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Early Sowing of Quinoa to Enhance Water Use Efficiency and Yield under Arid Conditions in Morocco †

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Abstract: Quinoa is a potential alternative crop for an adaptation strategy for salinization and climate change effects in dryland. A sowing date of February practiced in the Rehamna region, Morocco, resulted in stunted plants and low yields due to insufficient precipitations and high temperatures around the flowering stage. For this reason, a field experiment was conducted to investigate the effect of sowing date on quinoa water use efficiency, growth, and yield. The experiment was conducted at the UM6P experimental farm to evaluate five sowing dates for two short cycle quinoa cultivars. The results showed that the most early suitable sowing date of quinoa in the Rehamna region was December. Late sowing dates resulted in a significant decrease in WUE, growth and yield. The highest grain yield (0.84 t ha^{-1}) was obtained by ICBA-Q5 sown in December.

Keywords: sowing date; precipitation; temperature; water use efficiency; supplemental irrigation

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1. Introduction

Quinoa is used as alternative crop in the dryland of Morocco for soil salinity mitigation and drought tolerance. It is important to evaluate its performance after moving its cropping cycle backward. Planting date is one of the important agronomic practices for the success of the crop, and the optimal date depends on rainfall and its distribution, soil humidity and cultivar [1].

Rehamna is an arid region with annual precipitations rarely exceeding 170 mm. In addition, irrigated agriculture is threatened by water salinization that could reduce yields by up to 50% [2]. Quinoa tolerates better salinity and drought in comparison with cereals (wheat and barley) and has high nutritional and economic value, which makes it a strategic crop to increase farmers' income and improve food security [3]. Quinoa planted in February and March exhibited accelerated development and low yields due to high temperature and evapotranspiration associated with dry spells. Therefore, early planting of quinoa associated with supplemental irrigation, if needed, has increased rainwater use efficiency (WUE) and alleviated heat stress. In addition, the use of supplemental irrigation was reported to be a good strategy to secure and stabilize yield when rainfall is insufficient [4].

The only results published in Morocco so far are those carried out by [5] in Agadir, where quinoa sown in November and early December gave the highest grain yields with an average of 2.8 t ha^{-1}. Most previous research on quinoa had focused on evaluating the sowing date of quinoa long cycle cultivars with full irrigation. However, sowing quinoa short cycle cultivars with supplemental irrigation during sensitive stages was given little attention and needs to be more explored, especially under the arid climate of Morocco. Thus, the objective of the present study was to identify the most appropriate planting date for two commonly used quinoa short cycle cultivars (ICBA-Q5 and Titicaca) in Rehamna region, Morocco.

2. Material and Methods

A field experiment was carried out during the 2020–2021 cropping season at the experimental farm of UM6P. The soil is a sandy clay loam, having 1.86% of OM and pH of 8.28. Water used for supplemental irrigation has an Ec = 3.3 mS/cm. Two cultivars, ICBA-Q5 and Titicaca were used, and the planting dates were each month from 15 November to 15 March. The experimental design was a randomized complete blocks design with four replications. Full irrigation was applied to fulfill the crop's water requirement during the plant establishment, flowering, and seed filling stages. The quantity of irrigation water received by each treatment was around 140 mm and the quantity of rainfall received differed according to cultivars and sowing dates (Table 1).

Table 1. Amount of water received by each sowing date and cultivar.

	Rainfall (mm)+ Irrigation (mm) = Total Amount of Water Received (mm)				
	November	**December**	**January**	**February**	**March**
ICBA-Q5	77 + 140 = 217	108 + 142 = 250	76 + 139 = 215	65 + 144 = 209	8 + 148 = 156
Titicaca	119 + 142 = 261	108 + 141 = 249	78 + 140 = 218	65 + 142 = 207	9 + 145 = 154

Daily monitoring of plant development stages was carried out to determine the number of days from sowing to six true leaves, panicle emergence, flowering, and maturity. Before harvest, plant height was measured. At harvest, straw yield, grain yield, harvest index (HI), the weight of a thousand grains, and WUE were measured.

3. Results

3.1. Development Stages Length

Quinoa development stage lengths were significantly different for both sowing dates and cultivar (Table 2). Plant development was slow for the December planting date and more time was taken by the crop to reach the six true leaves, panicle emergence, flowering, and maturity, while late sowing (February and March) decreased this time significantly.

Table 2. Days from sowing to six true leaves, panicle emergence, flowering and maturity as affected by sowing dates and quinoa cultivars (mean ± SD, n =16).

	Days to Six True Leaves		Days to Panicle Emergence		Days to Flowering		Days to Maturity	
	ICBA-Q5	**Titicaca**	**ICBA-Q5**	**Titicaca**	**ICBA-Q5**	**Titicaca**	**ICBA-Q5**	**Titicaca**
November	$(21.44 \pm 0.23)_{d}$	$(21.25 \pm 0.2)_{d}$	$(50.63 \pm 0.39)_{e}$	$(52.50 \pm 0.30)_{d}$	$(72.63 \pm 0.39)_{c}$	$(76.56 \pm 0.31)_{b}$	101^{e}	119^{d}
December	$(32.19 \pm 0.22)_{a}$	$(32.38 \pm 0.19)_{a}$	$(61.00 \pm 0.28)_{b}$	$(70.38 \pm 0.39)_{a}$	$(71.31 \pm 0.40)_{d}$	$(78.63 \pm 0.39)_{a}$	112^{b}	125^{a}
January	$(25.25 \pm 0.12)_{c}$	$(26.63 \pm 0.13)_{b}$	$(52.00 \pm 0.49)_{d}$	$(58.56 \pm 0.42)_{c}$	$(68.44 \pm 0.51)_{e}$	$(78.19 \pm 0.44)_{a}$	103^{d}	127^{c}
February	$(19.75 \pm 0.18)_{e}$	$(21.00 \pm 0.16)_{d}$	$(40.69 \pm 0.49)_{h}$	$(49.50 \pm 0.49)_{f}$	$(54.75 \pm 0.53)_{h}$	$(64.50 \pm 0.40)_{f}$	98^{h}	111^{f}
March	$(15.25 \pm 0.12)_{g}$	$(16.44 \pm 0.16)_{f}$	$(34.06 \pm 0.37)_{i}$	$(45.69 \pm 0.49)_{g}$	$(47.56 \pm 0.51)_{i}$	$(57.31 \pm 0.40)_{g}$	83^{i}	109^{g}

Means followed by the same small letters are not significantly different at $p \leq 0.05$.

3.2. Plant Height

There was significant effect of sowing date and cultivar on the quinoa final height (Figure 1). However, no interaction between these two factors was recorded. Sowing in December gave the highest plant height for both cultivars, whereas February planting resulted in the lowest values.

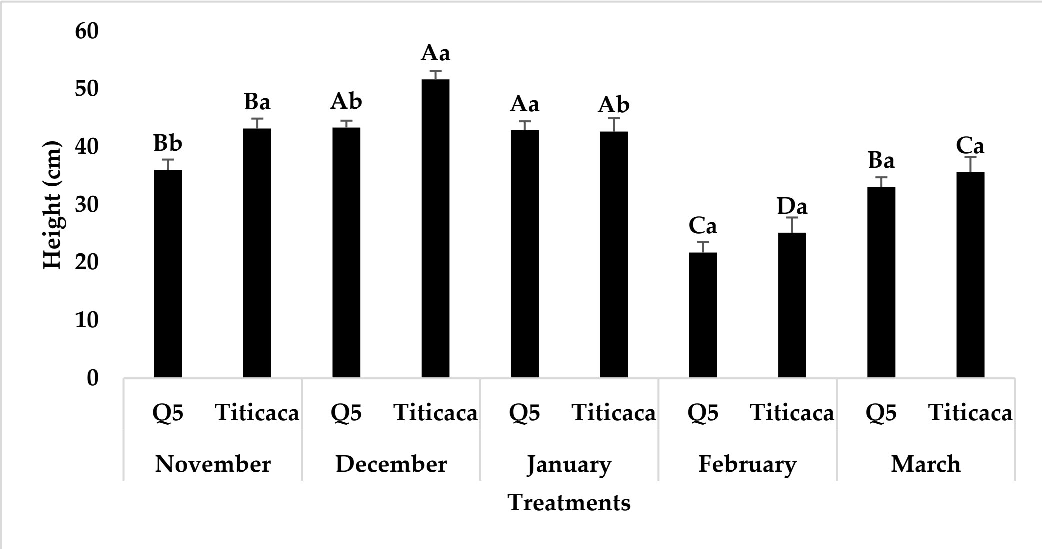

Figure 1. Final plant height of quinoa crop. For each cultivar, means followed by the same capital letters are not significantly different at $p \leq 0.05$. For each sowing date, means followed by the same small letters are not significantly different at $p \leq 0.05$.

3.3. Yield Components and WUE

December planting produced the highest grain yield (0.8 t ha^{-1}) for both cultivars (Table 3). Straw yield was significantly affected by both sowing date and cultivars. Planting in December, January and February gave the highest values (Table 3). The harvest index varied according to sowing dates and cultivars, and the highest values were recorded by early sowing dates (Table 3). The ICBA-Q5 cultivar had a higher 1000 grain weight than Titicaca cultivar.

Table 3. Yield components and panicle length of Titicaca and ICBA-Q5 for the different sowing date, Ben Guerir, Morocco (mean ± SD, *n* = 40).

	Grain Yield (t h^{-1})		Straw Yield (t h^{-1})		HI (%)		1000 Seed Weight (g)		WUE (kg mm^{-1} ha^{-1})	
	ICBA-Q5	Titicaca	ICBA-Q5	Titicaca	ICBA-Q5	Titicaca	ICBA-Q5	Titicaca	ICBA-Q5	Titicaca
November	(0.39 ± 0.05) ^{c}	(0.15 ± 0.01) ^{d}	(0.58 ± 0.07) ^{d}	(1.76 ± 0.08) ^{b}	(0.43 ± 0.04) ^{a}	(0.08 ± 0.01) ^{d}	(2.25 ± 0.04) ^{b}	(1.6 ± 0.05) ^{e}	(1.82 ± 0.23) ^{c}	(0.56 ± 0.06) ^{d}
December	(0.84 ± 0.05) ^{a}	(0.8 ± 0.04) ^{a}	(2.19 ± 0.14) ^{a}	(2.08 ± 0.17) ^{a}	(0.29 ± 0.02) ^{b}	(0.33 ± 0.04) ^{b}	(2.44 ± 0.05) ^{a}	(1.99 ± 0.03) ^{c}	(3.35 ± 0.2) ^{a}	(3.2 ± 0.16) ^{a}
January	(0.74 ± 0.05) ^{a}	(0.5 ± 0.05) ^{b}	(1.59 ± 0.12) ^{b}	(2.25 ± 0.12) ^{a}	(0.35 ± 0.03) ^{b}	(0.18 ± 0.02) ^{c}	(2.36 ± 0.04) ^{ab}	(1.76 ± 0.05) ^{d}	(3.42 ± 0.22) ^{a}	(2.34 ± 0.22) ^{b}
February	(0.22 ± 0.04) ^{d}	(0.18 ± 0.02) ^{d}	(2.14 ± 0.13) ^{a}	(2.22 ± 0.1) ^{a}	(0.11 ± 0.02) ^{d}	(0.08 ± 0.01) ^{d}	(1.69 ± 0.04) ^{de}	(1.4 ± 0.05) ^{f}	(1.05 ± 0.18) ^{d}	(0.86 ± 0.08) ^{d}
March	(0.08 ± 0.01) ^{d}	(0.09 ± 0.01) ^{d}	(0.96 ± 0.07) ^{c}	(0.77 ± 0.07) ^{cd}	(0.09 ± 0.01) ^{d}	(0.13 ± 0.01) ^{cd}	(1.28 ± 0.06) ^{f}	(1.04 ± 0.05) ^{g}	(0.53 ± 0.04) ^{d}	(0.61 ± 0.05) ^{d}

For each sowing date and cultivar combination, means followed by the same small letters are not significantly different at $p \leq 0.05$.

4. Discussion

Early sowing of quinoa short-cycle cultivars is a good strategy to secure good vegetative development and displace the growing cycle of the crop in the rainy season. A December planting date increased the number of days from sowing to maturity and enhanced plant height. However, late sowing decreased these parameters. Similar results were found in central Italy by [6], where high levels of temperature and photoperiod of late sowing decreased the number of days after emergence to panicle appearance and flowering. In other studies, late sowing also decreased the vegetative development of quinoa and resulted in stunted plants [5,7].

Sowing in December and January received the highest amount of rainwater and recorded the highest WUE. Low temperatures and a short photoperiod of this period decreased the evaporation, and the plant benefits better from water in the rainy season. Late sowing in February and March was associated with high evaporation, the rainwater was less effective for the plant use, and water losses were high. In addition, benefiting from rainwater during the rainy season helped in reducing the amount of salts applied in the irrigation water and thus contribute to mitigating the salinity effect in the arid and saline regions of Morocco.

In the present study, early planting dates (November, December, and January) placed the growing season of quinoa in the rainy season. However, it was observed that quinoa planted in November suffered from continuous low temperature and radiation from vegetative development to seed filling. This resulted in low straw and grain yield. A cool temperature is necessary to achieve good growth and a maximum yield of quinoa [8].

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