El-Harty EH *et al.* (2023)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 51, Issue 2, Article number 13209
DOI:10.15835/nbha51213209
Research Article

Water use efficiency (WUE) and productivity of promising quinoa (*Chenopodium quinoa* Wild.) genotypes grown under three water regimes

Ehab H. EL-HARTY, Muhammad A. KHAN, Mahmoud F. SELEIMAN*, Muhammed AFZAL, Salem S. ALGHAMDI

*King Saud University, College of Food and Agriculture Sciences, Plant Production Department, Riyadh, PO Box 2460, 11451, Saudi Arabia; ehabelharty@ksu.edu.sa; kmuhammad@ksu.edu.sa; mseleiman@ksu.edu.sa (*corresponding author); mmushtaq@ksu.edu.sa; salem@ksu.edu.sa*

Abstract

Quinoa is one of the most nutritious grains and currently has attention due to its adaptation to a wide range of environments and abiotic stresses. This study was conducted under field conditions of an arid agro-ecosystem to evaluate the response physiological and yield of nineteen elite quinoa genotypes grown under three water regimes (95, 65, and 35% Field capacity) using a drip system in sandy soil. The experiment design was a split-plot in a randomized complete block design during the 2019/20 and 2020/21 growing seasons. The results showed significant differences among evaluated genotypes, water treatments, and their interaction. Fluorescence chlorophyll components were sensitive to water stress and strongly decreased at low soil moisture. Fluorescence (Fo) was the most correlated with seed yield and water use efficiency (WUE) under both full irrigation and drought stress. This may be used for improving yield and WUE in breeding programs. The optimum WUE achieved from moderate irrigation (65% FC), indicated the importance of detecting water requirements. The seed production ranges between 3.8 and 2.2 t ha^{-1} under full irrigation, and it decreases to reach 62.8% under water regimes. The most suitable genotypes for growing under full irrigation were 'V9', 'Apelawa', '30TES', and '27GR' which produced 3.8, 3.7, 3.5, and 3.5 t ha^{-1}, respectively. The highest seed yield under stream drought (1.4 t ha^{-1}) was produced by 'Ames 10334' and 'QU629-99'. However, the genotype 'Apelawa' could outperform under different moisture conditions. It produced 1.2 t ha^{-1} under stream drought thus, recommended to cultivate it, especially in zones where precipitation fluctuates.

Keywords: chlorophyll a fluorescence; drought; irrigation; production; quinoa; WUE
Abbreviations: WUE – water use efficiency; Fo – minimal fluorescence; FC – field capacity.

Introduction

The global interest in quinoa (*Chenopodium quinoa* Wild.) is rapidly increasing due to its nutritional qualities and its ability to grow in marginal environments. It could be one of the crops destined to offer food security in the 21st century (Alandia *et al.*, 2021). Quinoa has been cultivated for millennia under low rainfall conditions and in different agroclimatic zones. It is well adapted to various environments and has physiological

---

Received: 15 May 2023. Received in revised form: 24 May 2023. Accepted: 08 Jun 2023. Published online: 09 Jun 2023.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

and morphological strategies (Bazile, 2016). This wide adaptability is due to the differentiation of a diversity of ecotypes originating in contrasting agro-environments (Zurita-Silva *et al.,* 2015). Furthermore, quinoa can be a good candidate for cropping systems in marginal agricultural areas (Alandia *et al*., 2021). It is a potential crop in the consideration of future climate change challenges (Zurita-Silva *et al.,* 2015). Quinoa is a very drought-resistant crop (Winkel *et al.,* 2002) as well as it displays various adaptive mechanisms to water regimes, from physiological to morphological adaptations that led to a range of responses to stress; avoidance, resistance, and tolerance. Quinoa copes with water regimes by modifying or changing vital physiological processes, such as photosynthesis, water relations, and hormone metabolism (Zurita-Silva *et al.,* 2015). The grain has high nutritional value due to its high protein content, with all essential amino acids and a wide range of vitamins and minerals. High levels of polyphenols and flavonoids are beneficial for human health (Repo-Carrasco-Valencia *et al.,* 2010). However, it also contains saponins and tannins used in the pharmaceutical and cosmetic industries (Escribano *et al.,* 2017).

Water deficit is one of the most challenging abiotic stress factors in arid and semi-dry regions, furthermore, water demand is increasing with increased population and global temperature (Huang *et al.,* 2015; Altun *et al.,* 2016; Hafez and Seleiman, 2017; Seleiman *et al.,* 2019; Eid *et al.,* 2020; Roy *et al.,* 2021). Changing climate prolongs the duration of water deficiency, causing a reduction in crop production and decreasing food security in the world (Krannich *et al.,* 2015; Ding *et al.,* 2021; Kheir *et al.,* 2021; Battaglia *et al.,* 2022). Agricultural activity is the primary consumer of freshwater; thus, the selection and cultivation of tolerant drought crops is an approach to increase crop production levels under water deficit conditions. Water is a critical component of plant metabolism and yield production (Babur *et al.,* 2021). Select adapted genotypes to stressful edaphic climatic conditions to resist periods of water shortage while maintaining high productivity for each situation is of great importance in breeding programs (Präger *et al*., 2018). Improving water use efficiency (WUE) should be an essential target in breeding programs, particularly in arid and semi-arid land (Elshayb *et al.,* 2022; Seleiman *et al*., 2023; Al-Selwey *et al*., 2023). However, the complexity of this trait and the difficulty of its phenotyping has prevented many breeders from attempting to select WUE directly (Araus *et al.,* 2002). WUE is a measure of the plant biomass produced per water used unit; it is defined in physiological concept, by Hatfield and Dold (2019) as the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop; thus, the response of WUE is directly related to the physiological processes can control the gradients of CO_2 and H_2O. Basso and Ritchie (2018) illustrated that the productivity of maize grain could be increased with no difference in water use due to increased WUE. Telahigue *et al.* (2017) found that the highest values of WUE, grain yield, and dry matter were in quinoa genotypes under moderate water irrigation. Also, Geerts *et al.* (2008) suggested that deficit irrigation can contribute to better agricultural planning due to better control of the phrenological development of quinoa and did not cause lower yields and resulted in equal or higher WUE than the wet fields. Analysis of chlorophyll fluorescence is appreciated as a widely used technique in researching photosynthetic efficiency in plants (Genty *et al.,* 1989). PSII (Fv/Fm) parameter is the most often employed parameter for maximizing the quantum yield (Maxwell and Johnson, 2000). Fghire *et al.* (2015) suggested the use PSII to assess water stress among quinoa genotypes; however, they mentioned that the Pindex (Performance index) was more sensitive to water stress. Pindex was used to quantify the effects of environmental factors on photosynthesis in several studies (Tsimilli-Michael and Strasser, 2008).

The objective of this study was to identify the adapted and highly productive quinoa genotypes grown under different water regimes (95, 65 and 35%) using a drip system in sandy soil as well as to assess the relationship between the yield and physiological traits.

Materials and Methods

Materials, treatments, and experimental design

The field experiments were carried out at Education Agricultural Farm, King Saud University (KSU) (24 °43' N, 46 °37' E), Al Riyadh, Saudi Arabia, during the winter seasons of 2019/20 and 2020/21. The experiment field received sand for 0.4 m depth while irrigation was by dripper web and controlled by ECH$_2$O soil moisture sensor and date recorded by ECHO Em50 (Decagon Devices, Inc.). The weather of the Al Riyadh area corresponds to thermal mild, with a dry sub-humid humidity regime, the average maximum temperature during January was 19.9 and 21.6 °C, and the average minimum temperature was 8.3 and 9.5 °C, in both seasons, respectively. There were dry weather conditions in the field confirmed by the cumulative precipitation curve (Figure 1). The experiment field received only 15.4 and 14.2 mm of precipitation in the first and second seasons, respectively. Nineteen quinoa genotypes were selected from the quinoa breeding program of KSU (EL-Harty *et al.,* 2021). The name and origin of these genotypes are presented in Table 1.

Table 1. Name and origin of the evaluated quinoa genotypes

SN	Name	Origin	SN	Name	Origin
1	'94R'	United States, New Mexico	**11**	Chadmo	Chile, Los Lagos
2	'Tundri'	United States, New Mexico	**12**	NSSL 106395	Chile, La Araucania
3	'27GR'	United States, New Mexico	**13**	Ames 10334	Bolivia, Cochabamba
4	'20TES'	United States, New Mexico	**14**	Q 18	Chile, Maule
5	'30TES'	United States, New Mexico	**15**	V9	Chile
6	'54ALC'	United States, New Mexico	**16**	Q 29	Chile
7	'Kaslaea'	United States, New Mexico	**17**	SU-5	Bolivia, La Paz
8	'Pison'	United States, New Mexico	**18**	QU629-99	United States, Colorado
9	'Apelawa'	Bolivia	**19**	NSSL 86628	United States, Maryland
10	'Q12'	United States, Colorado			

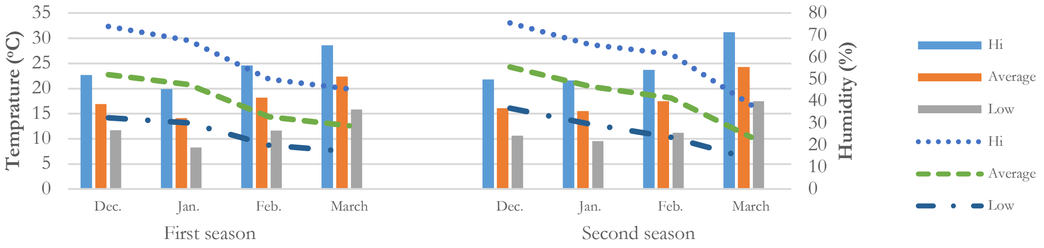

Figure 1. Monthly temperature and humidity % during the growing seasons 2019/20 and 2020/21

The field experiments were split plotted in a randomized complete block design with three replications. Three water treatments in the main plot corresponded to the level of available water (AW) in the root zone at 95%, 65%, and 35% of field capacity. The drip irrigation system was used and treatments were applied after the emergence of the quinoa plants. Each lateral drip line was 30.0 m long at a distance of 0.5 m from adjacent lines with a 0.10 m emitter spacing. The drippers had a discharge rate of 4 L h^{-1}. The nineteen quinoa genotypes were randomly assigned to the sub-plots and the experiment plot contents were 3 m long and 3 rows (plot size = 4.5 m^2). Quinoa seeds were sown alongside the drippers at the end of November in both seasons. Phosphorus [100 kg ha^{-1} in the form of single furrow-banded calcium superphosphate (15.5% P$_2$O$_5$)] was applied basally during the soil preparation for planting. Nitrogen [160 kg ha^{-1} as ammonium nitrate (33.5% N)] and potassium [50 kg ha^{-1} as potassium sulfate (50.0% K_2O)] fertilizers were applied through the fertigation system in five equal doses, respectively, from the time of planting to 70 days after planting.

Measurements

The behavior and performance of the photosynthetic apparatus at quinoa leaf in the second season were determined by recording the chlorophyll fluorescence using Hansatech Handy PEA (Hansatech Instruments, UK).

A pulse of saturating red light (peak at 650 nm, 3000 mmol m^{-2} s^{-1}) was applied after dark adaptation for 30 min. This leads to an increase in chlorophyll fluorescence increases from minimal fluorescence (Fo), when all reaction centers are open, to maximal fluorescence (Fm), when all reaction centers are closed. The Fm (maximum fluorescence) is measured during the first saturation pulse after the adaptation of the plant to darkness. The maximum quantum yield was obtained (Fv/Fm), where Fv is the difference between the maximum and minimum fluorescence after adapting the plant to darkness.

The Fv/Fm ratio estimates the maximum portion of the absorbed light that is used in photosystem II (PSII) reaction centers. That represents the maximum potential of quantum efficiency of the PSII.

The young leaves were used to determine relative water content (RWC%) where the leaf was weighted (FW) and then floated on distilled water for 4 h at 22 °C under dim light. The turgid weight (TW) was determined after blotting, and the dry weight (DW) was measured after the samples had been dried for 24 h at 80 °C.

$$\text{RWC} = \frac{(FW-DW)}{(TW-DW)} x100$$

At the maturing stage, data of the number of days from sowing to 95% maturing, plant height (cm), and number of branches/plants were recorded. All experiment plot plants were harvested together and seed yield per hectare was estimated as the ratio of the plot to the hectare. WUE was calculated as the ratio of seed yield per hectare (kg) to water applied for each treatment as follows: WUE = seed yield(kg)/water applied(m^3).

The stress tolerance index (STI) was calculated using the following formula according to Fernandez, 1992:

$$\text{STI} = \frac{(Yp*Ys)}{(Xp)2}$$

where Ys = grain yield of a test genotype under drought-stressed conditions; Yp = grain yield of a test genotype under non-stressed conditions, and Xp = mean yield of test genotypes under non-stressed conditions.

Statistical analysis

Statistical analysis was done for each season separately and after confirmation of errors homogeneity for the two seasons, then combined analysis of the two seasons was applied. Means of treatments and genotypes were compared by Tukey's test at a probability level of 5%. with the Turkey test using statistical analysis of MSTATC software. Correlation coefficients were estimated among studies traits according to (Steel *et al.*, 1997).

Results and Discussion

Physiological traits

The fluorescence parameters provide information about a plant's ability to tolerate stress and how this could damage the photosynthetic apparatus (Maxwell and Johnson, 2000). Fluorescence chlorophyll components were sensitive and decreased with increased water regimes; the percentage of decline was 10.7, for Fo, 6.5, for Fm, and 3.7, Fv/Fm while Pindex was the highly sensitive parameter to water regimes with 35.4% decline (Table 2). All genotypes had the same trend except for a few genotypes that increased under T2 and T3; however, these differences were insignificant in most cases. Furthermore, concerning the Fo parameter, the best five ranks under fully irrigated treatment (T1) and the average of the three treatments were occupied by the same genotypes ('94R', '27GR', '54ALC', 'Chadmo', and 'V9') with different ranks between them. The results indicated that these genotypes are less affected by a shortage of irrigation water.

Krause and Weis (1991) concluded that the quinoa plant could obtain stable parameters under a lack of water conditions. Values of maximal fluorescence (Fm) were high with a wide range (1839 for 'QU629-99' to 1074 for 'Q 29' under T1). The evaluated genotypes had changed their superior due to changes in available moisture; genotypes 'QU629-99', 'Kaslaea', and 'Pison' were higher under T1, while genotypes '94R', '30TES', and 'Kaslaea' recorded the highest values under T3. However, 'Kaslaea' and 'QU629-99' resaved their superior and took high rank at an average of all treatments. In contrast, a narrow range for Fv/Fm ranged from 0.773 for 'V9' to 0.547 for 'QU629-99' under T1, with an average of 0.700; this range became wider under water regimes; from 0.757 for 'Tundri' to 0.463 for '20TES' under T3. However, drought treatments (T2 and T3) had a more negligible effect on the average of Fv/Fm with a decrease of 5.2 and 3.7%, respectively, compared with full irrigation treatment. Winkel *et al.,* 2002 found that ontogenic variation was moderate to high for physiological parameters except for Fv/Fm. It may be due to Fv/Fm only reflecting changes in the values of Fo and Fm (Fghire *et al.,* 2015). These results are similar to Yang *et al.* (2016) on the quinoa variety 'Titicaca' which reduced FV/FM when plants were exposed to drought. Valdivia-Cea *et al.* (2021) presented differences among irrigation treatments for Fv/Fm values from 0.74 to 0.82. The Pindex was used to quantify the effects of environmental factors on photosynthesis in several studies (Guan *et al.*, 2022)). Pindex values had a wide range recorded among genotypes under irrigated treatments. The quinoa genotypes 'NSSL 86628' and '30TES' had the highest values under T1 and T3 combined with genotypes 'V9' under T1 and 'Tundri' under T3. Fghire *et al.* (2015) explained that the Pindex was much more sensitive to water regimes, maybe due to its response to changes in the fast fluorescence rise kinetics among the two fluorescence extremes (Fo and Fm).

These results, in agreement with Fghire *et al.* (2015) found that water regimes induced a significant decrease in Fv/Fm and Pindex. Physiological analyses revealed different responses of the genotypes to irrigation treatments, together with symptoms of water regimes; Da-Silva *et al.* (2021) reinforce the importance of detailed studies of the relationship between productivity, physiology, and water use. While Winkel *et al.* (2002) suggested using these parameters in assessing water stress in quinoa; contrast, Hamli *et al.* (2015) showed differences in the rank of durum genotypes according to these physiological traits; and proposed that these physiological parameters could not be recommended to replace grain yield field testing. Also, Valdivia-Cea *et al.* (2021) found that the environments play a main role in physiological parameters and estimated no significant differences among quinoa genotypes in season and other seasons. Also, Killi and Haworth (2017) reported that the indicators of the photosynthetic capacity were affected by water stress but retained photosynthetic capacity and photosystem II performance.

Table 2. Fluorescence chlorophyll parameters of the evaluated quinoa genotypes under three water regimes

Genotypes	**Fo**				**Fm**				**Fv/Fm**				**P index**			
	T1	**T2**	**T3**	**Mean**	**T1**	**T2**	**T3**	**Mean**	**T1**	**T2**	**T3**	**Mean**	**T1**	**T2**	**T3**	**Mean**
‘94R’	551.0	450.0	439.0	480	1460.0	1237.5	1690.0	1463	0.703	0.703	0.740	0.715	0.96	1.72	1.19	1.290
‘Tundri’	451.5	473.0	373.0	433	1564.5	1347.0	1390.0	1434	0.710	0.650	0.757	0.706	0.78	0.56	2.13	1.157
‘27GR’	505.2	400.0	395.0	433	1498.0	1044.5	1406.5	1316	0.730	0.330	0.720	0.593	2.48	0.27	1.59	1.447
‘20TES’	303.0	300.0	320.0	308	1240.5	1297.0	2066.0	1535	0.640	0.367	0.463	0.490	0.40	0.88	0.33	0.537
‘30TES’	456.0	417.0	300.0	391	1583.0	1136.0	1606.5	1442	0.773	0.600	0.660	0.678	3.04	0.95	2.06	2.017
‘54ALC’	516.0	491.5	468.0	492	1595.5	1675.0	1079.5	1450	0.580	0.710	0.627	0.639	0.44	2.09	0.99	1.173
‘Kaslaea’	430.0	404.0	409.6	415	1730.5	1576.0	1539.8	1615	0.677	0.737	0.660	0.691	0.19	2.85	1.38	1.473
‘Pison’	434.5	382.5	350.0	389	1617.0	1191.0	1539.8	1449	0.733	0.673	0.660	0.689	1.26	0.77	1.38	1.137
‘Apelawa’	500.0	328.5	403.5	411	1317.5	1261.0	1111.0	1230	0.710	0.740	0.610	0.687	1.83	4.05	0.88	2.253
‘Q12’	395.0	448.0	391.0	411	1323.5	1345.5	1298.0	1322	0.703	0.667	0.583	0.651	1.29	0.78	0.55	0.873
‘Chadmo’	513.5	384.0	401.5	433	1479.0	1274.5	1286.5	1347	0.657	0.700	0.687	0.681	0.89	1.49	0.59	0.990
‘NSSL106395’	380.5	426.5	405.5	404	1330.0	1416.0	1471.0	1406	0.710	0.693	0.727	0.710	2.47	1.62	0.91	1.667
‘Ames 10334’	416.0	358.0	420.0	398	1553.0	1487.5	1334.0	1458	0.733	0.753	0.713	0.733	2.95	3.97	0.82	2.580
‘Q 18’	420.5	393.0	370.0	395	1188.0	1314.0	1309.0	1270	0.640	0.697	0.640	0.659	0.69	1.46	1.16	1.103
‘V9’	513.0	500.0	440.0	484	1512.5	1403.0	1170.0	1362	0.773	0.723	0.717	0.738	4.81	1.40	1.31	2.507
‘Q 29’	372.5	370.0	377.0	373	1074.0	1519.5	1164.5	1253	0.650	0.603	0.677	0.643	1.06	2.10	0.58	1.247
‘SU-5’	300.0	300.0	310.0	303	1432.0	1322.0	1156.5	1304	0.700	0.670	0.673	0.681	1.40	1.79	0.72	1.303
‘QU629-99’	346.0	380.5	415.7	381	1839.0	1551.5	1060.5	1484	0.547	0.757	0.590	0.631	2.45	4.36	0.69	2.500
‘NSSL 86628’	324.5	412.5	270.0	336	1267.5	1112.5	1139.0	1173	0.717	0.633	0.700	0.683	4.14	0.76	2.39	2.430
Mean	**427.8**	**401.0**	**382.0**		**1452.9**	**1342.7**	**1358.8**		**0.7**	**0.7**	**0.7**		**1.8**	**1.8**	**1.1**	
LSD 5% for:																
Genotypes	**28.5**				**155.1**				**0.099**				**1.089**			
Treatments	**31.9**				**74.7**				**NS**				**0.56**			
Interaction	**43.8**				**235.0**				**0.127**				**1.800**			

Mean performance; seed yield components

Based on the combined analysis of variance results, there were statistically significant differences among genotypes, irrigation treatments, and seasons and their interactions for all traits under the study. Seed yield and its components were decreased with decreased available irrigation water; seed yield was the most affected with 24.2 and 62.1% reduction under T2 and T3. The evaluated genotypes matured after 113.5 days; the earliest genotype was 'Q12' (102.7 days) and the latest one was 'QU629-99' (126.7 days) under full irrigation treatment (T1); however, both genotypes were among the earliest genotypes under water regimes, with mean values of 94.0 and 92.0 days, respectively (Table 3).

The tallest genotypes under T1 were '27GR' (160.0 cm), and 'Apelawa' (150 cm) had the highest depression under extreme drought (T3) with 53.1 and 55.0%. The average plant height was 128.3 cm under full irrigation treatment and reduced to 105.2 and 83.0 under T2 and T3. All genotypes had the same depression except 'Kaslaea', and 'NSSL 86628' had insignificant change under T2. High variation was shown among quinoa genotypes for seed yield and its components under Saudi Arabia conditions (EL-Harty *et al.*, 2021). Lin and Chao (2021) found that the plant height of all quinoa genotypes was affected under extreme drought, but under mild water regimes, the plant height of tolerant genotypes did not change compared with full irrigation treatment. The average number of branches per plant was high (11.3) under T1 and decreased by 22.1 and 48.8% due to water stress treatments.

Table 3. Mean of the number of days to mature, plant height, and number of branches per plant of the studied genotypes under three water regimes

Genotype	Number of days to mature				Plant height (cm)				Number of branches per plant			
	T1	T2	T3	Mean	T1	T2	T3	Mean	T1	T2	T3	Mean
'94R'	123.0	108.7	94.0	107.5	137.5	100.0	80.0	105.8	13.3	8.4	8.4	10.0
'Tundri'	124.2	116.7	110.7	117.2	140.0	105.0	80.0	108.3	12.6	10.5	4.7	9.3
'27GR'	118.0	104.7	103.2	105.7	160.0	107.5	85.0	117.5	13.3	9.1	5.8	9.4
'20TES'	106.7	104.2	102.2	104.3	110.0	102.5	75.0	95.8	9.1	7.0	5.4	7.2
'30TES'	122.0	106.7	102.2	106.8	127.5	95.0	67.5	96.7	13.3	8.4	4.2	8.6
'54ALC'	111.7	108.2	101.2	107.0	137.5	105.0	92.5	111.7	10.5	8.4	8.4	9.1
'Kaslaea'	105.7	104.7	96.7	102.3	105.0	105.0	80.0	96.7	10.7	8.4	6.3	8.5
'Pison'	106.2	99.7	94.7	100.2	115.0	83.5	75.0	91.2	12.6	9.1	8.4	10.0
'Apelawa'	106.7	102.7	99.7	103.0	150.0	117.5	82.5	116.7	13.3	10.5	5.6	9.8
'Q12'	102.7	97.2	85.7	95.2	110.0	97.5	77.5	95.0	9.1	7.0	5.6	7.2
'Chadmo'	115.7	111.2	110.2	112.3	110.0	97.5	92.5	100.0	13.1	10.5	8.4	10.7
'NSSL 106395'	108.2	101.7	98.7	102.8	125.0	107.5	80.0	104.2	10.7	9.1	7.0	8.9
'Ames 10334'	116.7	113.7	100.0	114.5	142.5	125.0	105.0	124.2	9.1	9.1	8.6	8.9
'Q 18'	116.7	112.7	105.7	111.7	117.5	100.0	75.0	97.5	9.1	8.4	6.3	7.9
'V9'	115.0	104.7	102.2	105.0	132.5	112.5	82.5	109.2	13.3	10.5	8.4	10.7
'Q 29'	114.7	107.7	106.7	109.7	137.5	105.0	75.0	105.8	11.9	6.3	7.0	8.4
'SU-5'	108.7	101.7	100.0	100.3	140.0	117.5	95.0	117.5	7.0	5.6	6.3	6.3
'QU629-99'	126.7	116.7	94.0	118.0	135.0	112.5	97.5	115.0	11.9	10.5	10.5	11.0
'NSSL 86628'	116.2	114.2	107.2	112.5	104.5	102.5	80.0	95.7	10.5	9.8	7.0	9.1
Mean	**113.9**	**107.2**	**100.8**		**128.3**	**105.2**	**83.0**		**11.3**	**8.8**	**7.0**	
LSD at 5% for genotypes	**10.2**				**8.6**				**3.4**			
LSD at 5% for treatments	**7.3**				**16.9**				**1.1**			
LSD at 5% for interaction	**16.9**				**22.9**				**5.5**			

Table 4 presents the RWC, WUE, SY, and STI of the evaluated genotypes under the three irrigation treatments. The highest RWC was estimated in the genotypes 'V29', 'V9', 'Ames 10334', and 'Chadmo' which maintain their superiority during all conditions, in contrast to other genotypes that had negative responses to drought. This result, in agreement with Jensen *et al.* (2000) estimated higher RWC under fully watered conditions, then decreased during severe soil drying. González *et al.* (2009) reported that high RWC under fully watered treatment was not significantly changed than under drought conditions.

The average of WUE under full irrigation treatments (T1) was 6.7 and reduced to 5.3 kg per m^3 due to water regimes (T3); however, most of the evaluated quinoa genotypes showed more water use efficiency under moderate irrigation conditions (T2) with average 7.0 kg per m^3. The highest values of WUE under full irrigation were 8.3, 8.1, and 7.9 in the genotypes 'V9', 'Apelawa', and '27GR', while these genotypes decreased their efficiency under T2; the Bolivian genotype 'Apelawa' increased its efficiency to 8.4 and occupied the first rank with the genotypes '94R' (8.3), 'Chadmo' (7.8) this genotype had not deserved under both T1 and T3 treatments emphasizing that it is distinguished only under these while the genotypes 'Apelawa' and '27GR' were distinguished under both T1 and T2 the genotype '94R' was among the best genotypes under both T2 and T3 treatments. These genotypes recorded the highest average of WUE for the three treatments besides 'Ames 10334' and 'QU629-99' which had the highest WUE under extreme drought conditions. These indicated water use efficiency (WUE), and selected particular genotypes for each environment should be an essential target in breeding programs and importance increases in an arid and semi-arid land. Select adapted genotypes to stressful edaphic climatic conditions to resist periods of water shortage while maintaining high productivity for each situation is of great importance in breeding programs (Präger *et al.*, 2018). The results of WUE were lower than the results of Da-Silva *et al.* (2021) found that quinoa WUE reaches up to 9.7 kg per m^3 for high production genotype under optimum conditions. But it is higher than irrigation WUE and total water (irrigation+ rainfall) WUE estimates, 3.6 and 2.3 kg per m^3, respectively presented by Telahigue *et al.* (2017); but their low WUE may be due to the low production of their genotypes. The optimum WUE in bread wheat; was 12.4 kg per m^3 (Verma *et al.,* 2021); but higher than the estimated WUE in chickpeas and lentils under Mediterranean environments; 3.4 and 3.2 kg per m^3, respectively (Zhang *et al.,* 2000). The low WUE in this study may be due to being grown in sandy soil without organic matter. These results, similar to the results of Telahigue *et al.* (2017) and Naggar *et al.* (2017) showed increased water use efficiency (WUE) and reduction in quinoa yield under mild moisture.

The seed production of evaluated genotypes ranges between 3.8 and 2.2 t ha $^{-1}$ for both US improved genotypes ('V9' and '20TES', respectively) under full irrigation, and it decreases to reach 62.8% under water regimes (T3) with a range between 1.3 to 0.6 t ha^{-1}. The highest seed yield was obtained by 'V9' (3.8 t ha^{-1}), 'Apelawa' (3.7 t ha^{-1}), '27GR' (3.5 t ha^{-1}), '30TES' (3.5 t ha^{-1}), and '94R' (3.4 t ha^{-1}) under fully irrigation treatment. However, the reduction in their production was dramatically under both moderate (T2) and drought (T3) treatments except 'Apelawa' and '94R' which reduced only 24 & 68% and 21 & 62% compeering with the control treatment. The lowest reduction (9% under T2) was estimated in '20TES' and 'SU-5' which came at the bottom of the list of productivity under optimal conditions (T1). Nine genotypes occupied high rank under water regimes *i.e.*, 'QU629-99', 'Ames 10334', '94R', '54ALC', 'Apelawa', 'Q12', 'Q18', 'V9', and 'SU-5' whit mean values between 1.4 and 1.2 t ha^{-1}. Naggar *et al.* (2017) estimated a 12.2% reduction in the drought-tolerant quinoa variety ('CICA-17') under 35% FC. Valdivia-Cea *et al.* (2021) estimated an average yield of 3.0 t ha^{-1} under full irrigation and decreased combined with water irrigation rate. Stress tolerance index (STI) and the average seed yield over the three irrigation treatments indicated the superiority of three genotypes, i.e., '94R', 'Apelawa', and 'Ames 10334', with seed yield 2.5, 2.5, and 2.4 t ha^{-1} and STI was 0.5 for the three genotypes. Production of quinoa under full irrigation in Tunisia was between 2.1 and 0.3 t ha^{-1} (Telahigue *et al.,* 2017). The variability in quinoa production in Egypt was significant and between 2.7 and 1.7 t ha^{-1} among early maturing genotypes (Naggar *et al.,* 2017).

Table 4. The mean of relative water content, water use efficiency, and seed yield of the studied genotypes under three water regimes and stress tolerance index (STI)

Genotype	RWC (%)				WUE (kg/m^3)				Seed yield (t)				STI
	T1	T2	T3	Mean	T1	T2	T3	Mean	T1	T2	T3	Mean	
‘94R’	49.9	47.2	42.1	46.4	7.6	8.3	6.0	7.3	3.4	2.7	1.3	2.5	0.5
‘Tundri’	51.4	48.6	43.3	47.8	5.9	6.7	5.0	5.9	2.5	2.1	1.0	1.9	0.3
‘27GR’	57.5	49.0	35.4	47.3	7.9	7.6	5.1	6.9	3.5	2.4	1.0	2.3	0.4
‘20TES’	55.1	52.7	49.0	52.3	5.3	6.6	5.0	5.6	2.2	2.0	1.0	1.8	0.3
‘30TES’	58.6	56.0	38.4	51.0	7.7	6.5	4.4	6.2	3.5	2.0	0.8	2.1	0.3
‘54ALC’	55.0	53.2	49.8	52.7	6.2	6.4	6.1	6.2	2.7	2.0	1.3	2.0	0.4
‘Kaslaea’	47.9	45.5	40.0	44.5	6.0	5.6	4.8	5.5	2.6	1.6	0.9	1.7	0.3
‘Pison’	58.5	53.7	38.5	50.2	6.7	6.1	4.7	5.8	2.9	1.8	0.9	1.9	0.3
‘Apelawa’	52.6	47.0	32.6	44.0	8.1	8.4	5.6	7.4	3.7	2.8	1.2	2.5	0.5
‘Q12’	59.9	59.0	55.5	58.2	6.2	7.3	5.6	6.4	2.7	2.3	1.2	2.0	0.4
‘Chadmo’	58.3	53.3	39.6	50.4	7.0	7.8	4.8	6.5	3.1	2.5	0.9	2.2	0.3
‘NSSL 106395’	70.0	61.3	42.9	58.1	5.9	6.4	5.4	5.9	2.5	2.0	1.1	1.9	0.3
‘Ames 10334’	53.9	50.0	53.3	62.0	7.0	7.9	6.4	7.1	3.1	2.5	1.4	2.4	0.5
‘Q 18’	70.0	68.7	64.7	67.8	6.1	6.9	5.7	6.2	2.6	2.1	1.2	2.0	0.4
‘V9’	70.3	69.0	65.7	68.3	8.3	6.4	5.6	6.8	3.8	1.9	1.2	2.3	0.5
‘Q 29’	48.0	47.0	40.0	45.0	6.7	7.0	5.5	6.4	2.9	2.2	1.1	2.1	0.4
‘SU-5’	57.2	55.4	49.7	54.1	5.5	6.8	5.6	6.0	2.3	2.1	1.2	1.9	0.3
‘QU629-99’	52.9	50.0	37.9	46.9	6.6	7.2	6.2	6.7	2.9	2.3	1.4	2.2	0.5
‘NSSL 86628’	58.7	55.0	43.4	52.4	6.5	6.5	3.9	5.6	2.8	2.0	0.6	1.8	0.2
Mean	**57.1**	**53.8**	**44.2**		**6.7**	**7.0**	**5.3**		**2.9**	**2.2**	**1.1**		**0.4**
LSD at 5% for genotypes	**5.8**				**1.2**				**0.3**				**0.17**
LSD at 5% for treatments	**9.4**				**1.6**				**1.0**				
LSD at 5% for interaction	**18.1**				**2.2**				**1.1**				

RWC= relative water content; WUE= water use efficiency

A highly positive significant correlation between seed yield and all of the no. of branches, STI, and WUE under both full irrigation and drought (T1 and T3) conditions was observed, in addition to plant height under T3 only (Table 5).

Table 5. Correlation between yield traits and physiological traits under normal conditions (above) and stream drought (below)

Traits	Fo	Fm	Fv/Fm	Pindex	No of days to mature	Plant height	No of branches	RWC	WUE	Seed yield	STI
Fo	1.0	0.4	0.2	-0.1	0.2	0.3	0.7**	-0.1	0.6**	0.6**	0.5*
Fm	-0.2	1.0	0.2	0.0	0.2	0.1	0.3	-0.2	0.1	0.2	0.1
Fv/Fm	0.2	0.2	1.0	0.7**	0.1	0.2	0.4	0.4	0.4	0.5*	0.1
Pindex	-0.2	0.2	0.5*	1.0	0.3	0.2	0.3	0.5	0.5*	0.5*	0.3
No of days to mature	-0.4	0.1	0.3	0.3	1.0	0.4	0.4	-0.1	0.3	0.4	0.4
Plant height	0.6*	-0.6*	0.2	-0.2	-0.1	1.0	0.2	-0.4	0.3	0.4	0.6**
No of branches	0.6*	-0.3	0.1	-0.2	-0.3	0.5*	1.0	-0.1	0.7**	0.8**	0.4
RWC	-0.1	-0.1	-0.1	-0.1	0.1	-0.2	-0.1	1.0	0.0	0.1	-0.2
WUE	0.7**	-0.3	0.0	-0.4	-0.4	0.5*	0.5	0.1	1.0	1.0**	0.8**
Seed yield	0.7**	-0.4	-0.1	-0.4	-0.3	0.5*	0.5*	0.1	0.9**	1.0	0.7**
STI	0.7**	-0.3	0.2	-0.2	-0.3	0.4	0.4	-0.1	0.7**	0.8**	1.0

*, ** significant at 0.05 and 0.01 probability levels, respectively. For abbreviations, see Tables 2 and 4.

Among the physiological parameters, only Fo positively correlated with no. of branches, seed yield, STI, and WUE under full and extreme drought treatment. Also, Pindex was significantly correlated with seed yield and WUE under normal conditions (0.54 and 0.51, respectively). Physiological traits associated with WUE and/or seed yield could be used in quinoa breeding programs, particularly under drought conditions. This finding is similar to the results of other authors: Saddiq *et al.* (2021); Akram *et al.* (2021) and Valdivia-Cea *et al.* (2021) who documented a direct relationship between seed yield and WUE and leaf water content. Telahigue *et al.* (2017) recorded a correlation between yield and WUE under three water stress.

Conclusions

Physiological parameters were decreased with increased water regimes, but Pindex was the most responsible. Fo was the most related to seed yield and showed a positively correlation with no. of branches, seed yield, STI, and WUE under full irrigation (T1) and under extreme drought treatment (T3). Also, Pindex showed a positive correlation with seed yield and WUE under normal conditions. These traits could be used as selection criteria in breeding programs to select high-seed yield genotypes under different water regimes. Mild drought (65%FC) increased WUE; indicted the importance of assessing the water requirements of each quinoa genotype. Quinoa can grow under drought-stress conditions with an acceptable seed yield. The stress tolerance index (STI) and the average seed yield of the three irrigation treatments indicated the superiority of genotypes '94R', 'Apelawa', and 'Ames 10334', with mean values of 2.5, 2.5, and 2.4 t ha^{-1}. These genotypes had high water use efficiency. However, seed yield potential was high in the case of full irrigation, with mean values of 3.8, 3.7, 3.5, and 3.5 t ha^{-1} for the genotypes 'V9', 'Apelawa', '27GR', and '30TES'. The genotype 'Apelawa' was among the best genotypes under each water treatment and due to its high WUE under all water regimes, it was recommended to be released as a new cultivar.

Authors' Contributions

Conceptualization: EHE, MAK, MFS, MA and SSA; Data curation: MFS; Formal analysis: EHE, MAK, MFS and MA; Investigation: EHE, MAK, MFS, MA and SSA; Methodology: EHE, MAK and MA; Resources: EHE and SSA; Software: MAK, MFS and MA; Supervision: MFS and SSA; Writing - original draft: EHE and MFS; Writing - review and editing: MAK, MA and SSA. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

The authors extend their appreciation to Researchers Supporting Project number (RSPD2023R751), King Saud University, Riyadh, Saudi Arabia.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Akram MZ, Basra SMA, Hafeez MB, Khan S, Nazeer S, Iqbal S, Saddiq MS, Zahra N (2021). Adaptability and yield potential of new quinoa lines under agroecological conditions of Faisalabad-Pakistan. Asian Journal of Agriculture and Biology 2:1-8. *https://doi.org/10.35495/ajab.2020.05.301*

Alandia G, Odone A, Rodriguez J P, Bazile D, Condori B (2021). Quinoa—Evolution and future perspectives. The Quinoa Genome 179-195. *https://doi.org/10.1007/978-3-030-65237-1_11*

Al-Naggar AM, Abd El-Salam RM, Badran AE, El-Moghazi MM (2017). Effects of genotype and drought stress on some agronomic and yield traits of quinoa (*Chenopodium quinoa* Willd.). Bioscience Research 14(4):1080-1090.

Al-Selwey WA, Alsadon AA, Ibrahim AA, Labis JP, Seleiman MF (2023). Effects of zinc oxide and silicon dioxide nanoparticles on physiological, yield, and water use efficiency traits of potato grown under water deficit. Plants 12(1):218. *https://doi.org/10.3390/plants12010218*

Altun L, Kezik U, Kara Ö, Babur E (2016). Potential of water purification of Maçka forest ecosystems in northeastern Turkey. Journal of Environmental Protection and Ecology 17(2):557-565.

Araus JL, Slafer GA, Reynolds MP, Royo C (2002). Plant breeding and water relations in C3 cereals: what should we breed for? Annals of Botany 89:925-940. *https://doi.org/doi.org/10.1093/aob/mcf049*

Babur E, Dindaroğlu T, Yilmaz C, Sünbül M (2021). Effects of organic materials obtained from different tree species on some chemical parameters of water quality: study case of Andirin-Akifiye forest management unit. Aquatic Sciences and Engineering 36(1):15-21. *https://doi.org/10.26650/ase2020714556*

Basso B, Ritchie JT (2018). Evapotranspiration in high-yielding maize and under increased vapor pressure deficit in the US Midwest. Agricultural & Environmental Letters 3:170039. *https://doi.org/10.2134/ael2017.11.0039*

Battaglia ML, Thomason WE, Fike JH, Evanylo GK, Stewart RD, Gross CD, … Harrison MT (2022) Corn and wheat residue management effects on greenhouse gas emissions in the Mid Atlantic USA. Land 11(6):846. *https://doi.org/10.3390/land11060846B*

Bazile D, Pulvento C, Verniau A, Al-Nusairi MS, Ba D, Breidy J, … Padulosi S (2016). Worldwide evaluations of quinoa: Preliminary results from post international year of quinoa FAO projects in nine countries. Frontiers in Plant Science 7:850. *https://doi.org/10.3389/fpls.2016.00850*

da Silva PC, Ribeiro Junior WQ, Ramos MLG, Celestino SMC, Silva ADN, Casari RADCN, … Vinson CC (2021). Quinoa for the Brazilian Cerrado: Agronomic characteristics of elite genotypes under different water regimes. Plants 10(8):1591. *https://doi.org/10.3390/plants10081591*

Ding Z, Ali EF, Elmahdy AM, Ragab KE, Seleiman MF, Kheir AM (2021). Modeling the combined impacts of deficit irrigation, rising temperature, and compost application on wheat yield and water productivity. Agricultural Water Management 244:106626. *https://doi.org/10.1016/j.agwat.2020.106626*

Eid MA, Abdel-Salam, AA, Salem, HM, Mahrous, SE, Seleiman, MF, Alsadon AA, Solieman TH, Ibrahim AA (2020). Interaction effects of nitrogen source and irrigation regime on tuber quality, yield, and water use efficiency of *Solanum tuberosum* L. Plants 9(1):110. *https://doi.org/10.3390/plants9010110*

EL-Harty EH, Ghazy A, Alateeq TK, Al-Faifi SA, Khan MA, Afzal M, Alghamdi SS, Migdadi HM (2021). Morphological and molecular characterization of quinoa genotypes. Agriculture 11(286):20-16.

Elshayb OM, Nada AM, Sadek AH, Ismail SH, Shami A, Alharbi BM, Alhammad BA, Seleiman MF (2022). The integrative effects of biochar and ZnO nanoparticles for enhancing rice productivity and water use efficiency under irrigation deficit conditions. Plants 11(11):1416. *https://doi.org/10.3390/plants11111416*

Escribano J, Cabanes J, Jimenez-Atienzar M, Ibañez-Tremolada M, Gomez-Pando LR, García-Carmona F, Gandía-Herrero F (2017). Characterization of betalains, saponins and antioxidant power in differently colored quinoa (*Chenopodium quinoa*) varieties. Food Chemistry 234:285-294. *https://doi.org/10.1016/j.foodchem.2017*.

Fernandez GC (1992). Effective selection criteria for assessing plant stress tolerance. In: Proceeding of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress. Aug. 13-16, Shanhua, Taiwan, pp 257-270. *https://doi.org/10.22001/wvc.72511*

Fghire R, Anaya F, Ali OI, Benlhabib O, Ragab R, Wahbi S (2015). Physiological and photosynthetic response of quinoa to drought stress. Chilean Journal of Agricultural Research 75:174-183. *http://dx.doi.org/10.4067/S0718-58392015000200006*

Geerts S, Raes D, Garcia M, Mendoza J, Huanca R (2008). Crop water use indicators to quantify the flexible phenology of quinoa (*Chenopodium quinoa* Willd.) in response to drought stress. Field Crops Research 108(2):150-156. *https://doi.org/10.1016/j.fcr.2008.04.008*

Genty B, Briantais JM, Baker NR (1989). The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. Biochimica et Biophysica Acta 990:87-92. *https://doi.org/10.1016/S0304-4165(89)80016-9*

González JA, Gallardo M, Hilal M, Rosa M, Prado FE (2009). Physiological responses of quinoa (*Chenopodium quinoa* Willd.) to drought and waterlogging stresses: dry matter partitioning. Botanical Studies 50:35-42.

Guan X, Liu C, Li Y, Wang X, Liu Y, Zou C., Chen X, Zhang W (2022). Reducing the environmental risks related to phosphorus surplus resulting from greenhouse cucumber production in China. Journal of Cleaner Production 332:130076. *https://doi.org/10.1016/j.jclepro.2021.130076*

Hafez E, Seleiman M (2017). Response of barley quality traits, yield, and antioxidant enzymes to water-stress and chemical inducers. International Journal of Plant Production 11(4):477-490. *https://doi.org/10.22069ijpp.2017.3712*

Hamli S, Labhilili M, Alyadini M, Tagouti M, Manzeri R, Gaboun F, Bouzerzour H (2015). Heat shock effects on chlorophyll fluorescence, membrane stability, and metabolites accumulation in durum wheat (*Triticum turgidum* L. var. *durum*) seedlings and relationships with yield stress tolerance indices. Advances in Environmental Biology 9(8):116-125.

Hatfield JL, Dold C (2019). Water-use efficiency: advances and challenges in a changing climate. Frontiers in Plant Science 10:103. *https://doi.org/10.3389/fpls.2019.00103*

Huang G, Zhang X, Wang Y, Feng F, Mei X, Zhong X (2019). Comparisons of WUE in twelve genotypes of winter wheat and the relationship between δ13C and WUE. Peer J 7:6767 *http://doi.org/10.7717/peerj.6767*

Huang J, Yu H, Guan X, Guo R (2015). Accelerated dryland expansion under climate change. Nature Climate Change 6:166-171. *https://doi.org/10.1038/nclimate2837*

Jensen CR, Jacobsen SE, Andersen MN, Núñez N, Andersen SD, Rasmussen L, Mogensen VO (2000). Leaf gas exchange and water relation characteristics of field quinoa (*Chenopodium quinoa* Willd.) during soil drying. European Journal of Agronomy 13(1):11-25. *https://doi.org/10.1016/S1161-0301(00)00055-1*

Kakabouki I, Bilalis D, Karkanis A, Zervas G, Tsiplakou E, Hela D (2014). Effects of fertilization and tillage system on growth and crude protein content of quinoa (*Chenopodium quinoa* Willd.): An alternative forage. Emir. Journal of Food and Agriculture 26(1):18-24. *https://dx.doi.org/10.9755/ejfa.v26i1.16831*

Kheir AM, Alkharabsheh HM, Seleiman MF, Al-Saif AM, Ammar KA, Attia A, Zoghdan MG, Shabana, MM, Aboelsoud H, Schillaci C (2021). Calibration and validation of AQUACROP and APSIM models to optimize wheat yield and water saving in arid regions. Land 10(12):1375. *https://doi.org/10.3390/land10121375*

Killi D, Haworth M (2017). Diffusive and metabolic constraints to photosynthesis in quinoa during drought and salt stress. Plants 6:49. *https://doi.org/10.3390/plants6040049*

Krannich CT, Maletzki L, Kurowsky C, Horn R (2015). Network candidate genes in breeding for drought tolerant crops. International Journal of Molecular Sciences 16: 16378-16400. *https://doi.org/10.3390/ijms160716378*

Krause GH, Weis E (1991). Chlorophyll fluorescence and photosynthesis: the basics. Annual Review of Plant Physiology 42:313-349. *https://doi.org/10.1146/annurev.pp.42.060191.001525*

Lin PH, Chao YY (2021). Different drought-tolerant mechanisms in quinoa (*Chenopodium quinoa* Willd.) and djulis (*Chenopodium formosanum* Koidz.) based on physiological analysis. Plants 10:2279. *https://doi.org/10.3390/plants10112279*

Maxwell K, Johnson G N (2000). Chlorophyll fluorescence – a practical guide. Journal of Experimental Botany 51:659-668. *https://doi.org/10.1093/jexbot/51.345.659*

Präger A, Munz S, Nkebiwe PM, Mast B, Graeff-Hönninger S (2018). Yield and quality characteristics of different quinoa (*Chenopodium quinoa* Willd.) cultivars grown under field conditions in Southwestern Germany. Agronomy 8:197. *https://doi.org/10.3390/agronomy8100197*

Repo-Carrasco-Valencia RA, Encina CR, Binaghi MJ, Greco CB, Ronayne PA (2010). Effects of roasting and boiling of quinoa, kiwicha and kañiwa on composition and availability of minerals *in vitro*. Journal of the Science of Food and Agriculture 90:2068-2073. *https://doi.org/10.1002/jsfa.4053*

Roy R, Núñez-Delgado A, Sultana S, Wang J, Battaglia ML, Sarker T, Seleiman MF, Barmon M, Zhang R (2021). Additions of optimum water spent mushroom compost and wood biochar to improve the growth performance of Althaea rosea in drought-prone coal-mined spoils. Journal of Environmental Management 295:113076. *https://doi.org/10.1016/j.jenvman.2021.113076*

Saddiq MS, Wang X, Iqbal S, Hafeez MB, Khan S, Raza A, ... Gulshan AB (2021). Effect of water stress on grain yield and physiological characters of quinoa genotypes. Agronomy 11(10):1934. *https://doi.org/10.3390/agronomy11101934*

Seleiman MF, Al-Selwey, WA, Ibrahim AA, Shady M, Alsadon AA (2023). Foliar applications of ZnO and SiO_2 nanoparticles mitigate water deficit and enhance potato yield and quality traits. Agronomy 13(2):466. *https://doi.org/10.3390/agronomy13020466*

Seleiman MF, Kheir AM, Al-Dhumri S, Alghamdi AG, Omar ES. H, Aboelsoud, HM, Abdella, KA, Abou El Hassan, WH (2019). Exploring optimal tillage improved soil characteristics and productivity of wheat irrigated with different water qualities. Agronomy 9(5):233. *https://doi.org/10.3390/agronomy9050233*

Steel RGD, Torrie JH, Dicky DA (1997). Principles and procedures of statistics: A biological approach. 3rd Eds. Mcgraw Hill Inc. Book Co. N.Y. USA, pp 352-358.

Telahigue D C, Yahia LB, Aljane F, Belhouchett K, Toumi L (2017). Grain yield, biomass productivity and water use efficiency in quinoa (*Chenopodium quinoa* Willd.) under drought stress. Journal of Scientific Agriculture 2:22-32. *https://doi.org/10.25081/jsa.2017.v1.67*

Telahigue D, Yahia L, Aljane F, Belhouchett K, Toumi L (2017). Grain yield, biomass productivity and water use efficiency in quinoa (*Chenopodium quinoa* Willd.) under drought stress. Journal of Scientific Agriculture 1:222-232. *http://dx.doi.org/10.25081/jsa.2017.v1.67*

Tsimilli-Michael M, Strasser RJ (2008). *In vivo* assessment of stress impact on plant's vitality: applications in detecting and evaluating the beneficial role of mycorrhization on host plants. Mycorrhiza: state of the art, genetics and molecular biology, eco-function, biotechnology, eco-physiology, structure and systematics. 679-703. *https://doi.org/10.1007/978-3-540-78826-3_32*

Valdivia-Cea W, Bustamante L, Jara, J, Fischer S, Holzapfel E, Wilckens R (2021). Effect of soil water availability on physiological parameters, yield, and seed quality in four quinoa genotypes (*Chenopodium quinoa* Willd.). Agronomy 11:1012. *https://doi.org/10.3390/agronomy11051012*

Verma HP, Sharma OP, Sharma S, Kumar R, Khatik P (2021). Effect of irrigation scheduling and organic manures on yield and economics of bread wheat (*Triticum aestivum* L.). Indian Journal of Agronomy 66 (2):186-190.

Winkel T, Méthy M, Thénot F (2002). Radiation use efficiency, chlorophyll fluorescence, and reflectance indices associated with ontogenic changes in water-limited Chenopodium quinoa leaves. Photosynthetica 40:227-232. *https://doi.org/10.1023/a:1021345724248*

Yang A, Akhtar SS, Amjad M, Iqbal S, Jacobsen SE (2016). Growth and physiological responses of quinoa to drought and temperature stress. Journal of Agronomy and Crop Science 202(6): 445-453. *https://doi.org/10.1111/jac.12167*

Zhang H, Pala M, Oweis T, Harris H (2000). Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment. Australian Journal of Agricultural Research 51:295-304. *https://doi.org/10.1071/AR99059*

Zurita-Silva A, Jacobsen SE, Razzaghi F, Alvarez-Flores R, Ruiz K, Morales A, Silva H (2015). Quinoa drought responses and adaptation. In: State of the Art Report of Quinoa in the World in 2013. FAO & CIRAD. Rome, Italy, pp 157-171.

The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.

License - Articles published in ***Notulae Botanicae Horti Agrobotanici Cluj-Napoca*** are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.
© Articles by the authors; Licensee UASVM and SHST, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:

- Material disclaimer: The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- Maps and affiliations: The publisher stay neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- Responsibilities: The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.