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Study of Morphological Parameters and Climate Change Vulnerability in Selected Durum Wheat Genotypes

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Abstract

In three areas under Mediterranean climate: two in North-eastern Algeria (Tiffech and Sidi Fredj) and one in France (Montpellier), we conducted our study on some Durum wheat (*Triticum durum*) genotypes. The effect climatic conditions of said areas had on the performance of these genotypes was noted through changes in their morphological characteristics: average stem height, distance between the spreading leaf and the ear, ear length and awns length). The results obtained show significant interactions between the genotypes studied and the climatic parameters of the experimental sites. A positive correlation between stem height average and distance flag leaf-spike was recorded in all three study areas. Climatic conditions in each area affected spike length and awn length differently. In Sidi-Fredj, climatic conditions stimulated the development of the awns of majority of the cultivars studied compared to the other experimental sites. This conditioning can be interpreted as an adaptation mechanism of durum wheat genotypes to environmental stress.

Keywords: *Adaptation; Environment; Mediterranean; Stress; Triticum durum*

Introduction

The recent report by the IPCC (Intergovernmental Panel on Climate Change) indicates that the global surface temperature has risen by 1.1°C compared with the pre-industrial period. Data for North Africa (NA) indicate that global warming is more pronounced in this region than the global average. In Algeria, according to the various scenarios, global warming has had a greater negative impact than elsewhere. While the global temperature increase in the 20th century was around 0.74°C, the rise in Algeria was between 1.5° and 2°C, more than double the global average. Global warming has also led to an estimated 10-20% drop in rainfall (Tabet-Aoul, 2010).

The increase in temperatures and their variability will lead to a shift and reduction in growing seasons, as well as an acceleration in soil degradation and the loss of productive land. As a result, agricultural production will see average reductions in cereal yields of between 5.7% and almost 14%. Climate change will also reduce vegetable yields by 10-30% by 2030 (Mohamed, 2012).

Cereals are the most important annual crops for Algerian agriculture (Hadibi et al., 2009). Durum wheat plays a central role in the country's economy. It covers half the surface area devoted to this activity (Mazouz, 2006). Research on winter wheat in the Mediterranean region shows that future increases in temperature will bring forward the onset of phenological stages, accompanied by a shortening of their duration (Mo et al. 2016, Rezaei et al. 2018), resulting in a lower accumulation of total dry matter and a reduction in yields (Tubiello et al., 2000, Giannakopoulos et al., 2009, Moriondo et al., 2011).

Algerian cereal crops are exposed throughout their development cycle to a series of hydric and thermal stresses. Water stress is always accompanied by, and interacts with, other abiotic stresses such as low and high temperatures and excess light (Mekhlouf, 2009). Lack of water remains the most limiting factor for durum wheat cultivation, although recent studies show that it is low winter and spring temperatures that are most detrimental to this crop (Annicchiarico, 2002, Annicchiarico et al., 2005). The aim of this article is to study the mechanisms by which durum wheat genotypes adapt to climate change. Our hypothesis was that the climatic conditions of each experimental site will affect, in different degrees, the morphological characteristics of the genotypes studied.

Materials and Methods

Plant material

29 genotypes of durum wheat (*Triticum durum* Desf.) (Table 1) were grown in each of the three environments. Germplasm was supplied by the Melgueil DIASCOPE Experimental Unit (INRA Montpellier, France).

Table 1. List of studied Plant material

N°	Genotype	Code	N°	Genotype	Code	N°	Genotype	Code
01	AGATHE	AGA	11	CAR1924	CAR	21	KIEVLANKA	KIE
02	AGRIAL	AGR	12	CEEDUR	CEE	22	MEGADUR	MEG
03	ANEMONA	ANE	13	DAMOISO	DAM1	23	MONDUR	MON2
04	ARCOUR	ARC	14	DAMOISOX	DAM2	24	MONTFERRIER	MON1
05	ARDENOIS 918448	ARD2	15	DIABOLO	DIA	25	NEPAL	NEP
06	ARDENTE	ARD1	16	DURENTAL	DUR2	26	ROMEO	ROM
07	ARMET	ARM	17	DURGAMM	DUR1	27	TELEDUR	TEL
08	BEAUDUC	BEA	18	ECLADUR	ECL	28	TOMCLAIR	TOM2
09	BIODUR	BIO	19	ESCAL	ESC	29	TOMCLAIR800 891	TOM1
10	BRUMAIRE	BRU	20	JAGUAR800 858	JAG			

Experimental sites

The study was carried out in three environments that were clearly differentiated by altitude, rainfall and average temperature (Table 2), during the 2019/2020 season.

Field device and measured parameters

At each site, the experimental set-up consisted of similar randomized blocks with parallel plots (1.5m x 0.5m).

The following morphological parameters were measured on botillons of 10 plants taken from each plot: (1) *Average stem height* (measured in centimeters from the base of the stem to the base of the ear); (2) *Ear length* (measured from the base of the spike to the end of the last

spikelet excluding the awns); (3) *Awn length* (measured from the end of the last spikelet to the end of the awns); (4) *Distance Flag leaf – Spike* (measured from the ligule of the last leaf to the base of ear).

Table 2. Ecological factors of the experimental sites

	Location	Altitude (m)	MAX.T (°C)	AVR.T (°C)	MIN.T (°C)	Precipitation (mm)	MWS (Km\h)
Site 1: Grain seed multiplication farm El-ARIBI	Tiffech (Algeria)	919 m	41 °C	20.4 °C	-0.3 °C	1079 mm	58 Km\h
Site 2: Private farm dedicated to grain farming	Sidi Fredj (Algeria)	805 m	43 °C	20.5 °C	-2 °C	1134 mm	46 Km\h
Site 3: experimental unit INRAE-Diascope	Mauguio (France)	9 m	43 °C	20 °C	-2.9 °C	758 mm	59 Km\h

MAX.T: Maximum temperature, AVR.T: Average temperature, MIN.T: Minimum temperature, MWS: Maximum wind speed.

Statistical analysis

Genotype x environment interaction and the variation in behavior due to the genotypes were the subject of an analysis of variance, a multivariate analysis (correlation) and a Principal Component Analysis (PCA) using statistical and graphical calculation software R.

Analysis of variance allowed us to determine the differences between parameters means.

Correlation analysis was used to see interaction between different morphological parameters of the genotypes studied at the same experimental site.

Principal component analysis enabled us to interpret the difference in genotype x environment interaction depending on the study area and parameters studied.

Results and Discussion

Analysis of variance showed a significant effect for all traits relating to strand morphology. There was a highly significant genotype x environment interaction for all traits.

Effect of the environment on morphological parameters

The PCA representing the 4 variables studied shows that the average height and the distance between the ear and the last leaf are highly correlated, whereas the length of the awns and the ear do not appear to be correlated (Figure 1).

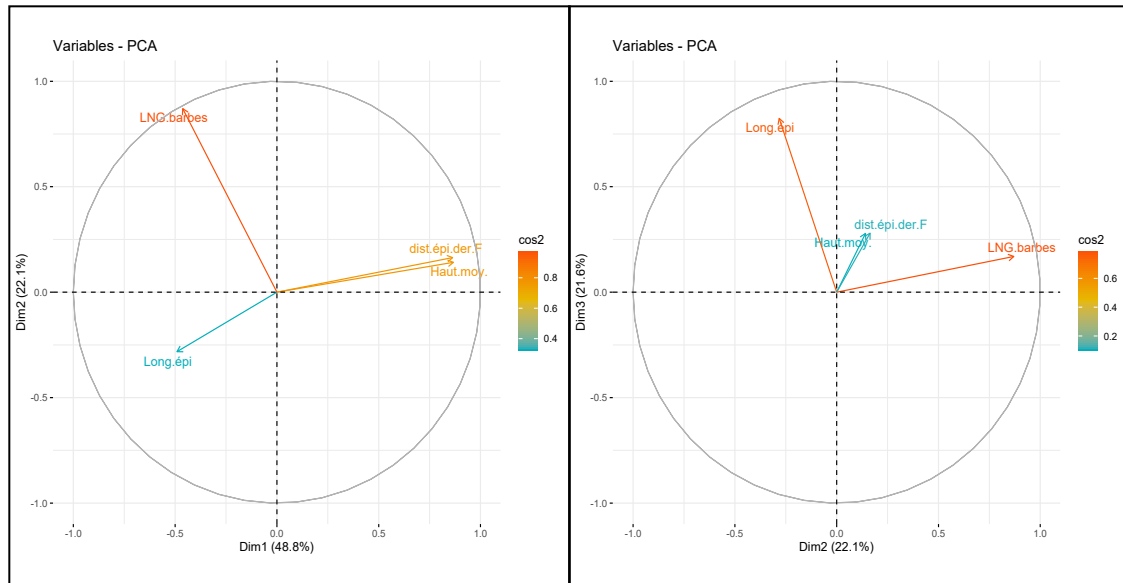


Figure 1. Results of the principal component analysis.

According to Figure 1, Dim 1 carries most of the information, which is explained mainly by stem height average and distance between the flag leaf and the spike. The variable contributing most to the explanation of Dim 2 is the awns length. Spike length explains Dim 3.

The 3 sites are well differentiated by the PCA integrating the total matrix of data (Figure 2, Figure 3).

Data measured at Montpellier are mainly on the right-hand side of the graph, with Sidi-Fredj on the left and the Tiffech site in between.

The stems average height and the distance between the spreading leaf and the shoot played an important role in the distribution of a large group of cultivars (Figure 2), in particular AGATHE, ARDENTE, MONTFERRIER (Montpellier), AGATHE, ECLADUR (Tiffech) and KIEVLANKA, DURGAMM, CAR1924 (Sidi-Fredj).

While, awn length contributes to the second-dimension formation (Figure 3). This makes it possible to distinguish a second group made up of DURGAMM, ROMEO, AGATHE (Sidi-Fredj), MONTFERRIER (Tiffech, Sidi-Fredj) and BEAUDUC (Sidi-Fredj, Tiffech).

The spur length parameter mainly explains the distribution on the third dimension, composed

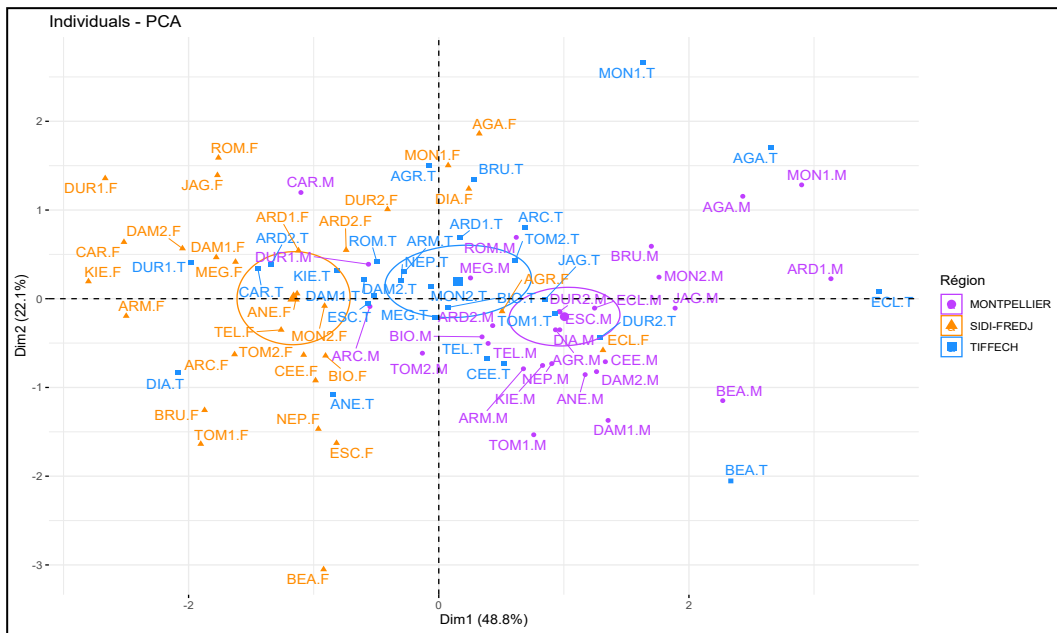


Figure 2. Graphical representation of individual genotypes on the 1X2 plane of the PCA and their distribution according to growing medium.

mainly of: BEAUDUC, ECLADUR (Sidi-Fredj), BEAUDUC (Tiffech) and BIODUR, TOMCLAIR800891 (Montpellier).

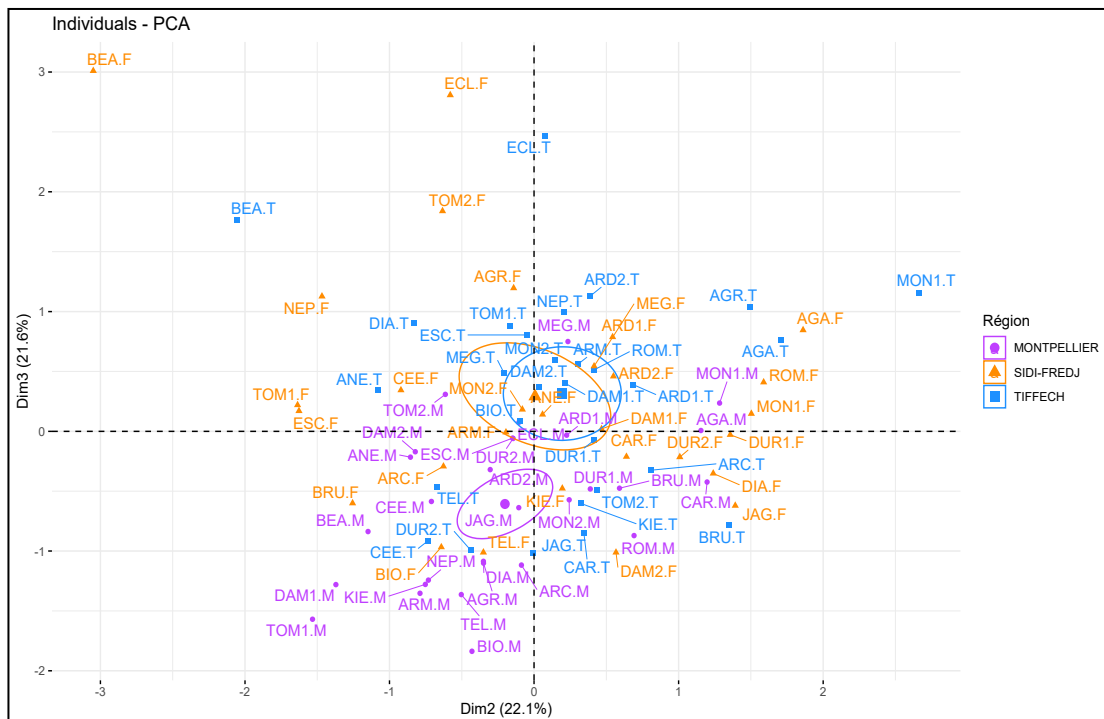


Figure 3. Individual graphical representation of genotypes on the 2X3 PCA. plane

Climatic conditions differed to a greater or lesser extent between the three trial sites (especially Montpellier compared with Tiffech and Sidi-Fredj). The genotype x environment

interaction was responsible for the instability in yields. The difference was particularly noticeable from the spike 1cm stage to maturity (water stress in Montpellier and heat stress in Sidi-Fredj).

Different behavior was observed for the parameters studied, especially for average stem height and awn length. However, some genotypes did not really show a significant environment-genotype interaction (AGRIAL, ANEMONA, ARCOUR, CEEDUR, ESCAL and MEGADUR). The average stem height and the distance between the spreading leaf and the shoot were positively correlated in the three study areas.

A closer look at each variable (Figure 4) clearly shows that these 3 sites differ greatly for each of the variables.

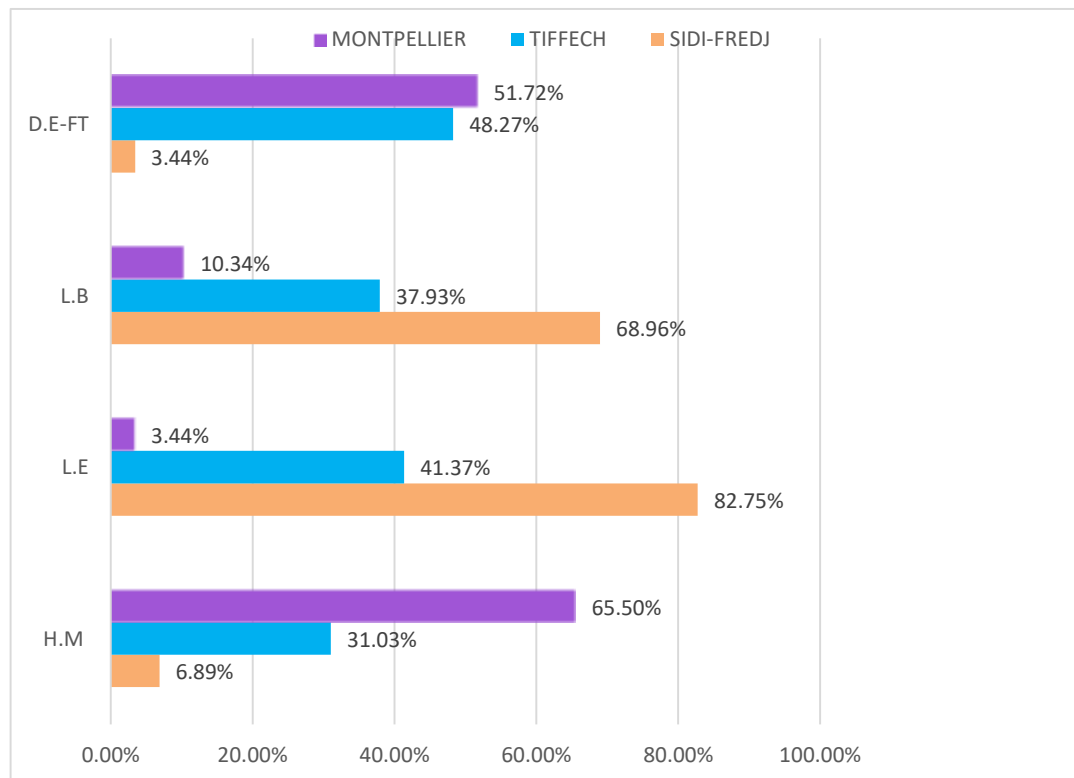


Figure 4. Comparison of the percentage impact of experimental sites on the morphological behaviour of cultivated genotypes (D.E-FT (cm): distance Flag leaf – Spike, L.B (cm): awn length, L.E (cm): ear length, H.M (cm): average stem height).

Distance Flag leaf - Spike

In Montpellier, the distance between the flag leaf and the ear of 51.71% of the cultivated genotypes was significantly affected compared to the other experimental sites (Figure 4). The average spike-to-last leaf distance of the genotypes in Montpellier was 11.38cm. In the Tiffesch experimental zone, 48.27% of the genotypes were positively affected. The average spike-last

leaf distance of the 29 genotypes grown at Tiffech was 10.95cm. However, the climatic conditions at Sidi-Fredj were the most unfavorable for the genotypes, with an impact percentage of 3.44%. The average distance between the last leaf and the shoot of the genotypes grown at Sidi-Fredj was 7.4cm.

Awn length

In the Sidi-Fredj study area, the awn length of 68.96% of the cultivated genotypes (20/29 genotypes) was significantly longer than that of 37.93% in Tiffech and 10.34% in Montpellier (Figure 4). The average awn length of the 29 cultivated genotypes was: 9.57cm in Montpellier, 11.76cm in Tiffech and 12.45cm in Sidi-Fredj.

Ear length

The average spike length of the cultivated genotypes was: 6.43 cm at Montpellier, 7.6 cm at Tiffech and 8.19 cm at Sidi-Fredj. The Sidi Fredj site favored the development of the ears of 82.75% of the genotypes (24/29 genotypes).

Average stem height

Regarding mean stem height, 65.50% of the genotypes grown at Montpellier (19 genotypes) were positively affected compared to the other sites. 31.03% of genotypes (9 genotypes) responded positively at the Tiffech experimental site (Figure 4). The average master strands height of the 29 genotypes grown was: 68.12 cm at Montpellier, 64.86 cm at Tiffech and 54.40 cm at Sidi-Fredj.

Correlation analysis

Analysis of the correlations between the measured parameters (Figure 5) shows that there are positive and negative links, both weak and strong.

A study of the correlation coefficients between the different variables measured in the 29 genotypes grown in Montpellier (Figure 5.1) shows that there is a significant positive correlation between stem height and flag leaf-spike distance.

Ear length and spike length were also positively correlated. On the other hand, spike length and distance between spike and flag leaf were negatively correlated. The results also showed

that there is no significant correlation between stem height and ear and awn length. There was also no correlation between the length of the awns and the distance flag leaf-spike.

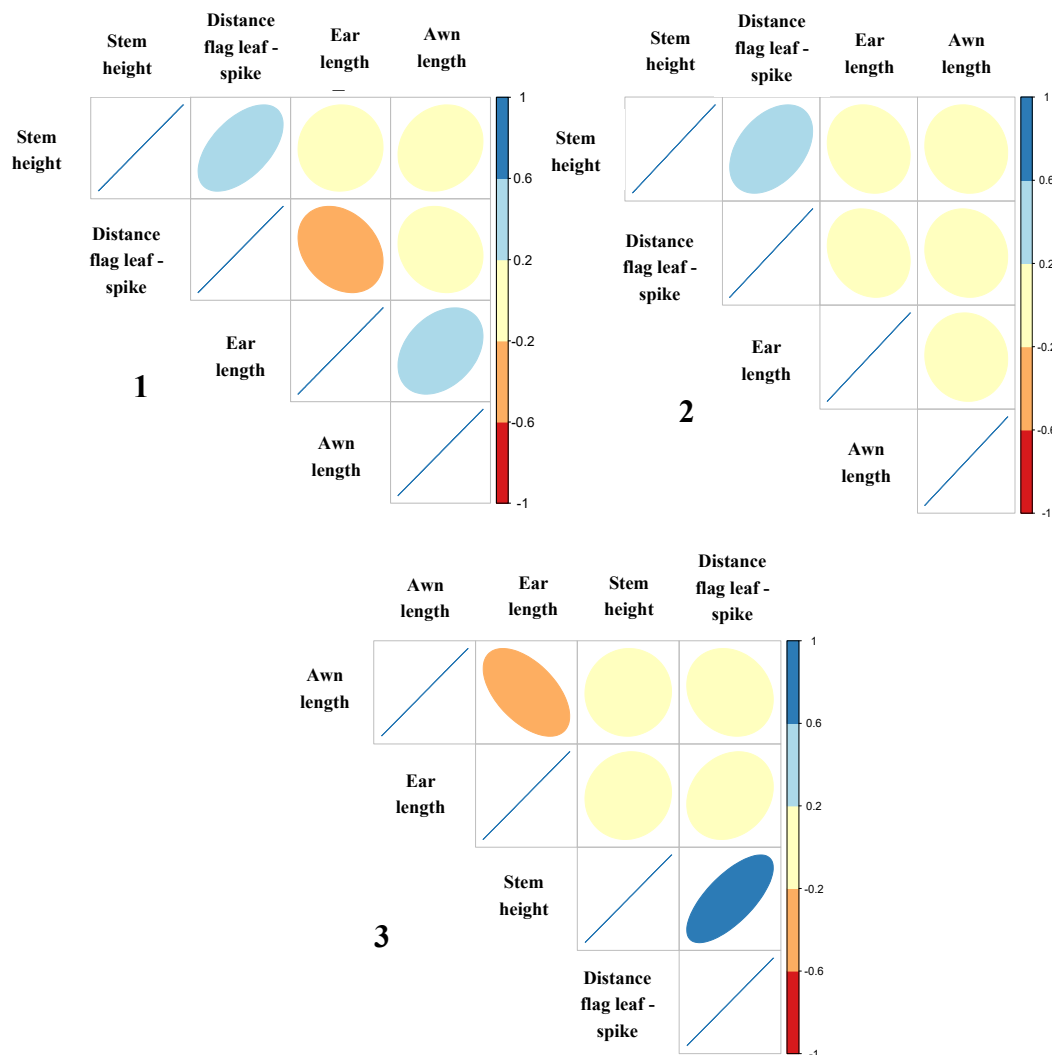


Figure 5. Correlation plot of morphological parameters at the experimental site in: 1: Montpellier 2: Tiffech 3: Sidi Fredj.

The results obtained from the Tiffech experimental area (Figure 5.2) showed that there was a significant positive correlation between stem height and distance between spike and flag leaf.

A study of the correlation coefficients between the other variables measured showed that there was no relationship between awn length, spike length and distance between spike and flag leaf. The correlation plot for the Sidi-Fredj experimental zone shows that there are two types of correlation between the morphological parameters of the 29 genotypes (Figure 5.3): a highly significant positive correlation between stem height and spike-flag leaf distance and a significant negative correlation between awn length and spike length.

Genotypes morphological behavior

The comparison of the genotypes behavior studied in each area showed a highly significant difference (Figure 6).



Figure 6. Inter-variety comparison of the morphological behaviour of some cultivated genotypes under the effect of the climatic conditions of each experimental site (H.M (cm): average height of the stem, L.E (cm): length of the ear, L.B (cm): length of the awns, D.E-FT (cm): distance between leaf and ear).

Average stem height

The genotypes that showed maximum height in the three study areas were: MONTFERRIER, BEAUDUC and ECLADUR (Montpellier and Tiffèche), ARDENTE

(Montpellier) and TOMCLAIR800891 (Tiffech). On the other hand, the least developed genotypes are: KIEVLANKA, CAR1924, DURGAMM, TELEDUR and TOMCLAIR800891 at the Sidi-Fredj site.

The genotypes that showed maximum development of average stem height were: MONTFERRIER (91 cm) in Montpellier, BEAUDUC (95 cm) in Tiffech, ECLADUR (77 cm) in Sidi-Fredj. On the other hand, the genotypes that had a reduced average height were: CAR1924 (53 cm) in Montpellier, DURGAMM (46.5 cm) in Tiffech, KIEVLANKA (39 cm) in Sidi-Fredj.

Ear Length

The genotypes that showed positive behavior in relation to the meteorological parameters of the experimental sites are: BEAUDUC (Sidi-Fredj and Tiffech), ECLADUR, NEPAL, TOMCLAIR, TOMCLAIR800891 at Sidi-Fredj; DIABOLO and ARDENOIS918448 at Tiffech.

The ears of BEAUDUC were the most developed compared to the other genotypes (12 cm), while only 6.5cm in length was recorded for DIABOLO. On the other hand, Montpellier site did not really affect the ears length (3.44% represented by DURENTAL).

Awn length

The genotypes with the longest awns were: CAR1924 in Montpellier (15 cm), MONTFERRIER in Tiffech (17 cm), DURGAMM and ROMEO in Sidi-Fredj (17 cm). The shortest awn lengths were recorded in Tiffech (BEAUDUC: 5 cm), Sidi-Fredj (BEAUDUC: 6cm) and Montpellier (BEAUDUC, DAMOISO and TOMCLAIR800891: 6cm).

Distance flag leaf - spike

The genotypes which showed a maximum flag leaf - spike distance are: ARDENTE (Montpellier), ECLADUR (Sidi-Fredj and Tiffech), AGATHE (Tiffech), MONTFERRIER (Tiffech and Montpellier). However, the genotypes with the shortest distance between the spike and the flag leaf were: KIEVLANKA, CAR1924, ARMET, TOMCLAIR800891, DURGAMM (Sidi-Fredj).

The meteorological parameters of the three experimental sites led to specific adaptations for each genotype.

It appears that some varieties of wheat have adapted to the climate by developing shorter stems. This adaptation helps to reduce the amount of water and nutrients that are lost from the plant, and it also helps to protect the plant from wind damage (Blum, 1988). A shorter stem means that the plant can put more energy into developing its grains rather than growing tall stems. In addition, wheat with reduced stem length is more resistant to lodging (Bagga et al., 1970). This goes along with what we found throughout our study, where the climatic conditions in Montpellier led to an increase in average stem height, whereas in Sidi-Fredj, the height of the stem was significantly reduced in comparison to Montpellier.

When it comes to spike adaptation, some varieties of wheat have adapted to the Mediterranean climate by developing shorter, thicker spikes. This adaptation helps to protect the developing grains from the sun and wind, and it also helps to reduce water loss from the plant. According to Jonard (1964), ear length is a varietal characteristic that can be influenced very little by environmental variations. However, some varieties of wheat have adapted to the Mediterranean climate by developing shorter, more compact ears. This adaptation helps to reduce the amount of water and nutrients that are lost from the plant, which helps the plant to conserve its resources during times of drought (Pradhan et al., 2012).

The length of the awn in wheat can increase the possibility of water use and dry matter production during the ripening phase. According to Blottière (2003), and Nemmar (1980), the length of the awn also contributes to limiting water loss. This morphological parameter seems to be closely linked to tolerance to terminal water deficit, at least in durum wheat (Salma, 2002). This is what we observed in Tiffech and Sidi-Fredj where the majority of the genotypes studied there were largely affected when it comes to awn length. The decrease in rainfall and the increase in temperature at the heading stage stimulated a significant increase in awn length for most of the genotypes grown at Sidi-Fredj. This can be seen as an adaptation mechanism to minimize water loss. Awns also help cool wheat spikes during grain filling in warm climates (Motzo and Giunta, 2002).

Auriau (1978) emphasized the role of the neck as a provisional organ in the translocation of assimilates to the ear, and found a positive correlation between the length of the ear neck and yield. Wheat genotypes with a larger distance between the flag leaf and the spike used more water. However, one thing to consider is that a larger distance can increase the amount of water required for irrigation. According to our results the majority of the genotypes that were

cultivated in Sidi-Fredj had a reduced distance flag leaf – spike in comparison to the other areas of study.

Conclusion

Our study focused on the behavior of 29 genotypes of durum wheat (*Triticum durum*. Desf), grown in three different areas under a Mediterranean climate. We tried to determine the effect of climatic conditions on the performance of these genotypes through changes in their morphological characteristics: average stem height, distance between the spreading leaf and the ear, ear length and awns length). Climatic conditions in each area affected spike length and awn length differently. At Sidi-Fredj, climatic conditions stimulated awn development in most of the cultivars studied compared with the other experimental sites. This conditioning can be interpreted as a mechanism by which durum wheat genotypes adapt to water and heat stress. The difference was observed at the maturity stage (hydric stress in Montpellier and thermal stress in Sidi-Fredj), for which different behavior was observed in terms of parameters (particularly the average height of the stem and the length of the awns). However, some genotypes showed stable behavior under the climatic conditions of the three sites (TELEDUR, NEPAL, ROMEO....). However, our results are only one stage in the identification of these genotypes through morphological characteristics. In Algeria, scientists have estimated that rainfall will fall by around 20 per cent in the coming years. They also estimate that temperatures will rise by a further 3°C by 2050 as a result of global warming. In future, therefore, it would be advisable to attach greater importance to the interaction between wheat and the environment, in order to better highlight the true potential for adaptation of each genotype and to find genotypes with stable behavior in their growing environment. In light of what we found in our study, there are two propositions that we think can greatly enhance drought resistance resulting in increased biomass and better yield: 1. *Early sowing* by doing so we ensure that the plants will benefit from as much precipitation as possible. In addition, the plant would have more time to reach maturity before the summer heat arrives. This can result in a higher yield, as the plant will have had more time to develop and mature which can reduce the risk of late-season heat stress. 2. *Mixed varieties* by planting two or more varieties of the same crop together. The key to using mixed varieties is to select varieties that have wanted characteristics like drought resistance and plant them together to create a sort of a genetic diversity that increases the development of said traits. This can help increase resilience to environmental stress, and it can also increase the yield.

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