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Article

Cultivation of (*Chenopodium quinoa* willd.) During Both Spring and Autumn Seasons in Constantine-Algeria

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Abstract: Quinoa's nutritional advantages have recently brought this plant back into the spotlight; however, this resurgence brings forth new ecological, scientific, and financial challenges. The crop's provenance and genetic diversity, exceptional resilience to salt and dryness, as well as its nutritional attributes, are the reasons behind its potential to offer various ecosystem services and the role of those Andean farmers in safeguarding the area's agro-biodiversity. This study aimed to investigate the pheno-morphological traits and yield variations among four quinoa varieties (*Chenopodium quinoa* Willd.) and their adaptation to semi-arid soil and climate conditions in El Khroub, Constantine, Algeria. The results show that all the factors examined in two different seasons vary considerably in terms of yield and quality. In both seasons, the varieties ASQ and Q26 proved to be the best-yielding. Highly significant positive relationships were found between grain size, WTG and grain yield, which were negatively related to flowering days, and that the four varieties show distinct responses according to the rainfall conditions they encounter. Considering the importance of this crop in semi-arid zones, this seed could be adapted to the semi-arid regions of Constantine.

Keywords: automne; quinoa; morphological characters; saponin; spring; yields.

1. Introduction

Between 3000 and 5000 BC, quinoa has been a staple diet for communities; in fact, the Aymara Indians named this plant "chisya mama," meaning "the mother of all seeds" [1]. Actually, quinoa is truly a fascinating plant species, with extraordinary nutritional value and the ability to survive in unfavourable climatic conditions. Consequently, further studies are warranted in all branches of plant biology, agronomy, and ecology. However, we also believe it's critical to keep in mind that quinoa's diverse genetic and cultural history must be protected throughout the International Year of Quinoa [2].

The investigation into the relationships between seasonal climate fluctuations and recurring biological events such as germination, blooming, migration, and reproduction, as defined by [3], is known as phenology.

However, it has been suggested that sea-level cultivars in Chile may be less sensitive to the negative effects of high temperatures and long days, which may explain their wider adaptation. Variability between cultivars in sensitivity to photoperiod and temperature for processes determining the onset of seed filling has not been quantified [4]. According to multiple studies, quinoa is also resistant to a number of environmental stress conditions, including drought, soil salinity, frost, disease, and pests [5, 6]. High-quality seeds should be sown at a depth of 1-2 cm in a uniform, finely structured, wet seedbed at a temperature of 8–108 °C to provide the best results [4]. The planting season lasts from August to December in the Andean highlands and from January to March in other areas [7]. Quinoa can grow with very little irrigation or little to no rainfal [8].

Quinoa cultivars often have little to no pigmentation on their leaves, stems, branches, and seeds in the agro-ecological zone (circunlacustre) closest to the lake. When in the vegetative phase of growth, panicles are green, and the seeds turn white when they are fully mature [9]. The purpose of this kind of study is to characterize quinoa's reactions to precipitation and flowering temperature in order to comprehend the fundamentals of quinoa's seasonal adaptability.

Biochemistry Quinoa seeds are characterized by the presence of saponins, which limits their use as a food. Their quantification is a useful parameter for distinguishing sweet genotypes from Ecuador and Bolivia and bitter genotypes from southern Chile; bitter genotypes contain more saponins (> 470 mg /100 g) than sweet genotypes (20-40 mg /100 g) [10,11].

The aim of the present study is to characterize quinoa's responses to rainfall and flowering temperature in order to understand the basis of quinoa's seasonal adaptability. Thus, to evaluate earliness precocity and 15 measures of morphological descriptors between four quinoa varieties of diverse origins and to quantify by applying approaches on yield and its components in the semi-arid region.

2. Materials and methods

Plant material

In this study, four quinoa varieties from different nations were assessed in rainfed conditions. These varieties included *Ammarilla Sacaca* (ASQ), *Santa Maria* (SMQ), *Salcedo inia* (SIQ), and *Q26*. The current investigation focuses on the growth of these four quinoa varieties. Research was conducted at the Institut Technique des Grandes Cultures (ITGC) in El Khroub, with fieldwork conducted during two seasons in the semi-arid region to examine variability in morpho-phenological traits: autumn (cultivated at the end of October 2022 and harvested at the beginning of May 2023) and spring (cultivated at the beginning of March 2022 and harvested in August 2022).

Location of the experiment

The experiment at the ITGC site in El Khroub, Constantine, Algeria, was conducted at an elevation of 640 meters, with a latitude of 36.25 degrees North and a longitude of 6.67 degrees East (Fig. 1). The soil at the site exhibits a flat contour, a dry, slimy-clayey texture, and a depth of 120 cm. The area has a Mediterranean climate, semi-arid bioclimatic stage, and 450 mm of annual rainfall on average over a 25-year period.

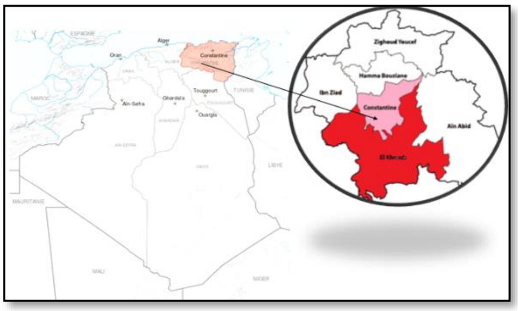

Figure 1. Geographical location of the study area.

Experimental set-up

A fully randomized block design with four blocks was adopted for the experimental setup. Three rows measuring 4 m each, placed 0.5 m apart, make up each micro-plots.

Experimental site conditions

At the site, both seasons experienced low rainfall at the beginning of the cycle, necessitating the use of irrigation to facilitate germination.

Table 1. Temperature and rainfall in the wilaya of Constantine during the spring growing season.

Season spring	March	April	Mai	June	July	August	Total
Tempe Max	24.6	28.0	37.9	43.1	42.3	42.2	-
Tempe Min	16.5	20.5	27.0	36.6	37.0	35.1	-
Cumul Precips	38.6	15.2	24.8	0.6	0.4	4.0	83.6

Table 2. Recorded temperature and rainfall in the wilaya of Constantine during the autumn growing season.

Season Fall	October	November	December	January	February	March	April	Total
Tempe Max	31.7	28.0	21.7	18.6	23.8	27.7	32.4	-
Tempe Min	28.2	20.3	17.6	11.9	14.0	19.0	21.9	-
Cumul Precips	33.5	61.7	22.0	47.4	14.2	11.4	19.8	210

Parameters measured in the field

Morphological characteristics

The standard characteristics listed in the Test Guidelines are those accepted by the International Union for the Protection of New Varieties of Plants (UPOV) [12].

a) Foliage: color (F/C); glaucescence (F/G).

b) Leaf: size (L/S); serration (L/D); base angle (F/A).

c) Stem: color (S/C); striae (S/S); striae color (S/CS); leaf axil pigmentation (S/P); height (P/H).

d) Inflorescence: color (I/C).

e) Panicle: color (P/C); density (P/D).

f) Seed: color (S/CL).

g) Total saponin: The saponin content of the seed is measured using a foam test. Typical afrosimetric method [13].

Precocity parameter

a) Days to flowering: the duration in days between the emergence date and the date when roughly 50% of the plants in a plot are in flower.

b) Days to maturity: the duration in days from the emergence date to the maturity date, when the plant has started to dry.

Yield parameters

The determination of yield and its components was carried out on all 10 plants and included seed yield as well as weight thousand-grain (WTG) and size grain (S/G).

Data processing and analysis

The analysis of variance (ANOVA) was conducted using SPSS software. If a significant difference was observed, the data were further examined for distinct groups using the Newman-Keuls test of comparison of means at the 5% cutoff. To explore relationships between agronomic characteristics, principal component analysis (PCA) and Pearson correlation coefficients were calculated. Additionally, to enhance understanding of patterns of variation among varieties, cluster analysis was employed using the distance matrix of morphological data as input.

3. Results

Morphological studies

Four types of quinoa cultivated in the semi-arid zone were assessed for their various qualitative morphological traits using fifteen morphological descriptors. Leaf colour exhibited variability based on the variety, as indicated by the leaf character descriptors (leaves and foliage): medium green leaves were observed in SIQ and Q26, dark green in SMQ, and purple in ASQ. Glaucescence was also prevalent in the SIQ, SMQ, and ASQ cultivars. Notably, SIQ and ASQ displayed broader leaves compared to SMQ and Q26. In terms of leaf serration, Q26 had nine to twelve teeth, SMQ had more than twelve teeth, and ASQ and Q26 both exhibited three to six teeth.

Five characteristics were taken into account while determining stem descriptors: leaf axil pigmentation, which was more pronounced in SMQ and ASQ kinds than the others; stem colour and striae, which varied from green in SIQ, Q26, and SMQ to purple in ASQ with striae present in all varieties.

The plant heights of the four quinoa varieties could be easily identified in both spring and autumn, and the mean heights of the different varieties were significant ($P > 0.001$). In spring, the ASQ variety recorded the highest quinoa height, at 61.66 cm; the two types Q26 and SIQ recorded the lowest heights, at 51 and 51.66 cm, respectively. In contrast, the height of the SMQ variety was 54.33 cm. For the autumn season, quinoa varieties showed a slight increase in height, with the exception of the SIQ variety. It recorded a height of 39.33 cm. The three varieties Q26, SMQ and ASQ measured 69.33, 72.66 and 81 cm, respectively (Table 3).

Throughout the two seasons, there was a wide divergence in the total saponins of the four quinoa varieties. Analysis of variance of total saponin revealed a highly significant difference ($P < 0.0001$). In spring, the two types ASQ and SIQ showed saponin variations of 4 and 5.63 cm, respectively, while the two varieties Q26 and SMQ had the same estimates of 0.7 and 0.7 cm, respectively. In contrast to the observations during the autumn season, which showed a noticeable drop in the saponin content of all the varieties examined. The levels for varieties Q26 and SMQ were 0.36 and 0.39 cm respectively. In contrast, the values for the two varieties ASQ and SIQ were 3.56 and 5 cm respectively (Table 3).

Hierarchical cluster analysis

To provide a more detailed description of the observed relationships, a similarity-based grouping of observable features was utilized (Fig. 2). The dendrogram resulting from the hierarchical classification of measurable features based on similarity reveals three distinct character groupings:

The relationships depicted in Figure 2 were further delineated by clustering measurable features based on similarity. The dendrogram resulting from the hierarchical classification of measured features according to similarity reveals three-character groups:

- Class 1: This class consists of the SIQ variety, which is the initial group in the cluster.
- Class 2: consists of two types: Q26 and ASQ.
- Class 3: This group is composed of the SMQ variant. The difference between classes 1 and 3 is 6.48%. Classes 2 and 3 are separated by a distance of 6.85%. The significant difference between classes 1 and 2 is 7.81 percent.

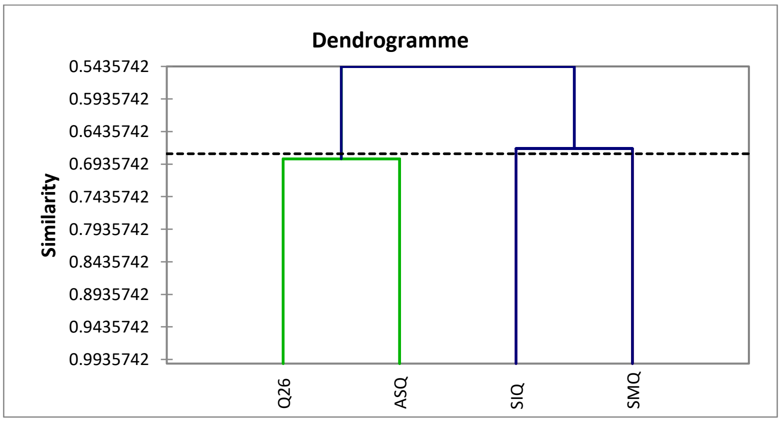

Figure 2. Hierarchical dendrogram illustrating the relationships between the qualitative characteristics of the quinoa varieties studied

Precocity study

The results of the phenological phases of the four quinoa varieties from the semi-arid region were documented. The development cycle of the SIQ and Q26 varieties for the spring season began fairly early, and that of the SIQ, Q26 and ASQ varieties for the autumn season between 3 and 7 days.

Analysis of variance reveals a highly significant difference (p< 0.0001). For the two varieties SIQ and Q26 in spring, the flowering phase lasts less than 80 days compared with the others. Comparing the two varieties, the flowering phase required 80 days for SMQ and 98 days for ASQ. On the other hand, SIQ and ASQ last 100 days during the autumn season, while Q26 and SMQ last less than 100 days.

Whereas the maturation stage took over 130 days for the SMQ and ASQ variety in spring. Analysis of variance for the number of days of flowering (NDF) and number of days of maturation (NDM) reveals a highly significant difference (p<0.0001). physiological maturity took place in less than 130 days for both varieties SIQ and Q26. Although the SIQ and Q26 varieties had an autumn season of less than 190 days, the SMQ and ASQ varieties had an autumn season of more than 190 days (192 and 206 days, respectively) (Table 3).

Yield study

A frequency distribution was employed to enhance the categorization of varieties based on seed size (mm), thousand-seed weight (WTG), and grain yield measurements taken over two seasons using a random sample of seeds in each replicated plot (Table 3).

The two seasons and the four varieties of quinoa studied had different grain diameters. The results for grain diameter were not statistically different (P<0.05). In spring, the three varieties (SMQ, Q26 and ASQ) have different grain diameters of 2.16, 2.33 and 2.5 mm, respectively. Whereas the SIQ variety has the smallest estimated diameter (1.66 mm), respectively. This compares with the autumn season data (table 3), which showed a relative reduction in seed diameter for two varieties, Q26 and SMQ, with diameters of 1.5 and 1.33 mm, respectively. In contrast, the diameters of the two varieties SIQ and ASQ grew relatively, measuring 2.16 and 2.83 mm respectively.

The WTG values tended to converge for all four quinoa varieties. Results were not statistically different (p<0.01). The ASQ variety obtained the highest WTG value for the spring season with 2.9 g, while the Q26 variety came second with 2.2 g. In contrast, the two quinoa varieties, SIQ and SMQ, achieved the lowest WTG values of 1.64 and 1.86 g, respectively. During the autumn season, the ASQ variety showed an improvement in WTG, with a weight of 3.3 g, while the three varieties SIQ, Q26 and SMQ showed a slight decrease in WTG, with the same weight recorded for the two varieties SIQ and SMQ of 1.86 g. Given that the WTG of variety Q26 was 2 g, (table 3).

That all the quinoa varieties studied had reasonable grain yields. The three quinoa varieties studied also visibly converged in terms of WTG over the two seasons. With the exception of ASQ, which diverged from the other varieties (Table 3). The results vary considerably (p<0.0001). The highest yield estimate during the spring season was recorded for ASQ with 8.43 qt/ha. While the three varieties SIQ, SMQ and Q26 had yields varying respectively between 3.35, 3.42 and 5.22 qt/ha. For the two varieties SIQ and ASQ, we observed a significant increase in grain yield throughout the autumn, with yields of 4.7 and 12.9 qt/ha, respectively. In contrast, the two varieties Q26 and SMQ recorded a remarkable reduction in yield. Q26 yielded 4.83 qt/ha. The lowest yield was achieved by SMQ, at 2.38 qt/ha.

Table 3. Variables values measured in the studied varieties of quinoa.

Season	**Varieties**	**NDF**	**NDM**	**WTG**	**Yield (qt/ha)**	**S/G**	**HP**
Spring	**SIQ**	78 ±1.11(a)	125 ±1.11(a)	1.64 ±0.11(a)	3.39 ±0.28(a)	1.6 ±0.44(a)	51.66 ±5.55(a)
	Q26	72 ±0.44(a)	128 ±1.11(a)	2.2 ±0.12(b)	5.22 ±0.56(b)	2.1 ±0.44(b)	51 ±7.33(b)
	SMQ	80 ±1.77(b)	135 ±1.77(b)	1.86 ±0.18(a)	3.42 ±0.22(b)	2.1 ±0.22(b)	54.33 ±4.22(b)
	ASQ	98 ±1.11(b)	147 ±1.17(b)	2.90 ±0.14(b)	8.42 ±0.86(b)	2.6 ±0.2(b)	61.66 ±7.77(b)
Fall	**SIQ**	100 ±1.33(b)	172 ±1.77(a)	1.86 ± 0.04(a)	4.70 ±0.44(a)	1.5 ±0.55(b)	39.33 ±2.22(a)
	Q26	72 ±1.55(a)	185 ±3.33(a)	2.00 ±0.046(a)	4.84 ±0.42(a)	2.3 ±0.33(a)	69.33 ±3.55(b)
	SMQ	82 ±1.33(b)	192 ±1.11(b)	1.86 ±0.04 (b)	2.38 ±0.29(b)	1.3 ±0.44(b)	72.66 ±11.55(b)
	ASQ	100 ±2.22(a)	206 ±1.17(b)	3.30 ±0.22 (b)	12.9 ±0.69(b)	2.9 ±0.22(b)	81 ±9.33 (b)
Sig-level	**	***	***	*	***	*	*

*,**,*** significant effects at 5,1, 0.1 %, respectively. In each column different letters mean significant differences ($p<0.05$). **NDF:** number days of flowering; **NDM:** number days of maturation; **WTG:** weight of thousand grains; **S/G:** size grain; **H/P:** height of plants; **qt/ha:** quintal / hectare.

Correlation between variables

Positive correlations between the measured values, ranging from low to high correlation, are revealed by the analysis of the correlations between the parameters (Table 3).

We can determine the elements to be used as selection criteria by understanding the connections between the various qualities. On the other hand, the correlation analysis (Table 4) revealed a strong positive association between yield and S/G (r = 0.84) and WTG (r = 0.96). Significant positive associations were also seen between WTG and NDF (r=0.59), S/G (r=0.85), and HP (r=0.56).

Table 4. Matrix of correlations between variables.

Variables	**NDF**	**NDM**	**WTG**	**Yield (qt/ha)**	**S/G**	**HP**
NDF	**1**	0.3960	0.5948	0.6253	0.2722	0.0608
NDM	0.3960	**1**	0.3849	0.4087	0.1674	0.6840
WTG	0.5948	0.3849	**1**	**0.9604**	**0.8554**	0.5680
Yield (qt/ha)	0.6253	0.4087	**0.9604**	**1**	**0.8484**	0.4964
S/G	0.2722	0.1674	**0.8554**	**0.8484**	**1**	0.4903
HP	0.0608	0.6840	0.5680	0.4964	0.4903	**1**

NDF: number days of flowering; **NDM:** number days of maturation; **WTG:** weight of thousand grains; **S/G:** size grain; **H/P:** height of plants; **qt/ha:** quintal / hectare.

PCA analysis

A principal component analysis (PCA) was performed on the 6 variables. The percentage of information given by axis 1 is 61.90% and that given by axis 2 is 18.78%, i.e. 80.68% of the total variation (Figure 3). On the positive side, axis 1 is defined by the majority of productivity-related traits, including WTG (r=0.49), Yield (r=0.49), S/G (r=0.42), and NDF (r=0.31). HP (r=0.58) and NDM (r = 0.64) determine the positive side of axis 2 (Table 5).

Table 5. Projection of the various traits studied onto the planes of the two PCA axes.

	F1	**F2**
NDF	0.3191	-0.2773
NDM	0.3081	0.6473
WTG	0.4982	-0.1931
Yield (qt/ha)	0.4951	-0.2237
S/G	0.4273	-0.2664
HP	0.3568	0.5881

NDF: number days of flowering; **NDM:** number days of maturation; **WTG:** weight of thousand grains; **S/G:** size grain; **H/P:** height of plants; **qt/ha:** quintal / hectare.

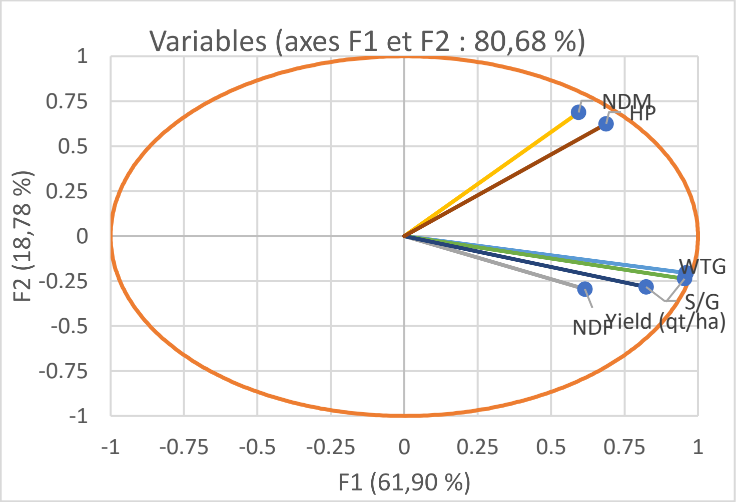

Figure 3. Correlation graph of analyzed precocity and yield parameters.

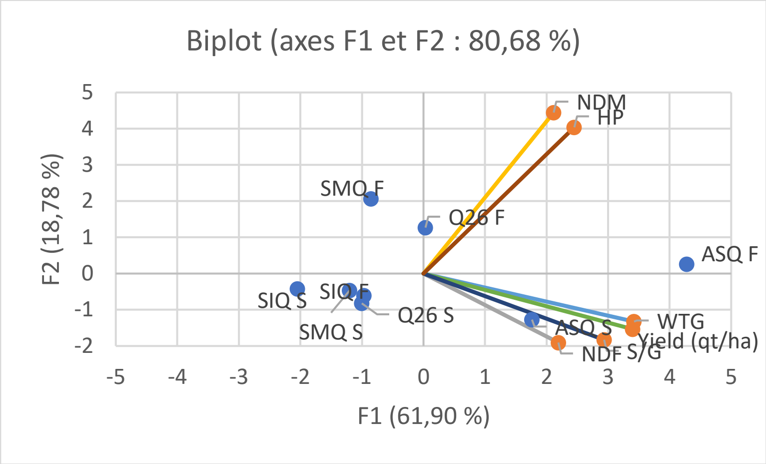

Figure 4. Graph showing correlations between varieties and the precocity and yield parameters analyzed.

4. Discussion

Temperature and precipitation differ during the spring and autumn seasons. In our study, climatic changes were mainly characterized by a decrease in water availability and an increase in temperature. Only 83.6 mm of total precipitation fell on the crop during the spring season, compared with 210 mm in the autumn. On the other hand, during spring cultivation, plants were exposed to high temperatures ranging from 37°C to 43 °C at flowering. In this study, the four quinoa varieties showed differences in phenology throughout the life cycle in both seasons. The varieties showed a longer vegetative phase; they reached visible flowering 60 days after emergence in both seasons. These results are in agreement with those of [14], their quinoa crop underwent a long vegetative phase. It's worth noting that in spring, both varieties SIQ and SMQ are semi-precocious, variety Q26 is late and variety ASQ is precocious. In autumn, variety Q26 is also early, variety SMQ is semi-precocious and varieties SIQ and ASQ are late. These results concur with those of [15], Both quinoa cultivars grew between 120 and 240 days, from sowing to harvest. According to [16], this means that different genotypes have different durations for their developmental stages, and different total growth periods: 126-157 days in Europe, 131-200 days in Peru and 110-190 days in South America. [7] states that quinoa can reach physiological maturity in 70 to 90 days; or it can take between 5 and 8 months to mature, depending on the type.

Given the early maturity of this plant, the timing of flowering could be retained as a valuable agronomic trait [3]. The manifestation of considerable genotypic heterogeneity and the effect of environmental variables both contribute to the development of significant phenotypic variability, as all these results show [17].

In general, the spring crop matures earlier than the autumn crop. During their growth cycle, the different varieties experienced abundant rainfall in June (0.6 mm), which likely affected flowering stages and created anaerobic conditions in the soil. These conditions may have contributed to growth differences between the two planting seasons. Seasonal temperatures reaching 43°C can significantly influence physiological maturity dates, grain yield, and the onset of flowering. Our findings align with those of [18], who observed early ripening in the Titicaca variety of quinoa under drought stress. Additionally, [5] suggest that variable phenology and early maturity are strategies employed by quinoa to adapt and escape water limitation". [19] has reported that the timing of flowering depends on the interaction of various complex processes that are controlled by genetic and/or environmental variables. This could be associated to the need for more water during flowering [20]. According to [21], irregular rainfall and high temperatures, which also contribute to desertification by reducing vegetation cover, are variables that limit the growth of plant species. Contrary to the effects of heavy rainfall, wet periods during the growing season have a significant impact on crop growth and yield due to the waterlogging or leaching of soil nutrients, as well as the concentration of specific ions that can be toxic and cause a defect in soil construction [22]. Ensuring water availability for all critical phenological stages (panicle formation, flowering and grain filling) is strongly recommended. However, early sowing is recommended in autumn to receive maximum annual rainfall.

The most precocious spring varieties had the shortest heights, attaining only less than 100 cm, while maximum plant height was observed during the majority of autumn season varieties. These results are consistent with [14]; they both reported that quinoa presents a height between 56 and 84 cm. Where, lack of rainfall has a detrimental effect on quinoa performance. As [23], indicates quinoa variety characteristics and growing environment have a significant impact on plant height. [24] demonstrate that the environment has a significant impact on plant height, in particular growth-limiting elements linked to meteorological parameters such as rainfall and thermal variations that can hinder plant development. In the absence of irrigation, [25] found that quinoa plants decreased considerably in height. [26] suggest that drought disrupts mitosis, cell elongation and expansion, resulting in reduced growth. Or, in the event of water deficit, perturbation of water flow from the xylem to the adjacent elongated cells may prevent the plant's superior cells from elongating, leading to reduced cell enlargement and increased leaf senescence in drought-exposed plants [27].

Quinoa's high saponin content, which varies from 0.1 to 5% of the seed, is one of its inconveniences [7]; its high content has made it difficult to diversify this crop. The different quinoa varieties had varying amounts of saponin. Among the abiotic factors influencing plant metabolism, and in particular saponin content, is water availability. Comparing the two seasons, spring saw an increase in the number of saponins in the seeds. The saponin content of some quinoa seeds varies according to the growing environment; in general, a dry climate presents higher saponin content [28]. Our results appear to be in line with those of [29], who found that quinoa seeds responded to drought by producing more saponins. According to a study by [8], the quinoa cultivar with high initial saponin content decreased by 9% under high irrigation and increased by 25% under low irrigation. In contrast, the cultivar with low initial saponin content decreased by 26% and 57% under high and low irrigation conditions, respectively.

Based on [30], the climatic temperature profile during the plant's growing season proved to be the decisive factor for yam saponin concentration. On the other hand, the steroidal saponins spirostanol and furostanol were shown to be more abundant at lower soil temperatures. [11] found that saponin levels were higher in trees growing in difficult environments. These results implicate that stress leads to an increase in saponin synthesis, which may play a role in a plant's ability to adapt to harsh soil-climate conditions. [8] affirmed that the saponin concentration measured varied between types and remained constant within the same order of magnitude from one harvest to the next. As regards the impact of irrigation conditions on saponin content, we are unable to conclude.

The grain size of quinoa exhibits notable variability across its four varieties. The SIQ and ASQ variants display the largest grains during autumn, whereas the Q26 and SMQ varieties exhibit their largest grains in spring. In a study by [31], grain diameters were reported to range from 1.44 to 2.15 mm. This variation may be attributed to the restrictive conditions prevalent during spring, particularly during the June–August period, coinciding with grain filling and flowering, resulting in a reduction in grain size. Furthermore, [32] found that heat stress could account for differences in seed size among various irrigation treatments. This stress was mitigated under conditions of long days and warm temperatures 21 days post-anthesis. Additionally, grain size may be influenced by the structure of panicles and their arrangement. However, [33] propose in the context of wheat that larger ears tend to produce larger grains, alongside constitutively smaller grains formed at distant positions.

Evaluation of Chilean germplasm under high-altitude conditions and multi-environment trials by [34] revealed significant differences in grain morphological characteristics among variables, suggesting the potential for genetic progress through simultaneous selection for both traits.

Quinoa varieties grown in two distinct seasons—spring and autumn—showed a significant decrease in WTG in spring, with the exception of the Q26 variety which produced a high WTG in autumn. Our results range from 1, 64 to 3, 3 g. These findings are consistent with those of [31], who estimated a WTG of between 3 and 4, 75 g. Temperature and rainfall are the explanatory variables that determine whether WTG levels drop or increase [31]. Moderate drought stress during grain loading is most likely the cause of the poor distribution of rainfall in the spring. The reduction in WTG seen in springtime quinoa varieties aligned with the findings of [15], who reported a correlation between this feature and the degree of water stress. In a similar vein, under heat stress, the WTG of quinoa seeds varied from 0.24 to 0.45 g [32].

Environmental factors can influence yield components both positively and negatively [35, 36]. Improvements in panicle width, Nb G/P, and WTG appear to be directly correlated with this phenomenon [37]. According to the results, the varieties performed better in autumn than in spring, yielding moderate harvests. The extended period of soil drying and high temperatures likely contributed to the low cereal production in spring. These findings align with those of [31], who noted that plants in northern regions yield very low quinoa grain quantities, ranging from 3.4 to 8.09 qt/ha, and in the central Bolivian Altiplano, between 1.2 and 2 Mg/ha [38]. In southwestern North America, between 1.88 and 19 qt/ha [32]; or less than 1 qt/ha in southern Chile [14]. These findings support other research that demonstrates drought can lead to poorer yields; two studies on the subject of quinoa, one by [15] and the other by [39], demonstrated this relationship. [40] found that genotypes varied greatly in terms of morphological characteristics and yields under three distinct water regimes. [38] quinoa study shown that drought stress during flowering and early grain filling significantly reduces yield. They do, however, contend that irrigation is necessary for early grain filling, flowering, and plant establishment in order to stabilize production over time. Thus, stomatal closure in response to low soil water content may be responsible for the drought-related reduction in plant yield that leads to reduced CO_2 absorption and, in turn, photosynthesis [27]. Furthermore, reduced yields have been associated with temperatures exceeding 40°C during both the blooming and seed-filling stages. [32] observed that when temperatures surpassed 35°C, inflorescences either produced no seeds or yielded empty seeds, consistent with findings from studies on quinoa. Additionally, research conducted by [14, 41] demonstrated diminished yields in regions exposed to intense heat, attributed to the adverse impacts of high temperatures on biomass production. Similarly, [42] revealed that elevated temperatures (35°C) during quinoa flowering led to the reabsorption of seed endosperm and inhibited anther dehiscence in flowers. Stress has a less damaging impact on organisms during the reproductive phase than the vegetative phase. According to [43], these effects are phase-specific and are most apparent during flowering and seed development; and suboptimal temperatures and drought at flowering, according to [26, 44] are crucial as they can increase pollen sterility and reduce yield.

5. Conclusion

In the semi-arid region of Algeria, a study was conducted to explore the pheno-morphological diversity of four quinoa varieties, aiming to assess the agro-morphological characteristics of this crop. The distinct morphological variations inherent to each variety were elucidated through fifteen morphological traits. Notably, the study found that temperature and drought had a substantial influence on quinoa growth, development, and productivity, diverging from conventional literature predictions. This complexity may be attributed to various environmental factors and the timing of planting. Despite these challenging climatic conditions, the autumn season is recommended as the optimal sowing period for comparative seasonal research on quinoa cultivation. Additionally, based on yield and WTG (waiting to germination), the varieties ASQ and Q26 are proposed as promising options. Low soil water availability frequently coincides with the grain filling period, resulting in low-yielding harvests. Consequently, cultivation should be carried out in autumn to benefit from autumn rains and moderate temperatures during the vegetative phase, or growth should start before early spring to avoid the end of the vegetation period and the hot, dry climatic conditions of summer in semi-arid regions, which make harvesting difficult and reduce seed quality. Thus, our initial results lead us to identify quinoa as a plant resistant to very difficult environmental conditions, and the significant correlations observed between morphological and agronomic characteristics make the traits concerned relevant indices for use in breeding programs. As a result, our preliminary findings indicate quinoa's resilience to challenging environmental conditions. Furthermore, the notable correlations observed between morphological and agronomic traits suggest that these characteristics can serve as valuable indicators in breeding programs.

To this end, the availability of water-tolerant quinoa varieties, the provision of drainage infrastructure and the dissemination of relevant seasonal information to farmers could help them better organize and profit from their farming activities, making quinoa a promising alternative crop for arid and semi-arid regions.

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