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Research Article

Effect of sowing dates on the vegetative growth and yield parameters of two quinoa (*Chenopodium quinoa* Willd.) genotypes

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Abstract

The aim of the present study was to select the best sowing time for two quinoa genotypes (*Chenopodium quinoa* Willd) grown in Ouargla, located in the Saharan region of Algeria. The adopted experimental device is of the random block type, comparing the effect of three sowing dates in 2018: October 16th, October 31st, and November 15th, on some vegetative growth parameters (number of seedlings raised, total number of plants, total fresh weight of plants, height of plants at panicle stage, number of branches per plant, average weight per plant), and yield parameters (number of panicles per plant, weight of the main panicle, weight of 1000 grains, and total weight of grains per square meter) of two quinoa genotypes: "Q102" Amarilla saccaca and "Giza". The obtained results show that the best sowing date for the "Q102" genotype is the first date (October 16th), which ranked first for most of the parameters studied. On the other hand, the best grain yield was observed by the second sowing date (October 31st). As for the "Giza1" genotype, no yield was observed for the first and second sowing dates, while a very low grain yield was observed only by the third sowing date. The results obtained make it possible to conclude the strong capacity of adaptation of genotype "Q102" to the edapho-climatic conditions of the south of Algeria compared to genotype "Giza1". In fact, this study shows that the production potential of quinoa in the Saharan regions is linked to both the genotype and the sowing date.

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Introduction

Faced with the challenge of increasing the production of quality food to feed the world population within the context of climate change, quinoa constitutes a viable alternative for countries suffering from food insecurity (Jacobsen, 2003; Bazile et al., 2016; Food and Agriculture Organization, 2011; International Center for Bionsaline Agriculture, 2016).

According to Bedoya-Perales et al. (2018), quinoa plants seem to offer a solution for food sovereignty and security in vulnerable areas. This plant is becoming more and more popular and its cultivation is among the fastest in the world, allowing it to contribute significantly to food security and nutrition in the regions of the Near East and North Africa (Del Castillo Gutiérrez & Winkel, 2014).

Being an alternative plant to gluten-free cereals, quinoa is considered today as a healthy food with high nutritional value as its grain contains high quantities of protein, essential amino acids, and essential minerals and vitamins. Because of these nutritional properties and health benefits, quinoa is considered a novel healthy food, occasionally referred to as a ”superfood”. Considering its importance, the United Nations General Assembly declared 2013 as the ”International Year of Quinoa” (Pathan & Siddiqui, 2022).

The morpho-phenological characteristics and food uses of quinoa show a great diversity of varieties (Del Castillo Gutiérrez & Winkel, 2014). This diversity is due to its enormous agronomic adaptation and genetic variability, as quinoa varieties are adapted to grow from sea level to an altitude of more than 4,000 meters above sea level and from cool highland climates to subtropical conditions (Iqbal, 2015).

In addition to having a very high nutritional value (Filho et al., 2017; Scanlin & Lewis, 2017; Singh et al., 2021; Sultanova et al., 2022; Vega-Gálvez et al., 2010), the interest in this plant lies in its ability to resist extreme climatic conditions (drought, poor soil, salinity), underlining its effectiveness in the fight against desertification, especially since it grows in an arid environment where it can even give acceptable yields (Bazile et al., 2016; Eisa et al., 2017; Ruiz et al., 2014).

The potential introduction of quinoa as an alternative crop has caught the attention of farmers around the world even in areas outside the geographic origin of this species (Bazile et al., 2016; Kezimana et al., 2020; Oustani et al., 2023; Rathore et al., 2019). This is particularly evident for arid environments like that of southern Algeria (Oustani et al., 2023). Since it grows on soils with poor fertility, quinoa could also be grown in the Saharan regions of southern Algeria (Oustani et al., 2019).

On the other hand, the most important determinant of the productivity of any new crop in a particular area is the identification of the optimal planting time that satisfies the plant’s environmental needs. The optimal planting time is presented as a first step in the agricultural production system and considered as a basis that leads to the development of a set of appropriate production technologies, especially for a new crop in a region (Erazzú et al., 2016; Sajjad et al., 2014).

Indeed, identifying the most appropriate planting date is one of the most important agronomic considerations for successful quinoa cultivation (Ramesah, 2016; Temel & Yolcu, 2020; Uke, 2016). According to Shoman (2018); Temel & Yolcu (2020), in order to obtain the desired yield and quality performances in the quinoa plant, it is necessary to establish appropriate sowing and harvesting periods according to ecological conditions of the region where it will be grown.

According to Isobe et al. (2016); Ramesah (2016); Temel & Yolcu (2020) and Uke (2016), in order to achieve the desired yield and quality performance in the quinoa plant grown for hay production. It is necessary to establish appropriate sowing times based on the ecological conditions of the region where it will be grown.

In this perspective, this study aims to determine appropriate sowing periods of two quinoa genotypes cultivated under Saharan conditions of Algeria for achieving better growth and high yield especially since the plant in this region grows under a harsh environment and is exposed to various stresses such as thermal stress, hydric stress, and salinity (Mehda et al., 2022).

Materials and methods

Study area

The experiment took place at the station of the Technical Institute for the Development of Saharan Agronomy (ITDAS) in Hassi Ben Abdallah (32° 02' 0.487'' N, 5° 28' 32.34'' E, 156 m). The station is located 26 km from the capital of the wilaya of Ouargla in South-East Algeria. The climatic factors characterizing the study area are provided by the National Office of Meteorology (Ouargla - Algeria). The data during the period of cultivation are presented in Table 1 and Figure 1. The analysis of climatic data indicates that the lowest temperature recorded was in January at 3.80 °C, while the highest recorded was in May at 33.84 C°. As for the average temperature throughout the experiment period, it was recorded at 17.91 C°. The average humidity, maximum wind speed, cumulative precipitation, evaporation, and insolation for the period of cultivation were 40.64 %, 9.45 km/h, 35.70 mm, 1524.20 mm, and 2117.30 hours, respectively (National Meteorological Office, 2019).

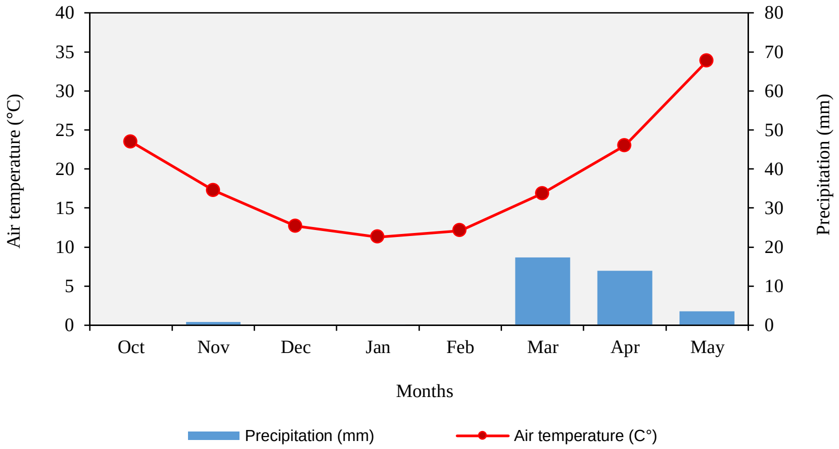

Figure 1. Gaussen ombrothermic diagram of the Study area

Table 1. Climatic data for the cultivation period (October - May)

Month	T Mim C°	T Max C°	T Moy C°	H Moy %	Wind Km/h	P mm	Evaporation mm	Insolation Hours
October	16.86	30.11	23.48	38.92	8.58	0	214.3	247.9
November	10.39	24.15	17.27	47.33	7.80	0.8	143.7	244.5
December	4.91	20.46	12.69	52.31	6.06	0	105.6	272.1
January	3.80	18.76	11.28	44.37	8.61	0.01	113.6	256.2
February	4.79	19.43	12.11	42.82	9.75	0	132.6	226.6
March	9.27	24.47	16.87	38.26	11.39	17.3	202.7	245.7
April	15.46	30.54	23.00	31.77	11.80	13.97	283.1	304.2
May	19.26	33.84	26.55	29.35	11.61	3.62	328.6	320.1
Average	10.59	25.22	17.91	40.64	9.45	-	190.53	264.66
Accum	-	-	-	-	-	35.7	1524.20	2117.30

Source: National Meteorological Office (2019)

According to Oustani (2006), the soil of the study site is characterized by a sandy texture, an alkaline pH (8.06), an electrical conductivity of 0.95 dS/m ($EC_{(1/5)}$), and low contents of organic carbon and total nitrogen. As for the water used for irrigation, it is characterized by an electrical conductivity of 2.7 dS/m and a pH of 8.4. According to the water classification established for Algeria by Durand (Durand, 1983), the water used is not recommended for irrigation under normal conditions, but it can be used when the soil is permeable with good drainage (Oustani & Mehda, 2021; Oustani, 2006).

Plant material and experimental design

Plant material

The plant material used in the study corresponds to two genotypes of quinoa (*Chenopodium quinoa* Willd): Q102 (Amarilla sacaca) and Giza1 (Figure 2). It should be noted that the seeds of the two genotypes were recovered from the study station (ITDAS of Ouargla).

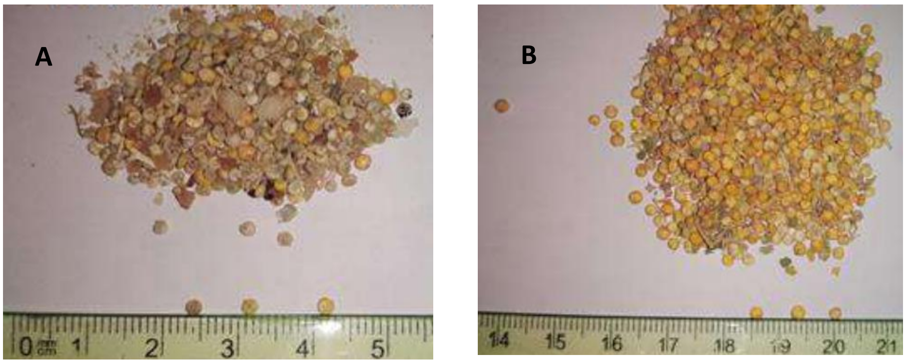

Figure 2. Quinoa genotypes used in the study
***A:** Giza1 genotype; **B:** Q102 (Amarilla sacaca) genotype.*

Experimental design

The field experiment was carried out during the 2018-2019 cropping season. The trial protocol compares the agronomic performance (growth and yield parameters) of two quinoa genotypes (Giza1 and Q102) sown on three different dates: on October 16th (Date 1), October 31st (Date 2) and November 15th (Date 3). The experiments were arranged in a complete randomized block design with four replicates for each genotype. The trial includes 24 elementary plots. The area of each elementary plot is 6 m^2 (3 × 2). Spacing between block, row and seedlings was 1.50, 0.4 and 0.35m, respectively. The sowing for each date was carried out manually by sowing 6-7 seeds per pocket in the soil at a depth of 1 to 2 cm. A seeding density was 15 kg. ha^{-1}. Weeds were manually weeded until the plants were 10 cm tall, then the plants were gradually thinned to 50 cm apart. The plots were irrigated every other day using the drip irrigation system. The irrigation was ceased a week before the harvest. Weeding and phytosanitary treatments were carried out manually to keep the crops weed-free throughout the growing season. The plots were harvested manually at maturity for each date.

Data collection and analysis

Monitoring of some phenological stages was carried out for the two genotypes (Q102 and Giza1) for the three sowing dates. In addition, other measurements related to some vegetative growth parameters (number of seedlings raised per square meter, total number of plants per square meter, total fresh weight of plants per square meter, height of plants at panicle stage, number of branches per plant, average weight per plant) and yield parameters (number of panicles per plant, weight of the main panicle, weight of 1000 grains, and total weight of grains per square meter). These measurements were taken from a sample of ten plants per square meter randomly chosen for each genotype.

Statistical analysis

The results obtained were evaluated by means of an analysis of variance (ANOVA) followed by Fisher's test with 95% confidence interval using SPSS software (version 24). This analysis was applied only for the results relate to the "Q102" genotype due to the futility of having results for the "Giza1" genotype since its growth stopped at an early stage of development.

Result and discussion

Monitoring of some phenological stages of the two genotypes

Before commenting on the results relating to the phenological stages of the two quinoa genotypes studied, it should be noted that for the "Q102" genotype, the harvest was carried out after the physiological maturation of the plant on April 15th, April 29th and May 5th 2019, respectively for the first, second and the third date. As for the "Giza1" genotype, the harvest took place on April 15th, 2019 only for the third sowing date (Table 2) due to the futility of having results for the other two dates (the growth stopped at an early stage of development).

Monitoring of phenological stages of the first sowing date (October 16th)

For the first sowing date, the emergence of the two genotypes took place on the 7th day after the sowing whereas the appearance of two true leaves was observed 20 days after sowing the two genotypes (Table 2). These findings correspond with those of Mujica & Canahua (1989), who reported that quinoa seedling emergence and appearance of the two true leaves will occur at (7–10 days) and (15–20 days) after sowing, respectively for both stages and both genotypes.

According to Mujica & Canahua (1989), the plant reaches the branching stage between 45 to 50 days after sowing and the inflorescence begins to appear from 55 to 60 days from sowing, which is not consistent with the observations made. In fact, in this case, the branching stage was observed 26 days after sowing and the beginning of panicle formation was after 42 days from sowing for both genotypes (Table 2).

Furthermore, Mujica & Canahua (1989) indicate that the complete formation of panicles of quinoa is done from 65 to 70 days after sowing. The flowering took place after 75 to 80 days of sowing, the blooming of 50% of the flowers is observed from 90 to 100 days after the sowing. These durations are totally different from the ones observed in this study.

In fact, the number of days recorded in our case for the "Q102" genotype was 98, 104 and 132 days, respectively, for the three stages of quinoa vegetative growth. The "Giza1" genotype stopped its development at the panicle stage and died, which may have been due to climatic conditions (cold) of the study area in this period.

On the other hand, for the last phenological stage which corresponds to the physiological maturity, it was noted that the plant accelerated its cycle a little and reached the physiological maturation after 182 days of sowing. These findings were similar to those of Mujica & Canahua (1989) for the same phenological stage. These heights indicated that the physiological maturity of quinoa will take place from 160 to 180 days after sowing.

Monitoring the phenological stages of the second sowing date (October 31th)

For the second sowing date, seedling emergence took place 5 days after sowing for both genotypes. The complete appearance of two true leaves was observed on the 11th day after sowing. Branching of leaves on the stem of plants for both genotypes was observed 31 days after the sowing (Table 2).

The beginning of panicle formation was observed on the 48th and 56th days after sowing for the "Giza1" and "Q102" genotypes, respectively. These findings correspond to those of Mujica & Canahua (1989) only for the "Q102" genotype. While they are considered late dates compared to the "Giza1" genotype, which was earlier for this phenological stage.

The complete formation of the panicle was observed after the 94th and 101st days after sowing for the "Q102" and "Giza1" genotypes, respectively. The beginning of flower formation took place on the 111th day after sowing for the two genotypes. While, the blooming of 50% of the flowers was observed on the 115th and 121st days after sowing for "Giza1" and "Q102" genotype, respectively. The physiological maturity for the "Q102" genotype took place 187 days after the sowing; however, the death of the "Giza1" genotype was noticed at this stage of development.

Monitoring the phenological stages of the third sowing date (November 15th)

For the third date of sowing, the emergence of the seedlings, the complete appearance of the two leaves and the branching stage took place on the 4th, 12th and 41st days after sowing, respectively for the two genotypes (Table 2). These durations seem to be earlier than those recorded by Mujica & Canahua (1989).

The panicle appearance was observed on the 78th and 80th days after sowing for the "Q102" and "Giza1" genotypes, respectively. As for the complete formation of the panicle, it was observed after 107th and 97th days after sowing respectively for the "Q102" and "Giza1" genotypes. The beginning of flower formation took place on the 115th and 101st day after sowing, respectively for "Q102" and "Giza1" genotypes.

The opening of 50% of the flowers was observed after 120 days for the genotype "Giza1" and after 137 days for the genotype "Q102". Compared to the results of Mujica & Canahua (1989), the plants in this experiment showed a growth delay for this stage of the vegetative cycle of quinoa for both genotypes.

Physiological maturity for the "Giza1" genotype was observed on the 151st day after sowing, marking a delay of 10 days compared to the observation of Mujica & Canahua (1989). As for the "Q102" genotype, it could not reach this physiological stage. In fact, complete sterility of flowers was reported, which may have been due to climatic conditions and/or varietal characters of this genotype.

The monitoring of the phenological stages of quinoa plants along their vegetative cycle allows for observing a significant variation between the three sowing dates for the "Q102" genotype. In fact, it is noted that there has been a 5 day difference between the first and the second sowing dates for the plants to reach their stage of maturity. The plants in this study matured on the 182nd and 187th days after sowing for the first and second date, respectively.

These findings allow for concluding that the best sowing date for the Amarilla sacaca "Q102" genotype is the first date (October 16th). On the other hand, the third date (November 15th) is considered as an unsuitable date for sowing this genotype under these experimental conditions. In fact, this sowing date did not allow the plant to reach the stage of maturity and the flowers remained sterile.

For the "Giza1" genotype, the best date under these experimental conditions was the third date (November 15th). In fact, the latter is the only date that allowed the plant to reach the physiological maturity stage. The growth delay reported at these stages of the vegetative cycle of our plants may be attributed to the cold weather observed during this period, which delayed the vegetative growth of these plants.

Table 2. Monitoring of the phenological stages of the two studied genotypes

Stage	First sowing date (October 16th)		Second sowing date (October 31th)		Third sowing date (November 15th)	
	Q102	Giza1	Q102	Gizza1	Q102	Gizza1
Seedling	16-10-2018.	16-10-2018.	31-10-2018.	31-10-2018.	15-11-2018.	15-11-2018.
Lifting	23-10-2018.	23-10-2018.	05-11-2018.	05-11-2018.	19-11-2018.	19-11-2018.
Two true leaves	05-11-2018.	05-11-2018.	11-11-2018.	11-11-2018.	27-11-2018.	27-11-2018.
Branching	11-11-2018.	11-11-2018.	01-12-2018.	01-12-2018.	26-12-2018.	26-12-2018.
Beginning of panicle	27-11-2018.	27-11-2018.	26-12-2018.	18-12-2018.	01-02-2019.	03-02-2019.
Panicle	22-01-2019.	22-01-2019.	11-02-2019.	09-02-2019.	02-03-2019.	20-02-2019.
Early flowering	28-01-2019.	-	17-02-2019.	19-02-2019.	12-03-2019.	24-02-2019.
Flowering	24-02-2019.	-	10-03-2019.	05-03-2019.	03-04-2019.	15-03-2019.
Physiological maturity	15-04-2019.	-	05-05-2019.	-	-	15-04-2019.
Number of days	182	-	187	-	-	151

Monitoring vegetative growth and yield parameters

The results obtained show that the sowing date has a significant influence on the number of seedlings raised per square meter, the total fresh weight of plants per square meter, the average weight per plant, the total weight of grains per square meter, the weight of 1000 the grains, and number of panicles per plant. While no significant effect was demonstrated for the sowing date on the total number of plants per square meter, height of plants, number of branches per plant and weight or main panicle (Table 3).

Table 3. Results of analysis of variance for vegetative growth and yield parameters

Parameters	F-value	P-value	Significance
Number of seedlings raised per m^2	56,700	0,000	v.h.s
Total number of plants per m^2	3,192	0,114	n.s.
Total fresh weight of plants per m^2 (kg)	75,221	<0,0001	v.h.s
Height of plants at panicle stage (cm)	3,021	0,066	n.s.
Number of branches per plant	2,923	0,072	n.s.
Average weight per plant (g)	3,365	0,050	s
Number of panicles per plant	9,126	0,001	h.s.
Weight of main panicle (g)	0,006	0,994	n.s.
1000 grains weight (g)	18,195	0,003	h.s.
Total weight of grains per m^2 (g)	7,516	0,023	s

- v.h.s: very highly significant
- h.s.: highly significant
- s: significant
- n.s.: not significant

Vegetative growth parameters

The analysis of variance relating to the number of seedlings raised per square meter indicates highly significant differences between the three sowing dates (Table 3). The Fisher test relating to the classification of the means shows two homogeneous groups: group (A) presented by the second and the third sowing dates with 59 and 65 seeds per square meter, respectively; and group (B) presented by the first sowing date with 35 seeds per square meter (Figure 3, A). On the other hand, the total number of plants per square meter showed no significant difference between the three sowing dates (Table 3). As for the total fresh weight of plants per square meter, the analysis of variance indicates very highly significant differences between the three sowing dates (Table 3). Fisher's test, comparison between categories with a confidence interval of 95%, shows three homogeneous groups: group (A) presented by the third sowing date with 4.545 kg; group (B) presented by the second date with 2.668 kg; and group (C) presented by first sowing date with 0.858 kg (Figure 3, C).

The height of plants at panicle stage and the number of branches per plant showed no significant difference between the three sowing dates (Table 3). On the other hand, significant differences between the three sowing dates were highlighted by the statistical analysis for the average weight per plant (Table 3). Fisher's test shows three homogeneous groups: group (A) presented by the first sowing date with 200.85 g; group (AB) presented by second date with 187.67 g; and group (B) presented by third date with 133.12 g (Figure 3, E).

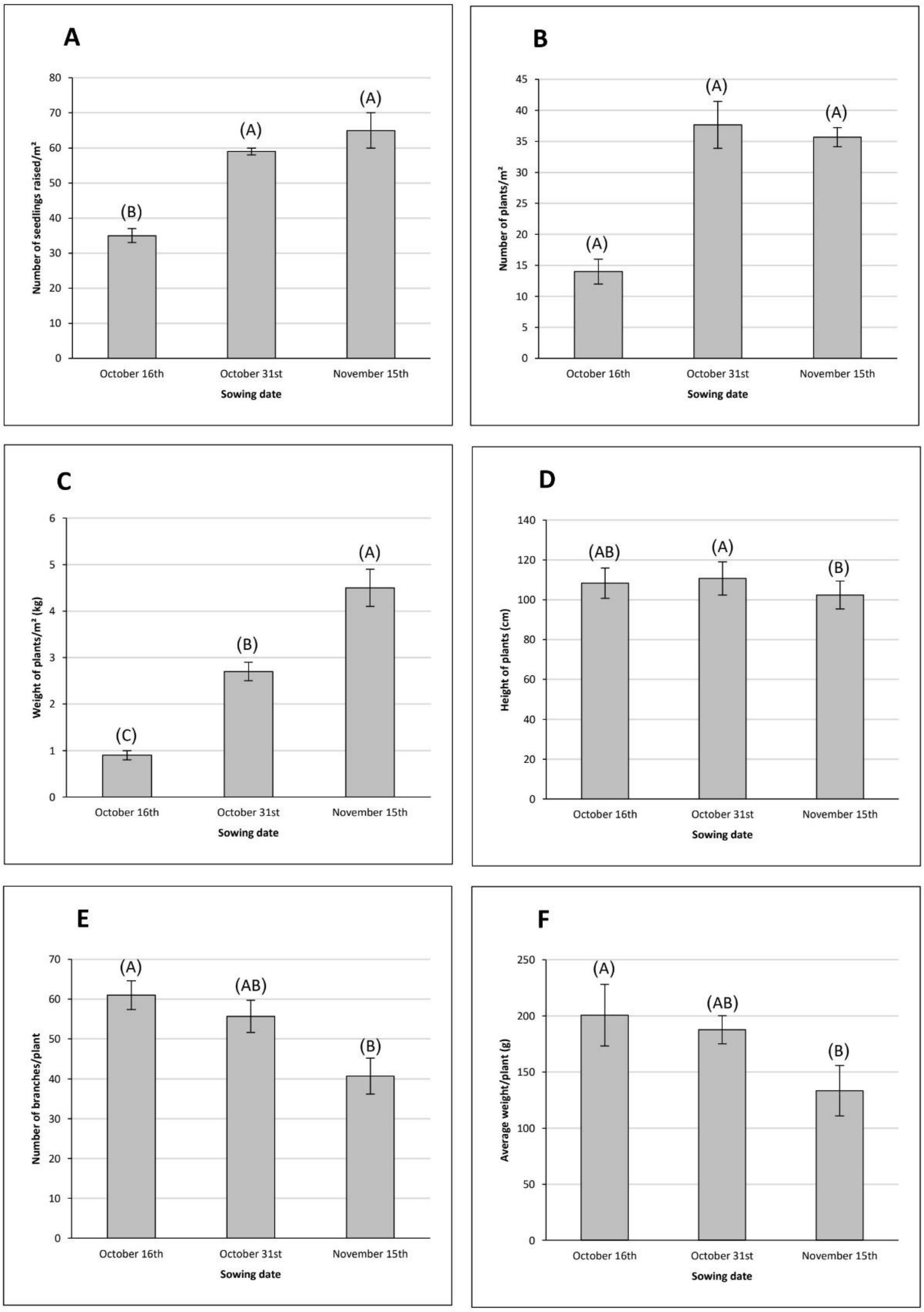

Figure 3. Variation of some vegetative growth parameters for "Q102" genotype as a function of sowing date.

A: *Number of seedlings raised per square meter;* ***B:*** *Total number of plants per square meter;* ***C:*** *Total fresh weight of plants per square meter (kg);* ***D:*** *Height of plants at panicle stage (cm);* ***E:*** *Number of branches per plant;* ***F:*** *Average weight per plant (g).*

Yield parameters

The analysis of variance relating to the number of panicles per plant indicates highly significant differences between the three sowing dates (Table 3). Fisher's test shows two homogeneous groups: group (A) presented by the first sowing date with 39.36 ramifications, the second sowing date with 37.72 ramifications, and group (B) presented by the third sowing date with 20.37 ramifications (Figure 4, A). As for the weight of the main panicle per plant, the statistical analysis showed no statistical difference between the three sowing dates (Table 3). The analysis of variance relative to the 1000 grains weight indicates highly significant differences between the three sowing dates (Table 3). Fisher's test, comparison between categories with 95% confidence interval, shows two homogeneous groups: group (A) presented by the first sowing date with 2.78 g, the second sowing date with 2.28 g, and group (B) presented by the third sowing date with no yield in grains (Figure 4, C). The analysis of variance relative to the total weight of grains per square meter also indicates significant differences between the three sowing dates (Table 3). The Fisher test shows three homogeneous groups: group (A) presented by the second sowing date with 91.62 g (9.16 qx/ha); group (AB) presented by the first sowing date with 52.58 g (5.25 qx/ha); and group (B) presented by the third sowing date with no grain yield (Figure 4, D).

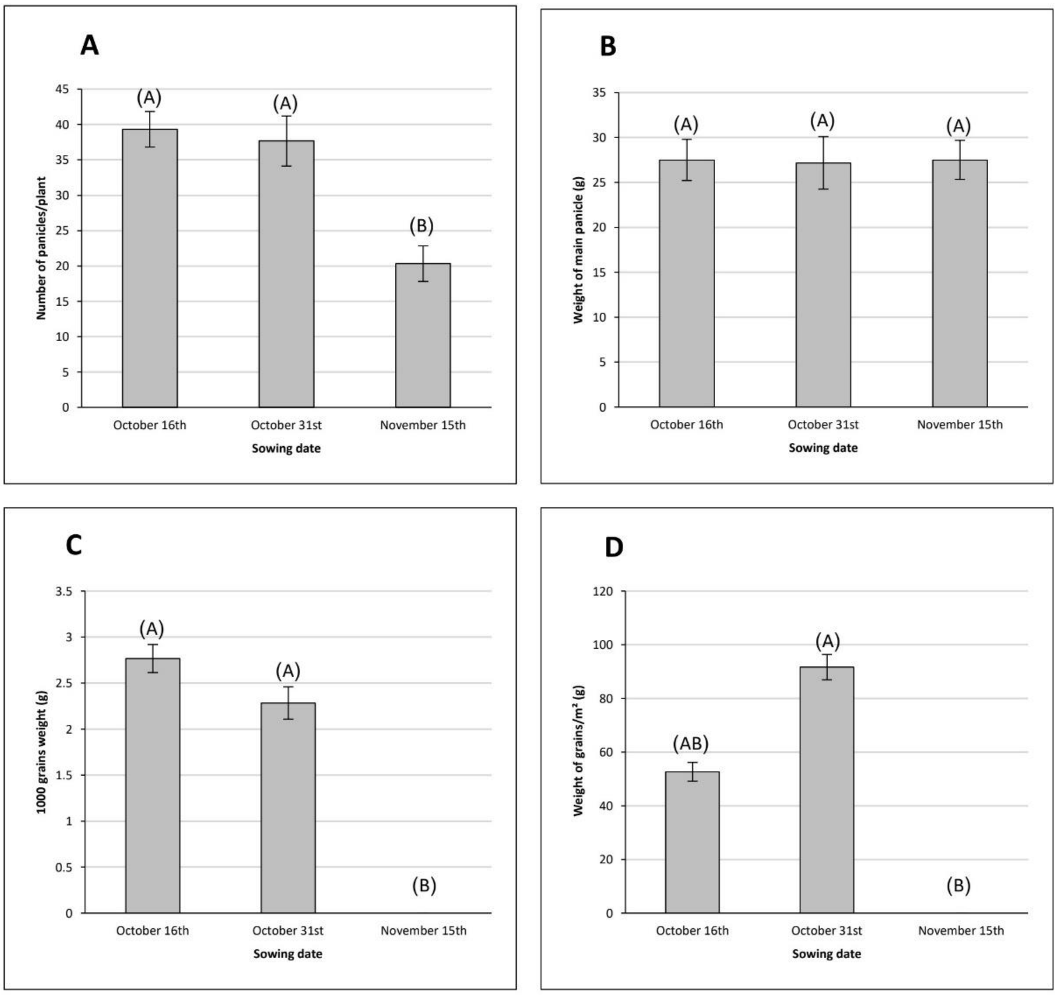

Figure 4. Variation of yield parameters for "Q102" genotype as a function of sowing date
A: *Number of panicle branches per plant;* ***B:*** *Main panicle weight (g);* ***C:*** *1000 seed weight (g);* ***D:*** *Total grain weight per square meter (g).*

In many countries, quinoa has been tested under different climatic conditions with varying yields depending on the sowing time (Aguilar & Jacobsen, 2003; Ujiie et al., 2007). It is considered that the sowing time has a great effect on the yield of quinoa. According to Casini (2019); Temel & Yolcu (2020), sowing dates affected growth and productivity of this plant due to differences in temperature, photoperiod, precipitation and radiation over the year.

According to Hirich et al. (2014), temperature is the main abiotic factor that directly influences the growth, germination and productivity of quinoa. These are also influenced by the varietal characters of each genotype. In fact, the climatic conditions of Ouargla region during the cultivation period have strongly influenced the vegetative growth and yield parameters of the two genotypes studied in this experiment.

According to Programme National de Transfert de Technologie en Agriculture (2005), a temperature above 30 C° render the quinoa plant sterile. In fact, the high temperatures that characterized the period of cultivation, especially at the flowering stage, had a negative influence on the plants of the two studied genotypes, which explains the stunted growth and the low yield obtained.

A high temperature during flowering and seed set can significantly reduce the yield and is one of the major barriers to the global expansion of quinoa (Hinojosa et al., 2019). According to Bilodeau (2016), the production of quinoa seeds requires specific environmental conditions and the pollen can become sterile at temperatures above 28 C°. According to Bois et al. (2006), at temperatures above 38 C°, the flowers abort and the stigmas and stamens die.

Like high temperatures, low temperatures can also affect quinoa plants. According to Hirich et al. (2014), the low temperatures of the winter period have a negative impact on the development of quinoa. In this case, it explains the death of the "Giza1" genotype planted on the first sowing date.

The death of this genotype on the second sowing date (early March) may also be linked to its susceptibility to several insects and diseases compared to the "Q102" genotype. This can be especially admitted if referring to the low saponin content of the seeds of this genotype. Saponin is considered a protective agent against several insects and microbial diseases that can attack quinoa. The same findings have been previously reported by Bilodeau (2016).

The low yields recorded for the first sowing date are due to low temperatures. In fact, a rain followed by a wave of cold air was recorded in the study area; it is possible that these factors prevented fertilization.

Whereas, for the second sowing date, the low yield obtained is due to the effect of frost on fertilization. The persistent and exceptional frost experienced by the Ouargla region at the time of flowering clearly explains the negative results recorded.

Conclusion

The comparison of effect of sowing time on varietal behaviour of the two studied genotypes and their responses to the ecological conditions of the study region allowed to concluding that the best sowing date for the "Q102" genotype is the first date (October 16th), which is ranked the first for most of the parameters studied. Moreover, under these experimental conditions, the "Q102" genotype is better for having a stronger resistance than the "Giza1" genotype and can be grown on the three sowing dates, which is not the case for the "Giza1" genotype, which can reach the physiological maturity only with the third sowing date (November 16th). Hence, the present study clearly shows the potential for success for cultivating quinoa in the Saharan regions of Algeria, and shows an interest of taking both genotype and seeding time into account.

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Author's declaration and contribution

The authors declare that they have no conflict of interest. The authors declare that they have contributed equally to the article.

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