin. On the other hand, the result of study by Salmi (2015) suggested that the accumulation of these osmolytes seems much more intended for stress tolerance but it is not able to have a contribution to the expression of yield in semi-arid areas. Maury et al. (2011) and Simonneau et al. (2014) mentioned that the fundamental biological mechanisms, of tolerance to droughts such as the reduction of the leaf surface, the closure of stomata, the osmotic regulation, which contribute to the maintenance of a water balance, between the plant and the soil, hinder the growth and the photosynthesis, are the main physiological functions of the plant, that leads to certain yield losses. Our results are consistent with those obtained by Fellah et al. (2002), who revealed a negative relationship between adaptation, as measured by tolerance to caloric stress, and grain yield. Sensitive varieties produce more under stress compared to tolerant varieties. Menad et al. (2011) recorded that highly productive genotypes suffer greater yield reduction under drought conditions compared to moderately yielding genotypes.

In conclusion, the obtained results revealed the existence of variability for most of the measured parameters in the studied varieties. This variability is only an ineluctable consequence of genetic variation which constitutes a gain that must rationally be preserved, enriched and valued according to the drowned objectives. Indeed, the phenology analysis (duration of heading) has revealed an inter-specific variability in the studied varieties, and has demonstrated that the use of more or less early varieties is favorable to the expression of grain yield; in which the varieties had the most important values for all the morpho-physiological parameters were those presented the highest yields. These findings lead us also to conclude that in order to improve the performance of cereals in areas dominated by conditions similar to those of our study area, it is recommended to develop a plant material characterized by good productivity (Nb S/m², Nb G/S) and adaptive (AFL, LS, LSP, LB) qualities; able to maintain its photosynthetic activity as long as possible with a stable yield. Finally, it should be noted that these types of studies require conducting both multi-site and multi-year behavioral tests to determine and characterize the performing genotypes; with a good approximation for the target environment; as well as they must be completed by molecular biology techniques that can help to identify desirable genes to support future durum wheat improvement programs.
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