Print ISSN: 0375-9237
Online ISSN: 2357-0350

EGYPTIAN JOURNAL OF BOTANY (EJBO)

Genotypic difference in salt tolerance during germination and early seedling growth between a native Libyan cultivar and a Ukrainian cultivar of barley (*Hordeum vulgare* L.)

Taha M. El-Katony, Naser G. El-Moghrbi

PUBLISHED BY
THE EGYPTIAN
BOTANICAL SOCIETY

Genotypic difference in salt tolerance during germination and early seedling growth between a native Libyan cultivar and a Ukrainian cultivar of barley (*Hordeum vulgare* L.)

Taha M. El-Katony[1], Naser G. El-Moghrbi[2]

[1]*Department of Botany and Microbiology, Faculty of Science, Damietta University, New Damietta City, Egypt*
[2]*Department of Botany, Faculty of Arts and Sciences, Benghazi University, Qaminis Branch, Libya*

Salinity adversely affects productivity of crops in arid regions primarily via impeding seed germination. Barely is an important cereal crop for human and animal feeding. The differential impact of salinity on seed germination of a Libyan cultivar (cv. Rihane) and a Ukrainian cultivar (cv. 10031000) was investigated. Seeds were germinated in the dark in 0, 50, 100, 200 and 300 mM NaCl at 25 °C. The high germination potential of cv. Rihane, with 200 mM NaCl threshold and moderate reduction at 300 mM NaCl, contrasts the lower germination potential of cv. 10031000 with severe salinity-dependent reduction. The effect of salinity on germination speed was stronger than on germination magnitude. The uniformity and synchrony of germination were comparable in the two cultivars and peaked at mild to moderate salinity followed by sharp reduction at high salinity. The mean germination time and germination lag were longer in cv. Rihane than cv. 10031000 and increased by salinity particularly in cv. 10031000. The length of embryonic axis exhibited more severe salinity-induced reduction in cv. 10031000 than cv. Rihane. Radicle fresh weight was comparable in the two cultivars but plumule fresh weight was higher in cv. Rihane than cv. 10031000. Increasing salinity, severely reduced embryo fresh weight either progressively (cv. Rihane) or beyond a 50 mM NaCl threshold (cv. 10031000). The superior salt tolerance at germination of cv. Rihane over cv. 10031000 points to an inherited trait of barley cultivar adapted to salt-affected, arid regions relative to a cultivar native to a well-watered region.

Key words: Barley, Germination, Genotype, Salinity, Germination speed, Embryo growth

ARTICLE HISTORY
Submitted: July 05, 2024
Accepted: November 17, 2024

CORRESPONDANCE TO
Taha M. El-Katony,
Department of Botany and Microbiology, Faculty of Science, Damietta University, New Damietta City, Egypt
Email: tmsoliman2000@yahoo.co.uk
ORCID iD: 0000-0002-6222-7273
DOI: 10.21608/ejbo.2024.301906.2910

EDITED BY: R. Hafez

INTRODUCTION

Salinity is a global threat that affects productivity of the cultivated lands worldwide (Zörb et al., 2019). The impact of salinity is particularly serious in the arid and semi-arid regions of the world since aridity impedes leaching of soluble salts down the soil horizons, thus allowing salt buildup in the rhizosphere and the surface soil layers (Mohammed et al., 2021). Libya, as a part of North Africa and the Sahara, is considered one of the most arid regions in the world. The annual rainfall of Libya ranges from 100 to 500 mm and is mainly confined to the northern coastal strip, thus leaving most of the country (>90%) with scarce rainfall of about 10 mm (Ying et al., 2013). Excitingly, some parts of the Libyan south desert are arid with no rain at all (Belgasim et al., 2018). What aggravates the problem of aridity further in Libya is the lack of permanent resources of fresh water such as rivers and freshwater lakes.

Because of this extreme aridity, saline and salt-affected lands in Libya cover about one-fifth of the country area (Mahmoud, 1995). The high rates of evaporation cause accumulation of salts on the surface layers of the soil where seed germination occurs. These harsh conditions imped germination of annuals and lead to differential life-history strategies in perennials to maximize their fitness. Consequently, both soil salinity and aridity represent major constraints to agriculture and production of foodstuff in Libya. Furthermore, the aggravating secondary salinization due to human activities–exemplified by usage of poor-quality water in irrigation and the current climate change episode is worrying because most of the cultivated crops are salt-sensitive (van Zelm et al., 2020; Tarolli et al., 2024).

Germination is the earliest and most critical stage of plant development, enforced by water intake into the embryo leading to emergence of the radicle and plumule and subsequently to the seedling stage; thus, it plays an essential role in plant growth and the ultimate yield (Xue et al., 2019). The sensitivity of the germination stage to salinity relative to the succeeding growth stages of the plant varies according to plant species and cultivar (Madidi et al., 2004; Tarawneh, 2019; Atta et al., 2023). Salinity can influence seed germination through an osmotic stress, ion-specific effects and oxidative stress, which collectively result in slowed germination rate and extended germination time (Munns, 2002; Irik and Bikmaz, 2024). Salinity lowers the water potential gradient between the seed and the soil, thus reducing water uptake during imbibition (Munns & Tester, 2008; Atta et al., 2023). Meanwhile, salinity may affect the germination of seeds by the toxic effects of excess sodium and chloride ions on embryo viability (Jahromi et al., 2008; Daszkowska-Golec, 2011).

Barely (*Hordeum vulgare* L.) is one of the most important cereal crops all over the world, with prominent roles in human and herd feeding. Barely is the fourth cultivated cereal crop in the world, with vast adaptability to arid climates and tolerance to severe water tension (EL Sabagh et al., 2019). The genus *Hordeum* comprises 32 species including annual and perennial grasses. Germination and early seedling stage are the most critical phase in barley life cycle and has been claimed to be the most sensitive plant developmental stage to salinity (Bewley et al., 2012). Although barley is a salt-tolerant and drought-tolerant field crop, its growth and development are severely affected by water shortage and ionic concentration of the medium (EL Sabagh et al., 2019). In the present study, we investigate the differential impact of NaCl salinity on seed germination of two barley (*H. vulgare*) cultivars; a local Libyan cultivar (cv. Rihane) and an imported Ukrainian cultivar (cv. 10031000).

MATERIALS AND METHODS

Plant material and germination conditions

The experimental plant material was two barley (*Hordeum vulgare* L.) cultivars: a local Libyan cultivar (cv. Rihane) provided by the Research Center at Al-Bayda, Libya and an imported Ukrainian cultivar (cv. 10031000). Seeds, selected for homogeneity, were surface sterilized in 5% sodium hypochlorite for 20 min and then washed thoroughly with distilled water. Fifty seeds from each cultivar were germinated in the dark between filter papers moistened with the treatment solutions in 12-cm Petri dishes at a temperature of 25 °C. The treatment solutions included the following concentrations (mM) of NaCl: 0, 50, 100, 200 and 300. At frequent intervals, filter papers were moistened with the test solutions and seeds were transferred to new dishes moistened with fresh treatment solutions to prevent buildup of salt. Seed germination was recorded daily for a period of 8 days. Seeds were considered germinated when the radicle emerged from the coleorhiza to at least 2 mm. At the end of experiment, length and fresh weights of radicles and plumules were recorded.

Experimental design and statistical analysis

The experiment was factorial with a completely randomized design and four replications; each was a petri dish of 50 seeds. The main factors were barely genotype with two levels and salinity with five levels (0, 100, 200, 300 mM NaCl). Final cumulative germination percentage was arcsine-transformed before performing ANOVA to ensure homogeneity of variance. Data was subjected to two-way ANOVA using SPSS version 22 to evaluate the effect of the main factors and their interaction on seed germination, followed by mean separation according to Duncan's multiple range test. The correlation among the different germination indices and seedling growth was assessed using the Principal Component Analysis (PCA).

Definitions and calculations

The germination parameters considered in the present work included germinability or final germination percentage, rate or speed, times, uniformity and synchrony of germination according to Ranal & Santana (2006). Germinability or germination capacity is the final cumulative germination percentage and was calculated as the percentage of germinant at the end of germination period relative to the total number of seeds. Rate or speed of germination was estimated in terms of germination value (GV), also called the Czabator index of germination velocity and calculated as:

$$GV = PV \times \text{final MDG} \qquad (\% \, d^{-1})$$

where PV stands for the Peak value (also, the maximum MDG) and MDG is the mean daily germination or daily germination speed (DGS) and calculated as:

$$MDG = \frac{\text{cumulative germination \% at time ti}}{ti} \qquad (\% \, d^{-1})$$

Germination times:

Mean germination time (MGT or $\bar{t}$) is a measure of the average length of time required for maximum germination of a seed lot. It can be used as an inverse measure of speed of germination, and was calculated as:

$$MGT = \frac{\sum g_i \times t_i}{\sum g_i} = \frac{\sum g_i \times t_i}{N} \qquad (d)$$

Where g_i is the number of seeds newly germinated, or the daily germination percentage at time t_i from sowing and N is the total number of germinant or the final cumulative germination percentage. The first day of germination (FDG) is the time of the first germination event, that is the time of germination of the faster or most vigorous seeds. The last day of germination (LDG) is the time of the last germination event or the time of germination of the slowest or the least vigorous seeds. Time spread of germination (TSG) is the time elapsing between FDG and LDG and was calculated as:

TSG = (LDG - FDG) + 1

T_{10} or time to 10% germination is a measure of the lag period between the start of imbibition and onset of germination. Uniformity of germination was estimated in terms of the coefficient of uniformity of germination (CUG) which measures the variability among seeds in relation to the mean germination time and was calculated as:

$$CUG = \frac{\Sigma g_i}{\Sigma(\bar{t}-t_i)^2 \times g_i} \quad (d^{-2})$$

Where g_i is the number of newly germinated seeds on time t_i from sowing and $\bar{t}$ is the mean germination time. High values point to concentrated germination in time. Synchrony of germination was estimated using the synchronization index ($\overline{E}$), calculated as:

$$\overline{E} = -\Sigma f_i \times \log_2 f_i \text{ (bit) and } f_i = \frac{g_i}{\Sigma g_i}$$

where f_i is the relative frequency of germination and g_i the number of seeds germinated on day i. Low values of $\overline{E}$ refer to more synchronized germination.

RESULTS

Time course of germination of the two barley cultivars in the different salt solutions exhibited the typical sigmoidal pattern: with an initial lag phase, followed by a period of rapid rise in germination percentage and finally a steady stage. This pattern was expressed with different timing of germination onset and termination, different germination speed and final germination percentage depending on the level of salinity (Figure 1). The effect of the main factors (barley cultivar and salinity) and their interaction on the magnitude, speed, uniformity, synchrony and times of germination was mostly significant ($P<0.05$) or highly significant ($P<0.01$). Generally, the effect of salinity was stronger (with $P<0.001$) than the effect of genotype which was mostly non-significant or just significant ($P<0.05$) (Table 1).

The magnitude of germination (final germination percentage) was significantly higher in cv. Rihane than cv. 10031000, and the genotypic difference was particularly evident under the impact of salinity. For example, in non-salinized seeds, the final germination percentage of cv. Rihane was only 8% higher than that of cv. 10031000 but the superiority of cv. Rihane above cv. 10031000 approached 67% at 300 mM NaCl. This pattern arose from the differential impact of salinity on the final germination percentage of the two cultivars. In cv. Rihane, the final germination percentage exhibited a threshold of 200 mM NaCl, beyond which it was halved as salinity level further increased up to 300 mM NaCl. By contrast, the final germination percentage of cv. 10031000 was subjected to a progressive reduction of 68% as salinity increased from 0 to 300 mM NaCl (Figure 2a). The effect of treatments was more evident on speed of germination than on its magnitude. The germination value (GV) was, on average, significantly higher in cv. Rihane than cv. 10031000, although in absence of salinity the reverse was true. Like the final germination percentage, GV of cv. Rihane, exhibited robustness to salinity stress within 200 mM NaCl, and this salinity threshold involved a peak at 50 mM NaCl; but, as salinity increased beyond 50 mM up to 300 mM NaCl, GV experienced a sharp reduction of 84%. In cv. 10031000, the salinity-induced reduction in GV was progressive and amounted to 92% below the control across the whole range of salinity (Figure 2b).

The coefficient of uniformity of germination (CUG) was, on average, comparable in the two barley cultivars with similar pattern of response to salinity. Moderate salinity led to a peak in CUG that was followed by sharp reduction at high salinity. In cv. Rihane, the peak of CUG occurred at 100 mM NaCl with 150% higher CUG above the control and was followed by 81% reduction with further increase in salinity up to 300 mM NaCl. In cv. 10031000, the peaking salinity was 50 mM NaCl with 50% increase above the control, followed by 77% decrease at 300 mM NaCl (Fig. 2c). The synchronization index was non-significantly higher in cv. Rihane than cv. 10031000, with somewhat similar pattern of response to salinity. In cv. Rihane, a rhythmic pattern was observed which was manifested as initial 18% reduction at 100 mM NaCl, followed by 40% increase at 200 mM and finally 36% reduction at 300 mM NaCl. In cv. 10031000, the initial decrease at 100 mM NaCl was 37%, followed by 94% increase at 200 mM NaCl and finally a marginal decrease at 300 mM NaCl (Figure 2d).

The values of the first day of germination (FDG) and last day of germination (LDG) were, on average, greater in cv. Rihane than cv. 10031000, and the genotypic difference was most evident under the impact of salinity. Increasing salinity beyond a threshold of 200 mM up to 300 mM NaCl increased FDG by 83% and 25% in cv. Rihane and cv. 10031000, respectively. Similarly, increasing salinity beyond a threshold of 100 mM NaCl (in cv. Rihane) and 200 mM NaCl (in cv. 10031000) up to 300 mM NaCl increased LDG by an average of 50%.

Table 1. Two-way ANOVA showing the effects of the main factors (cultivar and salinity) and their interaction on germination of barley (*Hordeum vulgare* L.) and embryo growth

Variable and source of variation	df	F	P	Variable and source of variation	df	F	P
Germination capacity (degree)				**Last day of germination**			
Cultivar (Cv.)	1	120.0	0.000	Cultivar (Cv.)	1	5.400	0.031
Salinity (Saln.)	4	60.52	0.000	Salinity (Saln.)	4	14.27	0.000
Cv. × Saln.	4	2.851	0.051	Cv. × Saln.	4	1.733	0.182
Germination Value				**Time spread of germination**			
Cultivar (Cv.)	1	54.98	0.000	Cultivar (Cv.)	1	1.891	0.184
Salinity (Saln.)	4	151.8	0.000	Salinity (Saln.)	4	6.266	0.002
Cv. × Saln.	4	19.99	0.000	Cv. × Saln.	4	1.734	0.182
Coefficient of uniformity of germination (CUG)				**Radicle length**			
Cultivar (Cv.)	1	0.472	0.500	Cultivar (Cv.)	1	5.351	0.031
Salinity (Saln.)	4	5.957	0.003	Salinity (Saln.)	4	99.35	0.000
Cv. × Saln.	4	1.455	0.253	Cv. × Saln.	4	7.861	0.001
Synchronization Index ($\bar{E}$)				**Plumule length**			
Cultivar (Cv.)	1	7.846	0.011	Cultivar (Cv.)	1	3.062	0.095
Salinity (Saln.)	4	8.832	0.000	Salinity (Saln.)	4	119.6	0.000
Cv. × Saln.	4	3.747	0.020	Cv. × Saln.	4	4.581	0.009
Mean Germination Time (MGT)				**Radicle fresh weight**			
Cultivar (Cv.)	1	103.4	0.000	Cultivar (Cv.)	1	0.056	0.815
Salinity (Saln.)	4	97.79	0.000	Salinity (Saln.)	4	14.27	0.000
Cv. × Saln.	4	12.59	0.000	Cv. × Saln.	4	1.711	0.187
First day of germination				**Plumule fresh weight**			
Cultivar (Cv.)	1	12.25	0.002	Cultivar (Cv.)	1	7.049	0.015
Salinity (Saln.)	4	42.25	0.000	Salinity (Saln.)	4	60.67	0.000
Cv. × Saln.	4	12.25	0.000	Cv. × Saln.	4	0.646	0.636

Time spread of germination (TSG) was comparable in the two cultivars and increased by 33% and 50% in cv. Rihane and cv. 10031000, respectively with the increase in salinity from 0 to 300 mM NaCl. Mean germination time (MGT) was, on average, greater in cv. Rihane than cv. 10031000. In cv. Rihane, increasing salinity from 0 to 50 mM NaCl lowered MGT by 35%, followed by 90% increase with further increase in salinity up to 300 mM NaCl. In cv. 10031000, increasing salinity beyond a threshold of 100 mM NaCl up to 300 mM NaCl increased MGT by 51%. Germination lag (T_{10}) followed the same pattern of MGT, with higher values in cv. Rihane than cv. 10031000. In cv. Rihane, increasing salinity from 0 to 50 mM NaCl lowered T_{10} by 43%, followed by 160% increase with further increase in salinity up to 300 mM NaCl. In cv. 10031000, increasing salinity beyond a threshold of 100 mM NaCl up to 300 mM NaCl almost doubled the T_{10} (Table 2).

The length of embryonic axis was, in average, higher in cv. Rihane than cv. 10031000, and the difference was either significant ($P<0.05$) for radicle length or just non-significant ($P = 0.095$) for plumule length. However, the uncertain genotypic difference in length of embryonic axis emerged convincingly under the impact of salinity in favor of cv. Rihane. Increasing salinity from 0 to 300 mM NaCl progressively reduced radicle length and plumule length of cv. Rihane by 64% and 77%, respectively but led to almost complete cessation of embryo growth in cv. 10031000 (Figure 3). Radicle fresh weight was comparable in the two cultivars but plumule fresh weight was significantly higher in cv. Rihane than cv. 10031000; however, the superiority of cv. Rihane in biomass of the embryo was most evident in the non-treated seeds. Increasing salinity, severely reduced embryo fresh weight and the reduction was either progressive (cv. Rihane) or occurred beyond a 50 mM NaCl threshold in cv. 10031000 (Figure 3).

DISCUSSION

The pattern of time course of germination was subjected to strong genotype-salinity interaction, manifested as different timing of onset and termination of germination, different germination speeds and ultimately final germination percentages in the different genotype-salinity combinations. The genotypic variability between the two barley cultivars in germinability was associated with differential susceptibility to salinity stress that is the highly germinable genotype (cv. Rihane) exhibited also better resistance to salinity stress during germination relative to the other genotype (cv. 10031000).

Table 2. Germination times of cvs. Rihane and 10031000 of *Hordeum vulgare* L. seeds in response to NaCl salinity. Each value is the mean of three replicates ± SE. Means with common letters are non-significantly different at P≤0.05

Cultivar and salinity (mM NaCl)	FDG (days)	LDG (days)	TSG (days)	MGT (days)	T_{10} (days)*
Rihane					
0	2.00 ± 0.00^{a}	5.00 ± 0.00^{a}	4.00 ± 0.00^{a}	3.75 ± 0.03^{d}	2.10
50	2.00 ± 0.00^{a}	5.33 ± 0.33^{a}	4.33 ± 0.33^{ab}	2.46 ± 0.08^{a}	1.20
100	2.00 ± 0.00^{a}	5.33 ± 0.33^{a}	4.33 ± 0.33^{ab}	2.59 ± 0.05^{ab}	1.38
200	2.00 ± 0.00^{a}	7.33 ± 0.33^{b}	6.33 ± 0.33^{c}	3.44 ± 0.08^{c}	2.00
300	3.67 ± 0.33^{c}	8.00 ± 0.00^{b}	5.33 ± 0.33^{bc}	4.67 ± 0.22^{e}	3.15
10031000					
0	2.00 ± 0.00^{a}	4.67 ± 0.33^{a}	3.67 ± 0.33^{a}	2.58 ± 0.05^{ab}	1.20
50	2.00 ± 0.00^{a}	5.00 ± 0.58^{a}	4.00 ± 0.58^{a}	2.37 ± 0.08^{a}	1.20
100	2.00 ± 0.00^{a}	5.67 ± 0.67^{a}	4.67 ± 0.67^{ab}	2.37 ± 0.03^{a}	1.20
200	2.00 ± 0.00^{a}	5.67 ± 0.67^{a}	4.67 ± 0.67^{ab}	2.83 ± 0.07^{b}	1.34
300	2.50 ± 0.00^{b}	7.00 ± 0.00^{b}	5.50 ± 0.00b^{c}	3.58 ± 0.14^{cd}	2.50

*Values of T_{10} were calculated from the means of time course of germination curves, therefore, they were not followed by SE, and mean separation is not applicable.

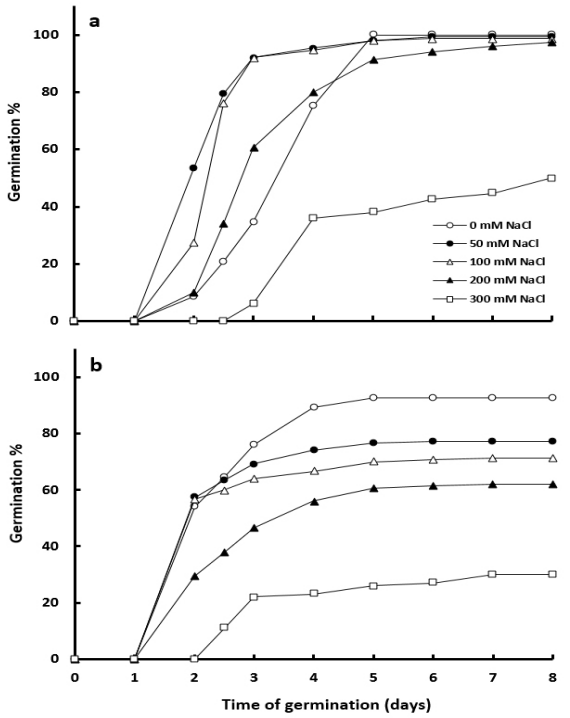

Figure 1. Time course of germination of cv. Rihane (a) and cv. 10031000 (b) of barley (*Hordeum vulgare* L.) in response to increasing NaCl salinity of the medium. Each value is the mean of three replicates.

Consequently, the superiority of cv. Rihane over cv. 10031000 in the final germination percentage became more evident under the impact of salinity. Genotypic variability in salt tolerance during germination has been reported for barley by Mohammed et al. (2021), Javed et al. (2022) and Bela (2023). The role of salinity in resolving the rather weak genotypic variability in germination efficiency has been reported for four faba bean cultivars (El-Bastawisy et al., 2018). Among three Tunisian barley cultivars, Abdi et al. (2016) demonstrated that Rihane was the most tolerant cultivar to salinity stress. The superiority of cv. Rihane over cv. 10031000 in the final germination percentage is manifested as existence of 200 mM NaCl threshold along with relatively moderate 50% reduction beyond the threshold in cv. Rihane compared with a progressive substantial reduction of 68% in cv. 10031000. Salt tolerance of plant performance or physiological processes can be evaluated in terms of the threshold salinity (if any) and the slope of the salinity-response regression line, which reflects the extent of inhibition post the threshold (Martínez-Cob et al., 1987; George et al., 2012; Pachepsky et al., 2024).

The salinity-induced changes in germination speed were more impressive relative to those in germination percentage that is the salinity threshold of germination speed of cv. Rihane included a peak rather than the plateau of final germination percentage. However, this peak was followed by a steeper reduction in germination speed of cv. Rihane relative to cv. 10031000. These findings suggest that evaluation of the effect of salinity on germination performance of barley is more reliable based on speed of germination than on magnitude of germination. Even, postemergence embryo growth is a more reliable indicator of the cultivar salt tolerance than speed of germination. Among the different indices used to assess salt tolerance, shoot fresh weight in addition to germination rate reliably represented the salt tolerance of 549 *Brassica napus* inbred lines at the germination stage (Wu et al., 2019).

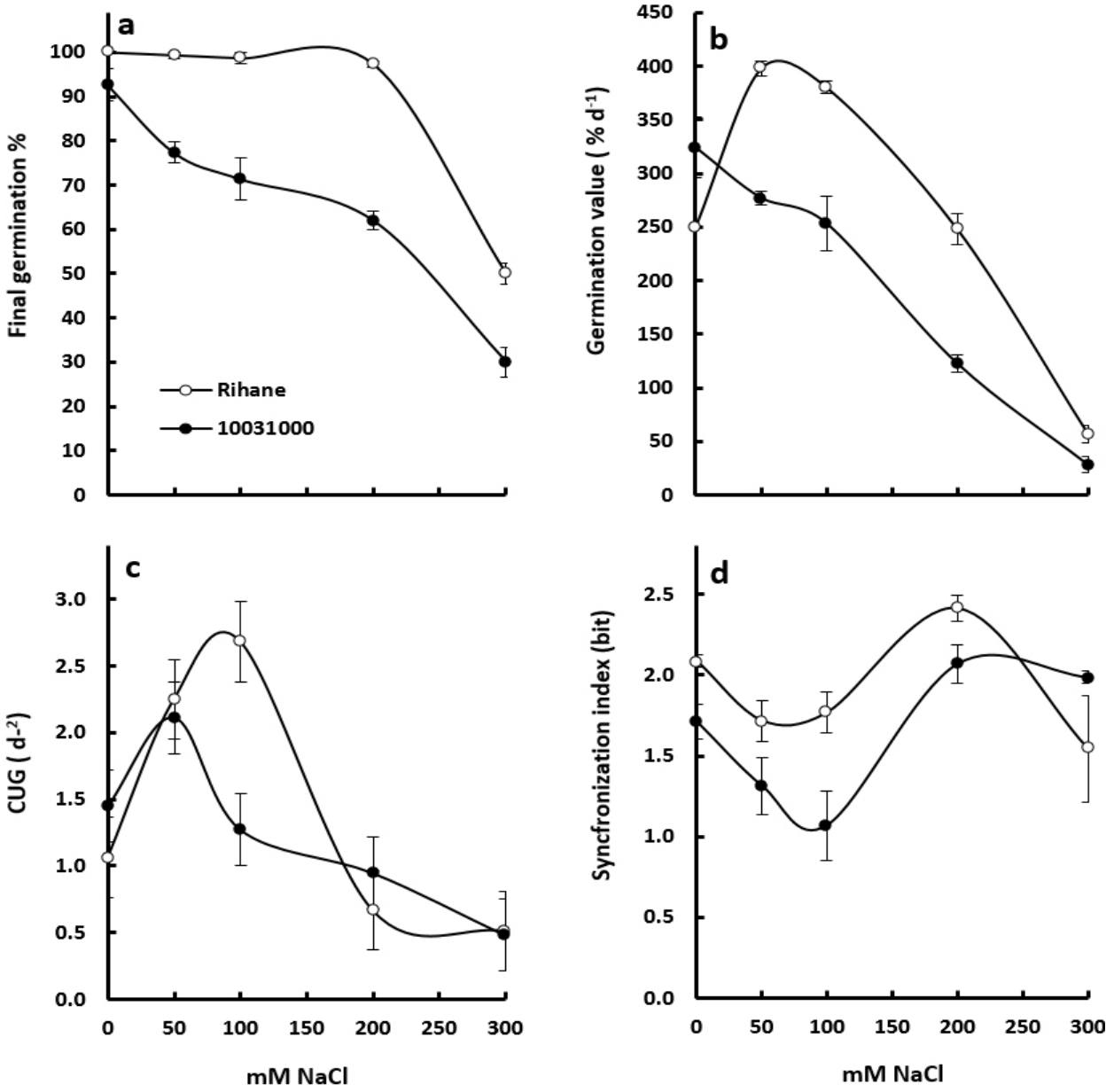

Figure 2. Final germination percentage (a), germination value (b), coefficient of uniformity of germination (CUG, c) and Synchronization index of germination (d) of the barley cultivars Rihane and 10031000 in response to increasing NaCl salinity of the medium. Each value is the mean of three replicates ± SE.

However, despite the average higher germination efficiency (magnitude and speed) of cv. Rihane than cv. 10031000 under the impact of salinity, the reverse was true for germination speed of non-treated seeds. This means that the non-treated seeds of the inferior genotype (cv. 10031000) may germinate faster than the seeds of the vigorous genotype (cv. Rihane) but with eventual lower final germination percentage. However, the intimate association of germination magnitude, germination speed and germination uniformity are evident from the high positive correlations depicted from PCA (Figure 4). Despite the marked superiority of cv. Rihane over cv. 10031000 in magnitude and speed of germination, such genotypic difference is less apparent in terms of germination uniformity and germination synchrony. Nevertheless, at moderate salinity of 100 mM NaCl the genotypic difference in germination uniformity and synchrony was maximal where CUG of cv. Rihane was twice that of cv. 10031000 and $\bar{E}$ of cv. Rihane was about 76% higher (lower germination synchrony) than that of cv. 10031000.

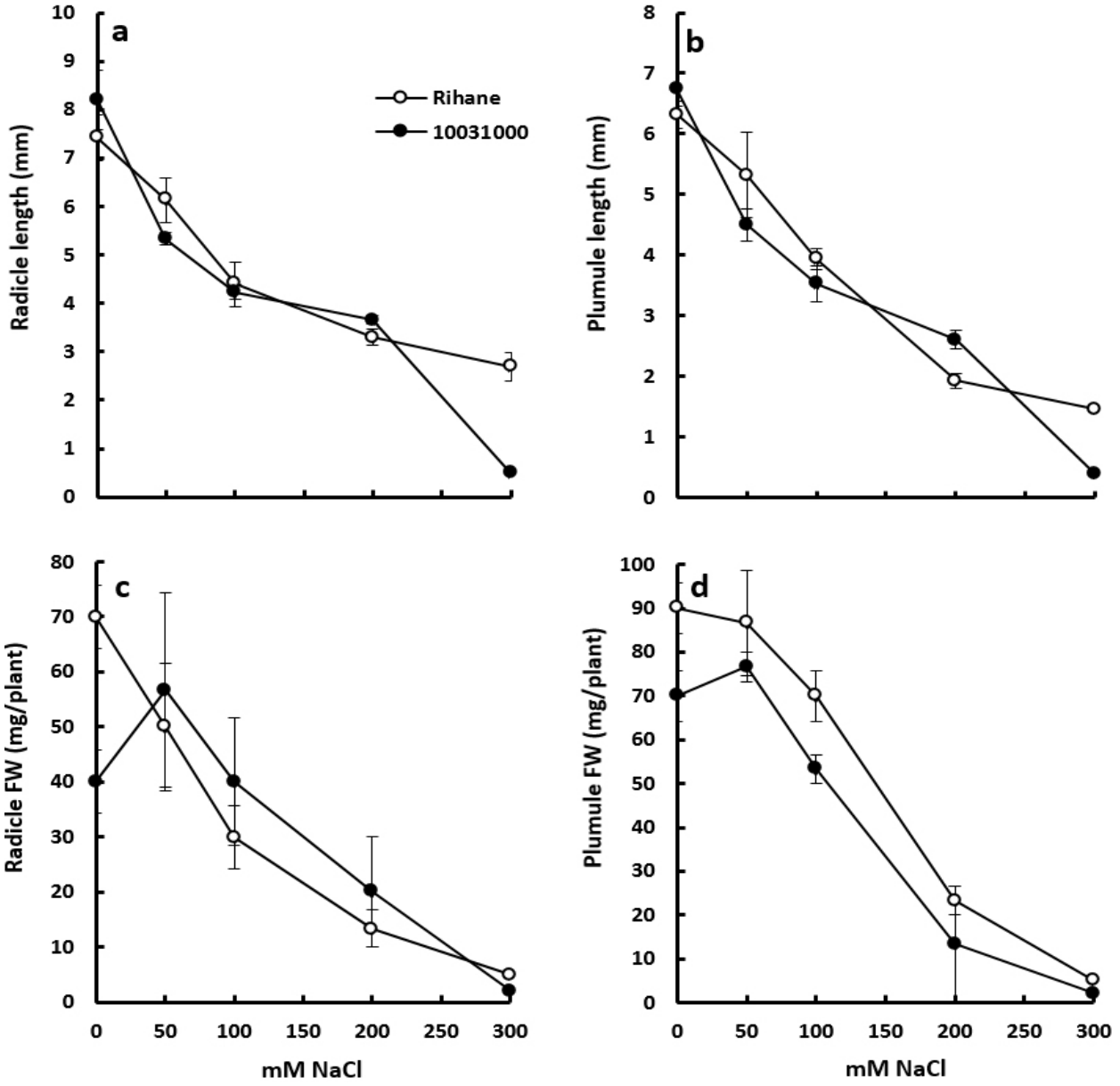

Figure 3. Radicle length (a), plumule length (b), radicle fresh weight (c) and plumule fresh weight (d) of the barley cultivars Rihane and 10031000 in response to increasing NaCl salinity of the medium. Each value is the mean of three replicates ± SE.

Also, at 300 mM NaCl germination synchrony was lower (higher $\bar{E}$) in cv. 1003100 than cv. Rihane. This signifies that the pattern of germination uniformity and synchrony of barley might vary according to the level of salinity as is evidenced from the periodic pattern of the synchrony-salinity relationship. The present findings suggest that germination uniformity approaches a peak at a certain level of salinity where the magnitude of peak and the corresponding peaking salinity might vary according to the genotype. The peak of germination uniformity of cv. Rihane was higher and occurred at higher salinity than that of cv. 10031000.

Salinity has been claimed to slow the germination rate with extension of germination time (Munns, 2002; Irik and Bikmaz, 2024). The reduction in germination efficiency of barley in terms of magnitude, speed and uniformity of germination was associated with delayed onset and termination of germination and prolonged germination lag (Figure 4). The salinity-induced lag (the increase in T_{10}) was more pronounced in the less-efficient genotype (cv. 10031000) than in cv. Rihane. The relatively shorter germination lag (T_{10}) of cv. Rihane under the impact of NaCl salinity is another aspect of the superiority of germination efficiency and the less severe impact of

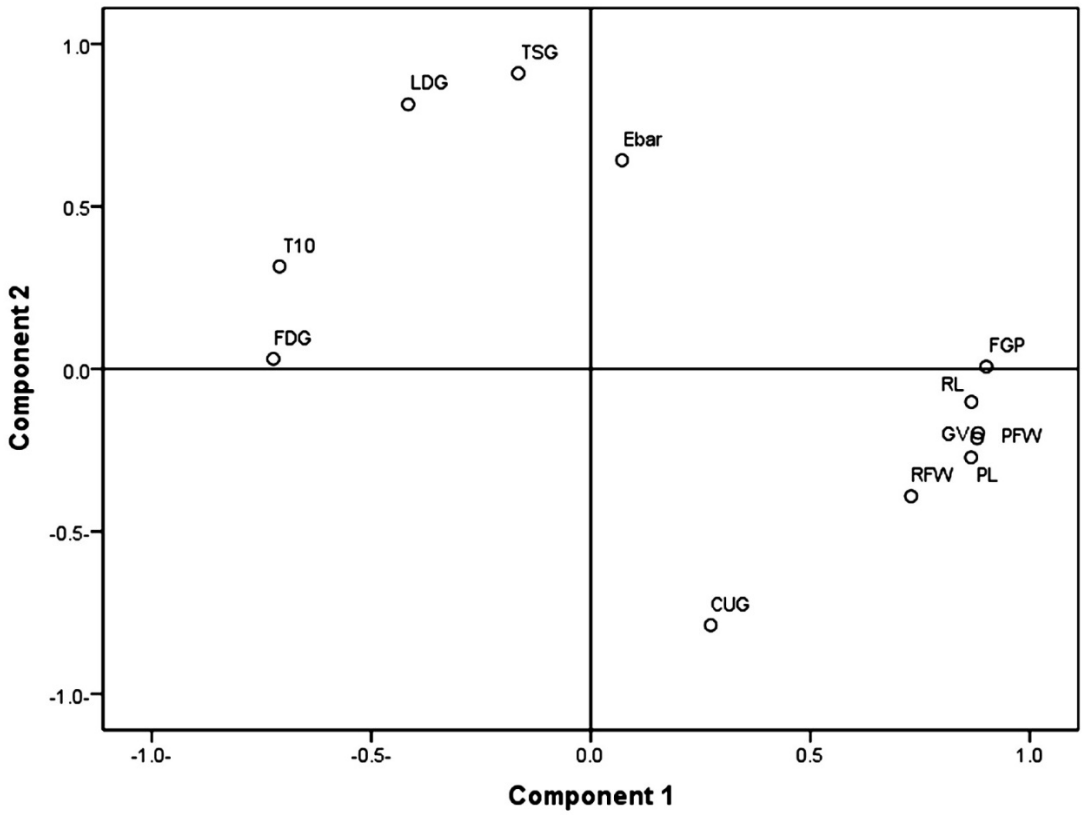

Figure 4. PCA summarizing the relationships between final germination percentage (FGP), germination value (GV), coefficient of uniformity of germination (CUG), synchronization index (Ebar), first day of germination (FDG), last day of germination (LDG), time spread of germination (TSG), radicle length (RL), radicle fresh weight (RFW), plumule length (PL) and plumule fresh weight (PFW) of barley cultivars in NaCl.

salinity on germination of this genotype. The inverse association of germinability, speed and uniformity of germination of barley seeds in one hand with germination lag in the other hand is depicted from Figure 4 and has been reported for black grass (Colbach et al., 2006).

The adverse effect of salinity was more aggressive on embryo growth than on seed germination and was in accordance with the genotypic response of germination. The more adverse effect of salinity on seed germination than on seedling growth was particularly evident in cv. 10031000 where the salinity -induced reduction in embryo growth was steeper than that in magnitude of germination despite the beneficial role of low salinity (50 mM NaCl) for embryo biomass. The stronger impact of salt stress on seedling growth than on seed germination has been reported for sesame (El Harfi et al., 2016) and sweet sorghum (Patanè et al., 2009). This seems reasonable since the water potential of the dry quiescent seed is very negative compared to the emerging embryo, and this renders water uptake and metabolic processes of the active embryonic cells more vulnerable to osmotic stress and ionic stress than the dry seed. The highly germinating cv. Rihane cultivar also produced more vigorous embryonic axis upon germination with relatively marked salinity resistance relative to cv. 10031000 even though embryo growth of the latter cultivar can benefit from mild salinity of 50 mM NaCl. The agreement between response of germination and embryo growth to salinity stress has been reported for *Brassica napus* inbred lines (Wu et al., 2019). Nevertheless**,** the contradiction between the two responses has been reported for nine barley genotypes (Madidi et al., 2004) and four faba bean genotypes (El-Bastawisy et al., 2018) where the salt-resistant cv. during germination was certainly not as such during seedling growth.

The more aggressive salinity-induced reduction in embryo biomass post the 50 mM NaCl threshold relative to the reduction in length of the embryonic axis seem to lead to the production of thin barley seedlings under the impact of NaCl salinity. The progressive reduction in embryonic length, along with the rise in embryo biomass at 50 mM NaCl of cv. 10031000 points to maximal girth of embryo of this cultivar at mild salinity of 50 mM NaCl.

CONCLUSIONS

Salinity stress can maximize the genotypic variability in germination efficiency of barley cultivars in favor of the native cultivar against the imported one. Evaluation of the effect of salinity on germination performance of barley is more reliable based on speed than on magnitude, uniformity and synchrony of germination. The non-treated seeds of the inferior barley genotype may germinate faster than the seeds of the vigorous genotype but with eventual lower final germination percentage. Germination uniformity approaches a peak at a certain level of salinity with different magnitudes and peaking salinity in the two genotypes. The genotypic difference in germination uniformity and synchrony was maximal at moderate salinity. There is an intimate association between germination magnitude, germination speed and germination uniformity and earliness of germination. The adverse effect of salinity was more aggressive on embryo growth than on seed germination. This seems reasonable in view of the very negative water potential of the dry quiescent seed compared to the emerging embryo, which renders water uptake and metabolic processes of the active embryonic cells more vulnerable to osmotic stress and ionic stress than the dry seed. Salinity leads to the production of thin barley seedlings although maximal girth of embryo of the sensitive cultivar occurred at mild salinity of 50 mM NaCl. The superiority of the native Libyan barley genotype (cv. Rihane) over the imported Ukrainian genotype (cv. 10031000) in germination and seedling growth under the impact of salinity justifies cultivation of the native cultivar in the arid and salt-affected lands.

AUTHOR CONTRIBUTIONS

Conceptualization: TME and NGE; Material preparation, data collection and analysis: NGE; Formal data analysis: TME; Writing—review and editing: TME. All authors read and approved of the final manuscript.

REFERENCES

Abdi, N., Wasti, S., Slama, A., Salem, M.B., Faleh, M.E. (2016) Comparative study of salinity effect on some Tunisian barley cultivars at germination and early seedling growth stages. *Journal of Plant Physiology and Pathology*, 4 (3), 1–9. http://dx.doi.org/10.4172/2329-955X.1000151.

Atta, K., Mondal, S., Gorai, S., Singh, A.P., Kumari, A., Ghosh, T., Roy, A., Hembram, S., Gaikwad, D.J., Mondal, S., Bhattacharya, S., Jha, U.C., Jespersen, D. (2023) Impacts of salinity stress on crop plants: Improving salt tolerance through genetic and molecular dissection. *Frontiers in Plant Science*, 14, 1241736. doi: 10.3389/fpls.2023.1241736.

Bela, K. (2023) Crop tolerance under biotic and abiotic stresses. *Agronomy*, 13(12), 3024. https://doi.org/10.3390/agronomy13123024.

Belgasim, B., Aldali, Y., Abdunnabi M.J., Hashem, G., Hossin, K. (2018) The potential of concentrating solar power (CSP) for electricity generation in Libya. *Renewable and Sustainable Energy Reviews*, 90, 1–15.

Bewley, J.D., Bradford, K., Hilhorst, H. (2012) Seeds: Physiology of Development, Germination and Dormancy. Springer Science & Business Media.

Colbach, N., Dürr, C., Roger-Estrade, J., Chauvel, B., Caneill, J. (2006) ALOMYSYS: modelling black-grass (*Alopecurus myosuroides* Huds.) germination and emergence, in interaction with seed characteristics, tillage and soil climate—I. Construction. *European Journal of Agronomy*, 24, 95–112.

Daszkowska-Golec, A. (2011) Arabidopsis seed germination under abiotic stress as a concert of action of phytohormones. *OMICS: A Journal of Integrative Biology*, 15(11), 763–774.

El-Bastawisy, Z.M., El-Katony, T.M., El-Fatah, S.N.A. (2018) Genotypic variability in salt tolerance of *Vicia faba* during germination and early seedling growth. *Journal of King Saud University-Science*, 30, 270–277.

El Harfi, M., Hanine, H., Rizki, H., Latrache, H., Nabloussi, A. (2016) Effect of drought and salt stresses on germination and early seedling growth of different color-seeds of sesame (*Sesamum indicum*). *International Journal of Agriculture and Biology*, 18(6), 1088–1094. DOI: 10.17957/IJAB/15.0145.

EL Sabagh, A., Hossain, A., Islam, M.S., Barutcular, C., Hussain, S., Hasanuzzaman, M., Akram, T., Mubeen, M., Nasim, W., Fahad, S., Kumar, N., Meena, R.S., Kızılgeçi, F., Yıldırım, M., Ratnasekera, D., Saneoka, H. (2019) Drought and salinity stresses in barley: consequences and mitigation strategies. *Australian Journal of Crop Science*, 13(6), 810–820.

George, E., Horst, W.J., Neumann, E. (2012) Adaptation of plants to adverse chemical soil conditions. In: Marschner P. (ed) Marschner's mineral nutrition of higher plants, 3rd edn. (pp. 409–472). Academic Press. https://doi.org/10.1016/B978-0-12-384905-2.00017-0

Irik, H.A., Bikmaz, G. (2024) Effect of different salinity on seed germination, growth parameters and biochemical contents of pumpkin (*Cucurbita pepo* L.) seeds cultivars. *Scientific Reports*, 14(1), 6929. https://doi.org/10.1038/s41598-024-55325-w

Jahromi, F., Aroca, R., Porcel, R., Ruiz-Lozano, J.M. (2008) Influence of salinity on the in vitro development of *Glomus intraradices* and on the in vivo physiological and molecular responses of mycorrhizal lettuce plants. *Microbial Ecology*, 55,45–53.

Javed, M.M., Al-Doss, A.A., Tahir, M.U., Khan, M.A., El-Hendawy, S. (2022) Assessing the suitability of selection approaches and genetic diversity analysis for early

detection of salt tolerance of barley genotypes. *Agronomy*, 12(12), 3217. https://doi.org/10.3390/agronomy12123217

Madidi, S.E., Baroudi, B.E., Aameur, F.B. (2004) Effects of salinity on germination and early growth of barley (*Hordeum vulgare* L.) cultivars. International Journal of Agriculture and Biology, 6, 767–770.

Mahmoud, K.B. (1995) Libyan Soils. 1st Edn. Tripoli: National Research Scientific Organization.

Martínez-Cob, A., Aragües, R., Royo, A. (1987) Salt tolerance of barley (*Hordeum vulgare* L.) cultivars at the germination stage: Analysis of the response functions. *Plant and Soil*, 104(1), 53–56. https://link.springer.com/article/10.1007/BF02370624.

Mohammed, A.H., Morrison, J.I., Baldwin, B.S. (2021) Evaluating salinity tolerance in progeny of domestic and wild barley crosses at germination stage. *Agrosystems, Geosciences and Environment*, 4(3), e20189. https://doi.org/10.1002/agg2.20189

Munns, R. (2002) Comparative physiology of salt and water stress. *Plant Cell and Environment*, 25(2), 239–250.

Munns, R., Tester, M. (2008) Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651–681.

Pachepsky, Y., Yakirevich, A., Ponizovsky, A.A., Gummatov, N. (2024) The osmotic potential of soil solutions in salt tolerance studies: Following M. Th. van Genuchten's innovation. *Vadose Zone Journal,* 23*,* e20299*.* https://doi.org/10.1002/vzj2.20299

Patanè, C., Cavallaro, V., Cosentino, S.L. (2009) Germination and radicle growth in unprimed and primed seeds of sweet sorghum as affected by reduced water potential in NaCl at different temperatures. *Industrial Crops and Products*, 30(1), 1–8. https://doi.org/10.1016/j.indcrop.2008.12.005.

Ranal, M.A., Santana, D.G.D. (2006) How and why to measure the germination process? *Brazilian Journal of Botany*, 29, 1–11. https://doi.org/10.1590/S0100-84042006000100002.

Tarawneh, G.H. (2019) Response of barley varieties to salt stress at different growth stages in arid environment of Jordan. *Research on Crops*, 20(4), 667–675.

Tarolli, P., Luo, J., Park, E., Barcaccia, G., Masin, R. (2024) Soil salinization in agriculture: Mitigation and adaptation strategies combining nature-based solutions and bioengineering. *Iscience*, 27(2), 1–9.

Van Zelm, E., Zhang, Y., Testerink, C. (2020) Salt tolerance mechanisms of plants. *Annual Review of Plant Biology*, 71, 403–433.

Wu, H., Guo, J., Wang, C., Li, K., Zhang, X., Yang, Z., Li, M., Wang, B. (2019) An effective screening method and a reliable screening trait for salt tolerance of *Brassica napus* at the germination stage. *Frontiers in Plant Science*, 10, 444645. doi: 10.3389/fpls.2019.00530.

Xue, W., Yan, J., Jiang, Y., Zhan, Z., Zhao, G., Tondelli, A., Luigi, C., Cheng, J. (2019) Genetic dissection of winter barley seedling response to salt and osmotic stress. *Molecular Breeding*, 39, 1–19.

Ying, F., Lei, J.Q., Xu, X.W., Pan, B.R. (2013) Composition and characteristics of Libyan flora. *Archives of Biological Sciences*, 65(2), 651–657.

Zörb, C., Geilfus, C.M., Dietz. K.J. (2019) Salinity and crop yield. *Plant Biology*, 21, 31–38.