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In Vitro Assessment of Salinity Stress Impact on Early Growth in Ten Certified Palestinian Barley Cultivars (*Hordeum vulgare* L.) Potentially Suitable for Cultivation on Former Quarry Substrates

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Abstract: Salinity is a major constraint for crop health and productivity, particularly on arid, semiarid, and otherwise marginal soils, such as quarry residue. Quarries are a main pillar of national income in Palestine but have a long-lasting toll on the environment. We examined barley (*Hordeum vulgare* L.), another pillar of the Palestinian economy and one of the most important crops in the world, in this regard for its tolerance to salinity stress. This study is the first to evaluate the impact of salinity (50, 85, 120, and 175 mM NaCl) on seed germination, early growth stage, and morpho-anatomy on ten pre-selected certified Palestinian barley cultivars (Baladi, Improved Baladi, Rihan, ICARDA 1, ICARDA 15, ACSAD 68, ACSAD 176, ACSAD 1417, ACSAD 1732, and ACSAD 1744) to assess their potential for a successful growth start under adverse saline conditions. In addition, soil samples from quarries in Hebron governorate were randomly selected and tested for salinity level, electrical conductivity, and total of soluble salts for a first rough overview of options for applying our results, since local data are often scarce or outdated. The examined soil samples reached electrical conductivity (EC) ranges of 1.81×10^{-4}–9.071×10^{-4} dS m^{-1}, which are below the normal EC (11–57×10^{-4} dS m^{-1}). This result may contraindicate the hypothesis that quarry lands always suffer from salinity stress. Cultivars such as ACSAD 68 and Icarda 15 proved very sensitive to higher salinity stress with high G_{50} (time point when 50% of seeds have germinated) at 4.4 d, with 120 mM NaCl (ACSAD 68) or incalculable amounts (Icarda 15) and just 50 and 20% total germination, respectively. Concentrations of 175 mM NaCl were found in ACSAD 176 and Improved Baladi (no G_{50}, 37 and 30% germination, respectively). Some cultivars showed a moderate to high resilience to salinity, such as ICARDA I, ACSAD 1417, and ACSAD 1744, which reached > 80% seed germination at 120 mM NaCl and >60% at 175 mM NaCl, and G_{50} within 1.5–2.2 days; the most resilient was ACSAD 1732 with G_{50} < 2 days and germination still >80% at 175 mM NaCl. This is strongly supported by the monitored growth parameters. In conclusion, ACSAD1732 and Icarda 1 cultivars are highly recommended for cultivation in areas of low precipitation and high salt accumulation. In addition, the land and/or soil of quarries, their landfills, and nearby areas in Palestine may be fit for barley cultivation with recommended cultivars regarding salinity stress.

Keywords: abiotic stress; electrical conductivity (EC); barley; quarries; salinity stress; shoot system

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1. Introduction

Salts are essential for plant growth at compatible levels. However, salinity stress is the second-biggest abiotic factor, accounting for major global problems that negatively affect agricultural productivity by disturbing numerous physiological, biochemical, and molecular processes [1,2]. High salinity is mostly due to high concentrations of Na^+ and

Cl^- in the soil, which produce hyperosmotic and hypertonic solutions that stop water and nutrient uptake by plants [2]. The sources of soil salinity are rainfall, weathering of rocks, flooding of seashores, urbanization, and irrigation with brackish water [3–5]. In addition, the reuse of wastewater causes considerable salinization of groundwater [6], which in turn is used for irrigation. The most important mineral ions in soil–water extracts are Na^+, Cl^-, Ca^{++}, SO_4^-, HCO_3^-, K^+, Mg^{++}, and NO_3^- [7,8].

Increased sodium and magnesium ion levels can destroy soil structure. However, calcium carbonate can improve soil structure, forming calcareous alkaline soil and increasing soil pH. On highly saline soil, visible salt crystals often occur on the soil surface, making it vulnerable to erosion [5]. High salts levels in soil can also positively affect soil physical properties by causing fine particles to bind together in a process known as flocculation; this can have benefits in soil aeration, root penetration, and root growth [9].

Soil salt content is usually determined for different soil layers and at different depths, based on the plant species root growth [10]. The electrical conductivity of a soil sample is affected by the concentration and composition of dissolved salts, which increase the solution's ability to conduct an electrical current [11,12]. In this context, water-soluble salts in the soil act as strong electrolytes that have electrical conductivity (EC), which is defined as the ability of a material to conduct electrical current. Within a certain concentration range, the salt content in the soil is positively related to the electrical conductivity. Recently, a simple and quick approach has emerged that uses electrical conductivity to directly represent the total salt content in the soil. The SI unit of electrical conductivity is siemens per meter ($S\ m^{-1}$) [10].

The effects of salinity on plants are recognized as water stress, cytotoxicity that is caused by the excessive uptake of ions, and nutritional imbalance [13,14]. Increasing salinity stress can also induce oxidative damage to the plant cells, which can affect germination and the characteristics of the seedling [15]. This stress negatively affects seed germination by means of osmotic stress and ion toxicity [16–18]. The ion toxicity results from the accumulation of salt ions (Na^+ and Cl^-) in the seed. This inhibits the metabolism needed for seed germination, and in some cases will eventually lead to seed death. In addition, the plant will reduce its cell rigidity, the number of the roots, their length, the rigidity, the length of the shoot, and the crop yield [19,20]. Moreover, an excess of some ions can cause an imbalance and reduce the ability of plant to take up nutrients; i.e., high levels of calcium may inhibit the uptake of iron (lime-induced chlorosis), and high sodium may frustrate potassium uptake [5,21]. In addition, ion excess can decrease the uptake of phosphorus due to the precipitation of phosphate ions in the presence of Ca ions. Some elements, such as sodium, chlorine, and boron, have specific toxic effects on plants [22]. Symptoms of damage emerging from soil salts are similar to other plant diseases and can include browning leaf edges, chlorosis, wilting, leaf drop, etc., which makes diagnosis complex.

Plants firstly respond to the salts by a shoot-ion-independent reaction that is related to the detection of Na^+ and the signaling process. This causes the closure of the stomata in the leaves and inhibits the expansion of the leaf due to low water activity. The second phase is a salt-dependent response to the accumulation of toxins in the leaves that causes a premature leaves senescence. Another mechanism is genetic control by several genes that can control the salinity tolerance [20,23,24]. Moreover, the impact of salinity on plant is salt-specific in regards to bioactive compound production. For example, in one study, the highest polyphenol concentrations were obtained with Na_2SO_4 variants, while in anoother, the highest flavonoid content was obtained with salt mixtures of NaCl and Na_2SO_4 (100% higher than control) [25,26].

Barley (*Hordeum vulgare* L.) is a valuable grain crop that has ranked fourth among the cereal crops [27] and as the second-most economically important cereal after wheat in the world and Palestine as well [28]. It is commonly used in breads, soups, food, alcoholic beverages, and health products, as well as for animal fodder [20,29,30]. Barley is an annual plant that belongs to the Poaceae family. It is adaptable to a great range of climates and does best in growing seasons of at least 90 days; in Palestine, it is mainly cultivated in autumn. It grows with greater resistance to dry heat than other small grains and thrives in near-desert areas. In addition, it shows a wide range of responses to salinity stress depending on the phylogenic of the cultivars [31]. Salinization is a problem that results from quarry operations. There are almost 300 quarries in Palestine, and 142 of them are within the Hebron governorate. Quarries, their landfill, and their nearby areas have deleterious effects on the environment, resulting in areas of poor substrate [24–26]. However, they are considered essential pillars of national economic development in Palestine. As of now, little research has been conducted on the consequences of quarries in terms of environmental and climate change [32–34]. Therefore, screening for salt-tolerant crop cultivars is a prerequisite to mitigate the quarries' negative impact on otherwise agriculturally usable land.

This study therefore aimed to identify barley cultivar(s) showing salinity resilience during the stages of seed germination and early seedling growth. The ultimate goal was the assessment of physiological and morphological features that assist the plant in tolerating salinity stress throughout its growth period. In addition, the study aimed to establish an initial, current overview of the salt content in the soil of quarries at Hebron governorate to enable recommendations for suitable cultivars as a novel approach to rehabilitating quarries, their landfills, and nearby areas.

2. Materials and Methods

2.1. Materials

The experiments were carried out in vitro from 2019 to 2020 at the Applied Biology Department and Palestine–Korea Biotechnology Center in Palestine Polytechnic University. Seeds of ten certified barley cultivars growing in Palestine were kindly provided by National Agriculture Research Center (NARC)/Palestine. The barley cultivars were Rihan, Icarda1, Icarda15, Baladi, Improved Baladi, ACSAD176, ACSAD1732, ACSAD68, ACSAD1417, and ACSAD1744.

2.2. Area of Study and Soil Sampling

The study area was four regions in the Hebron governorate, which is located in the south of Palestine at latitude 31.31° north and longitude 35.8° east, 36 kilometers south of Jerusalem. The mean average of precipitation in the Hebron governorate is 595.6 mm [32], which has a semi-arid climate. The four regions we studied were Bani Naim, AlShyoukh, Taffouh, and Sier. The soil sampling was carried out via the quadrate method, in which grids of 10 m × 10 m were constructed and random selection was conducted. Substrate samples were taken from the surface and a depth of 20 cm and collected in sealed polyethylene plastic bags. EC was measured, and soluble salt content was calculated according to [10].

2.3. Methods

2.3.1. Plant Seed Disinfection and Germination

We selected 120 healthy and viable seeds with similar size and shape for each cultivar. The seeds were surface-sterilized by soaking in 1% (v/v) sodium hypochlorite solution for 20 minutes with the aid of Tween 20. After applying 70% ethanol, the seeds were washed with sterile distilled water three times [19]. In vitro germination was performed in 9 cm Petri dishes containing water–agar medium (0.8%) supplemented with 0 mM, 50 mM, 85 mM, 120 mM, and 175 mM NaCl for 10 days. The pH of the medium was adjusted to 5.8 with NaOH. The medium was autoclaved for 20 minutes at 121 °C and 1 atmosphere (Tuttnauer AC 2540E). Under aseptic condition, ten seeds of each barley cultivar were placed in each Petri dish in a triplicate form for each concentration. The plates were incubated in a plant growth room under fluorescent cool light with a 16 h photoperiod at 24 ± 2 °C.

During the seed germination stage, the number of germinated seeds (defined as the sprouting of the seeds after a period of dormancy, based on the emergence of radicle) was recorded daily for 10 days. The G_{50}, which is defined as time (in days) required for germination of 50% of the seeds, was calculated according to [19]; G_{50} was determined after daily monitoring from the point–slope formula, Formula (1):

$$y - y_1 = m(x - x_1) \tag{1}$$

where y = day when 50% of seeds germinated; y_1 = day before y; x = total number of germinated seeds at day of y; x_1 = total number of germinated seeds at day of y_1. The slope m represents G_{50}.

For morphological analysis, seedlings of ten days' growth were harvested. The roots and shoots were separated, and their lengths were measured by a regular caliper. The fresh roots and shoots were dried in an oven at 70 °C until reaching constant weight [33]. The dry biomass and total water content of constituent barley parts were measured (TWC calculation: fresh constituent barley part mass—dry constituent barley part mass/fresh constituent barley part mass × 100%) according to Cappelletti [34].

2.3.2. Electrical Conductivity (EC) and Salinity Contents of the Soil

Soil samples of 100 g were air-dried, sieved in a 1 mm sieve, and extracted by 500 mL of CO_2-free distilled water (5:1; distilled water: soil). The extraction was performed on a hotplate with the aid of air-pump filtration and a Buchner funnel. Then, 25 mL of the sample solution was used to determine the electrical conductivity (µS) and total soluble salt concentration according to Bado et al. [10].

2.3.3. Statistical Analysis

The data analysis for this paper was conducted using the Real Statistics Resource Pack software (Release 8.5), Copyright (2013–2023), Charles Zaiontz (www.real-statistics.com, accessed last 26 February 2023). Abbreviations used: analysis of variance, ANOVA; standard deviation, SD; standard error of the mean, SEM; compact letter display, CDL. Differences in means of anatomical and morphological variables between cultivars under the salinity treatments were assessed by one-way ANOVA due to its robustness with unequal sample sizes, followed by Tukey–Kramer test with Bonferroni correction for post-hoc comparisons and classical Cohen's D for effect size estimation. Since comparisons between salinity treatment levels were, with 2 exceptions, all significant, in this paper, we focus on reporting differences between the cultivars within each treatment level.

3. Results

3.1. Effect of Salinity Stress on Seed Germination of Barley

Salinity stress delayed seed germination, illustrated by G_{50} (see Table 1), and reduced germination percentage of all cultivars (see Figure 1). The results reveal that ACSAD 1732 proved to be the most resistant cultivar during germination and reached 80 ± 1% seed germination at 175 mM NaCl. ACSAD 1744, ACSAD 1417, and Icarda 1 were at the second order for salinity stress resilience, since they reached lower germination percentages than ACSAD 1732 under the effect of 175 mM NaCl (Figure 1).

The most sensitive cultivar was Icarda 15, which possessed the lowest percentage of germinated seeds at all tested salt concentrations. Rihan, Baladi, and Improved Baladi cultivars revealed a high germination percentage at 120 mM NaCl (67% ± 1.5; 70% ± 1; 77% ± 2.08, respectively) and a dramatical reduction in seed germination percentage (40% ± 1; 37% ± 1.15; and 30% ± 1.53, respectively) only at the highest concentration of 175 mM NaCl. The remaining cultivars such as ACSAD 176 and ACSAD 68 showed stronger decline over increasing salinity levels and can be considered moderately to weakly resilient.

Table 1. The average time [d] of G_{50} for the ten certified Palestinian barley cultivars grown under salinity stress followed by SEM where applicable, calculated from the point–slope formula (see Formula (1)).

	Baladi	**Rihan**	**ACSAD 176**	**Icarda 1**	**ACSAD 1417**	**Improved Baladi**	**ACSAD 1744**	**ACSAD 68**	**ACSAD 1732**	**Icarda 15**
0 mM NaCl	3.0 ± 0.11	1.1 ±0.11	1.9 ± 0.02	1.5 ± 0.03	1.5 ± 0	0.2 ± 0.72	1.5 ± 0	1.8 ± 0	1.3 ± 0	N/A
50 mM NaCl	2.3 ± 0.08	1.2 ± 0.05	2.3 ± 0.13	1.6 ± 0.09	1.8 ± 0.03	0.2	1.1 ± 0	4.1 ± 0.13	1.5 ± 0.12	N/A
85 mM NaCl	3.4 ± 0.31	1.3 ± 0.07	N/A	1.6 ± 0.05	1.6 ± 0.03	0.3	1.6 ± 0.01	2.2 ± 0.13	1.8 ± 0	N/A
120 mM NaCl	1.6 ± 0.49	2.6 ± 0.06	N/A	1.8 ± 0.08	1.8 ± 0.03	2.2	2.0 ± 0.06	4.4	1.2 ± 0.01	N/A
175 mM NaCl	N/A	N/A	N/A	2.1	4.4 ± 0.83	N/A	3.9 ± 0.54	N/A	1.8 ± 0.05	N/A

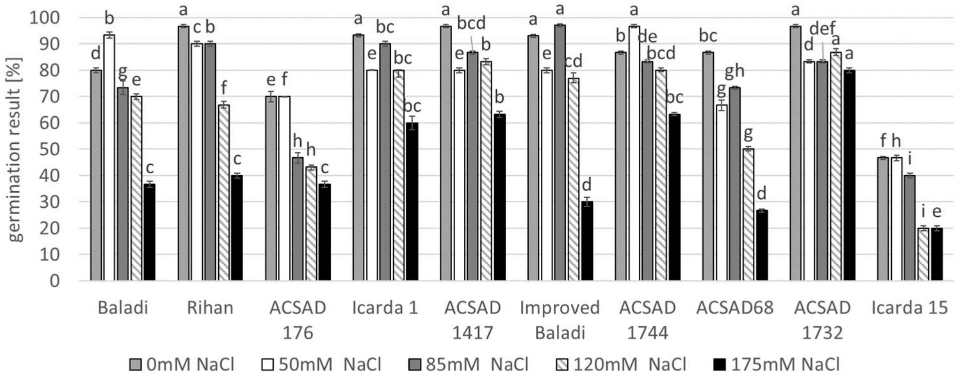

Figure 1. Seed germination mean [%] ± SEM of Palestinian barley cultivars under different salt concentrations. Comparisons between cultivars within each treatment (same-colored bars) visualized by compact letter display (CDL) visualized by letters a,b,c,d; shared letters between plotted result bars of one treatment mean no significant differences between those results at the level of $p < 0.05$.

The Baladi cultivar revealed a higher germination percentage at 50 mM NaCl than its control. In addition, Icarda 1, ACSAD 1417, and ACSAD 68 revealed a higher seed germination percentage in 85 mM NaCl than in 50 mM NaCl but less than in control, while ACSAD 1732 possessed a slightly higher percentage at 120 mM NaCl than in 85 mM NaCl.

The G_{50} is illustrated in Table 1. In this context, the best cultivars were ACSAD 1732 and Icarda 1, which possessed the lowest G_{50}. The G_{50} of ACSAD 1732 was 1.3 days in control and 1.87 days in 175 mM NaCl. Thus, we observed narrow fluctuations under high salt concentration. Icarda 1 behaved in a similar way under the same salt concentrations. ACSAD 1744, ACSAD 1417, and Rihan cultivars possessed moderate values of G_{50}. Baladi, ACSAD 68, ACSAD 176, and Icarda 15 were among the least efficient, with the highest or non-computable values of G_{50} at 120 and 175 mM NaCl.

Regarding the morphological data collected at day 10 after sowing and the early growth stage, the total seedling height of all cultivars increased with time, but growth decreased inversely with salinity (see Figures 2–4). Increasing salinity caused a reduction in plant height, stem length, and root length. However, no significant effects on the number of the fibrous roots under the effect of salinity stress were observed. ACSAD 1417 showed the highest length of shoot system (2.5 cm) at 175 mM NaCl, followed by Icarda 1 (1.7 cm). However, Icarda 1 showed better growth at all other salt concentrations (see Figure 3). Moreover, Rihan and Improved Baladi cultivars did not grow at all at a salinity level of 175 mM NaCl.

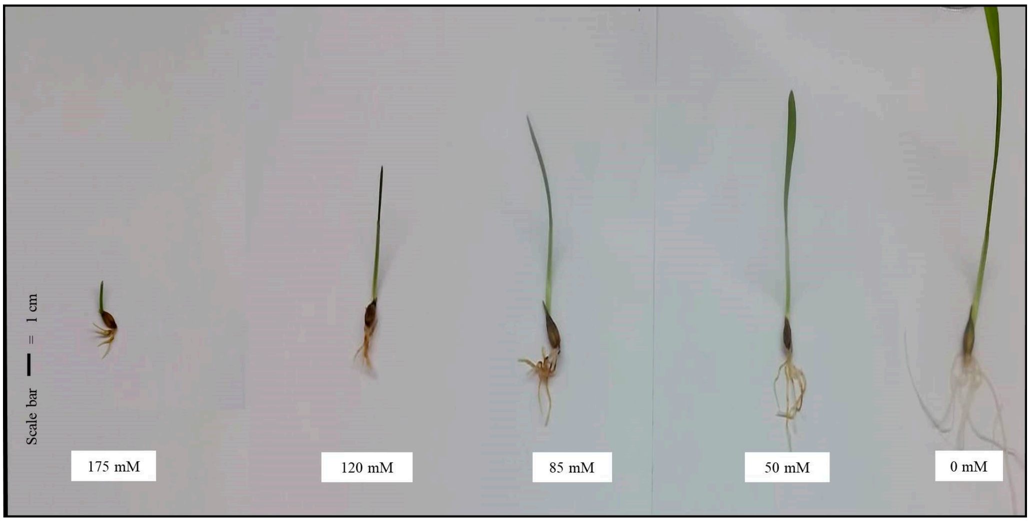

Figure 2. Photograph of 10-day-old seedlings of ACSAD 1732 illustrate its morphology under different NaCl concentrations. Scale bar = 1 cm.

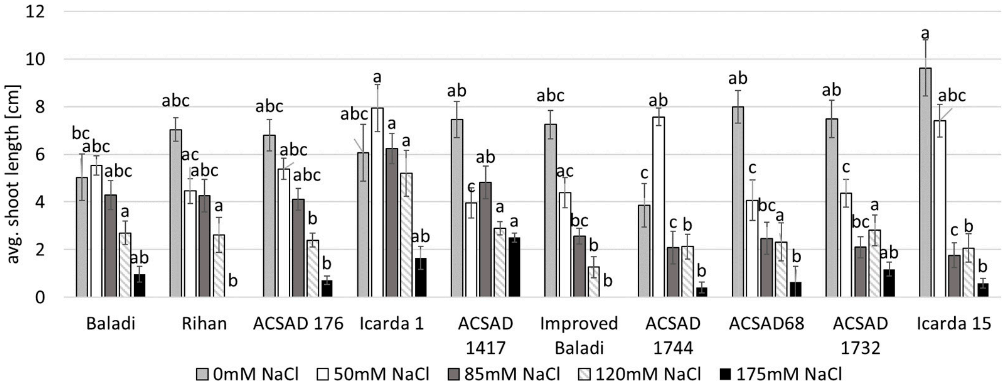

Figure 3. Average shoot system length [cm] ± SEM for the ten certified Palestinian barley cultivars grown under salinity stress during early growth stage (10 days from seed germination); comparisons between cultivars within each treatment (same-colored bars) visualized by compact letter display (CDL) visualized by letters a,b,c,d; shared letters between plotted result bars of one treatment mean no significant differences between those results at the level of $p < 0.05$.

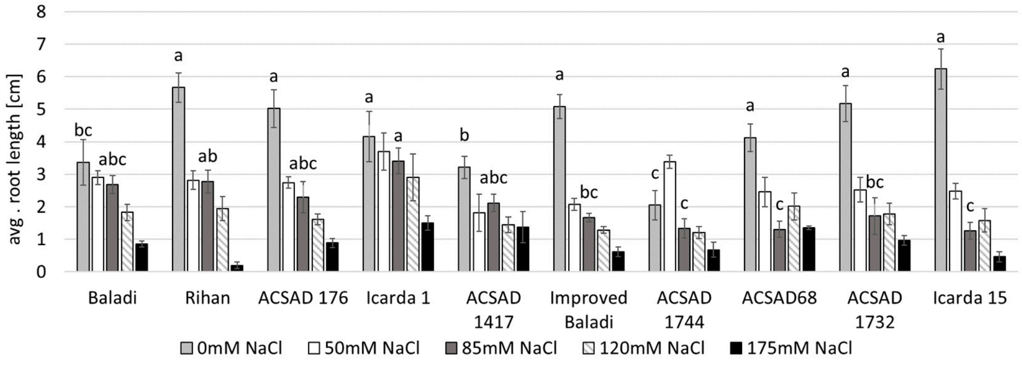

Figure 4. The average root-system length [cm] ± SEM for the ten certified Palestinian barley cultivars grown under salinity stress during early growth stage (10 days from seed germination); comparisons between cultivars within each treatment (same-colored bars) visualized by compact letter display (CDL) visualized by letters a,b,c,d; shared letters between plotted result bars of one treatment mean no significant differences between those results at the level of $p < 0.05$.

The average root lengths of the barley cultivars showed significant reduction under the effect of salinity stress in comparison to the 0 mM controls (see Figure 4). Icarda 1 and ACSAD1417 cultivars revealed the least fluctuation in root-system length and still possessed the longest roots of 1.5 cm and 1.4 cm, respectively, at 175 mM NaCl,. Meanwhile, Rihan, Improved Baladi, and Icarda 15 possessed the lowest root-system length at higher NaCl concentrations.

3.2. Effect of Salinity Stress on Water Content and Biomass

Water content and biomass are parameters that indicate productive plant growth and biochemical allocation in plant tissues. The results revealed that the shoot water content percentage was affected by salt stress (see Figure 5A). The total water content was semi-constant for most cultivars. However, it increased significantly in ACSAD 1744, ACSAD 68, and ACSAD 1732, mainly at 175 mM NaCl. The roots also expressed semi-constant total water content for most cultivars, but it increased significantly in ACSAD 1732, ACSAD 1417, and Icarda 1 (see Figure 5B). In addition, ACSAD 176, ACSAD 1417, ACSAD 1744, ACSAD 68, and Icarda 15 possessed higher water content at 175 mM NaCl than in their controls (see Figure 5B).

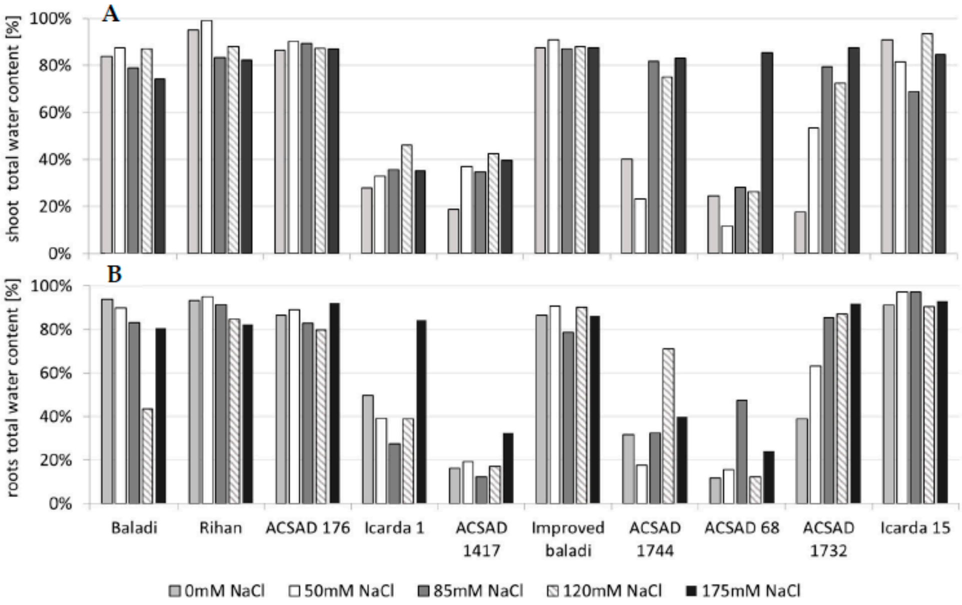

Figure 5. The average total water content [%] of the shoot system (**A**) and of the root system (**B**) for the ten certified Palestinian barley cultivars grown under salinity stress during early growth stage (10 days from seed germination). Plant parts were weighed in bulk for higher precision to report per total biomass, measured according to Cappelleti [34].

The effect of salinity stress on biomass of barley during the early growth stage was evident; it was reflected in the calculations of water content, where dry weight percentage and water content percentage form 100% (see Figure 5). Shoot dry weight/water content was semi-constant for most cultivars except for ACSAD 1744, ACSAD 68, and ACSAD 1732, where it increased with salinity level. Root water content was also semi-constant for most cultivars except for ACSAD 1732, and comparably much lower for Icarda 1, ACSAD 1417, ACSAD 1744, and ACSAD 68.

3.3. Electrical Conductivity for Quarry Substrate

Electrical conductivity is a parameter that relates to the ions in a sample with a direct relation between them. The electrical conductivity was measured for substrate samples collected from quarry land at different depths and distance in Hebron governorate (see Table 2). The results revealed that Seir Jamal Nassar samples possessed the highest EC values, while EC from samples collected from a quarry of Taffouh were lowest. Overall, the Bani Naim region possessed the high EC values, and the other regions were variable in EC values. For those regions, EC decreased toward the core of the stones in the samples that were directly taken from the cutting machines (samples number 2, 3,7, 9, an 16). EC of the soil near quarries was at times higher than in the quarries themselves. There was no significant difference in the EC values at different temperatures. TSS was calculated from EC values and in moderate range. Overall, samplings showed less pronounced salinity/soluble salt concentrations than expected.

Table 2. Electrical conductivity for sixteen soil samples collected based on the quadrate method from quarries at different depths and distances located in the Hebron governorate.

Soil Sample	Region in Hebron Governorate	Measured Temperature (°C)	Measured Conductivity of Soil/Water Mix (5:1) [μS/cm]	EC_t Calculated for Soil [μS/cm]	EC_{25} Calculated for 25 °C [$dS\ m^{-1}$]	TSS–Total Soluble Salts (ppm)
1. Red soil, middle of stones, north-west Hebron	Bani Naim 31°30′57.1″ N 35°10′58.5″ E	23.1	702	667	6.923×10^{-4}	0.443
2. Bani Naim Ashour 1	Bani Naim	24	344	309	3.152×10^{-4}	0.097
3. Bani Naim 1, center of quarry	Bani Naim	23.6	417	382	3.927×10^{-4}	0.150
4. Bani Naim Ashour 2	Bani Naim	22.8	493	458	4.782×10^{-4}	0.219
5. Bani Naim sample 3	Bani Naim	23.8	550	515	5.274×10^{-4}	0.272
6. Side of quarry, 2 cm depth	AlShyoukh	24	348	313	3.193×10^{-4}	0.099
7. Light soil, 15 cm depth	AlShyoukh	25.8	219	184	1.81×10^{-4}	0.0333
8. Red stones, middle of quarry	AlShyoukh	26.4	546	511	4.967×10^{-4}	0.254
9. Light soil under the cutting machine	AlShyoukh	24.8	403	368	3.695×10^{-4}	0.140
10. Abu Bassam, white stone	Seir 30°11′10.2″ N 35°19′05.7″ E	26.2	356	330	3.221×10^{-4}	0.106
11. Seir Jamal Nassar 220 cm depth	Seir	23.4	914	879	9.071×10^{-4}	0.797
12. White, soft road of quarry	Seir	22.6	278	243	2.547×10^{-4}	0.0619
13. Light red, Jamal Nassar, 15 cm above stone	Seir	26.1	543	508	4.968×10^{-4}	0.252
14. Red stone, Jamal Nassar, from surface of quarry	Seir	25.9	839	804	7.895×10^{-4}	0.635
15. Quarry road, Taffouh	Taffouh 31°32′20.7″ N 35°03′09.5″ E	30	461	448.6	4.037×10^{-4}	0.181
16. Quarry, Taffouh	Taffouh	30.8	295	282.6	2.498×10^{-4}	0.071

4. Discussion

Seeds are dormant embryos, adapted to endure harsh, unsuitable environmental conditions that endanger the vegetative structures of plants and will only germinate well under favorable conditions. The germination event starts by imbibition of water, which activates the hydrolytic enzymes that break down the stored nutrients, which are used for the development of new below- and aboveground tissue [19]. These processes are coordinated and controlled by several hormones, brassinosteroids, gibberellins, abscisic acid, and ethylene, and they can be hampered by excessive salinity [35–37]. Salinity stress is one of the major abiotic stresses limiting crop production in arid and semi-arid regions [38] as well as the quarries and their landfills. According to our results, salinity stress caused a delay in the seed germination, especially at 120 and 175 mM NaCl. This coincides with observations in sunflower [39] and Palestinian tomato that showed deep decreasing rates at the 100 mM level [19].

The differences in G_{50} values (germination rate) under salt stress conditions exhibited by the cultivars (Table 1) could be interpreted as a consequence of differences in ion plasma lamella extrusion pumps. Therefore, the ACSAD 1732 cultivar may harbor a larger number of such transporters than the other cultivars. In addition, it may also have more efficient mechanisms for salt compartmentalization into the vacuoles. The reduced number of toxic ions due to the action of these mechanisms of ion translocation in turn exerts less toxic effect on the metabolic enzymes, thereby allowing seed germination processes to occur [17,19,21,40].

In the presented results, the early growth stage showed a decline in both shoot and root systems with increased salinity. Comparable results were reported for barley genotypes in Iran [41]. A high sodium accumulation in the cells causing osmotic imbalance and ion toxicity has been proposed as underlying cause [42,43] due to a shortage in water supply. The plant will compromise under such conditions by suppressing growth hormones [23]. Stomata close as a defense mechanism against salinity stress to prevent the loss of their limited amount of water [44]. This leads to photosynthesis reduction because of the reduction in the CO_2 supply to photosynthetic mesophyll cells [19] and subsequently results in overall hampered performance.

Our findings indicate that the ACSAD 1732 and Icarda 1 cultivars show less reduction in root and shoot sizes compared to other cultivars in 120 and 175 mM NaCl (Tables 1 and 2). This is probably due to the lesser toxic effect imposed by ions in these cultivars due to their extrusion by active transport in the roots. The reduced root volume and/or root-to-shoot ratio may improve salinity tolerance by restricting the flux of toxic ions to the shoot, leading to a delay in the onset of the tolerance [19,45]. In addition, salinity stress negatively affects the root numbers of barley; i.e., the root number decreases with increased salinity stress. This occurs in order to reduce the saltwater uptake by roots, which results in a reduction of the efflux of toxic ions to the tissues in the shoot system, mainly the leaves.

Salinity stress affects the total water content percentage and dry weight percentage of barley. Our results revealed that the root and shoot development of all tested cultivars decreased due to salinity stress in comparison to corresponding controls. Such decrease in barley cultivar physiological features, e.g., gas-exchange-related traits as well as impacts on root and shoot biomass, is well-documented in barley genotypes in Iran and elsewhere [41]. Barley cultivars such as ACSAD 1732 and Icarda 1, with improved resistance during seed germination, also possess a higher percentage of total water content in their shoot and root system when they grow at higher levels of salinity than the respective controls. Other cultivars such as ACSAD 1417, ACSAD 1744, and ACSAD 68, try to resist the high salinity pressure through accumulation of water in their shoot and root system during the early growth stage. In general, the accumulation of solutes in the cytoplasm of the plant cell will increase its osmotic pressure. Thus, a plant increases its affinity to take up and accumulate water in the cell central vacuole, compelled by the demand for biological activity. This also leads to succulence in plant tissues, which is an important adaptive strategy to accumulate excessive salt and conserve water in saline-growing plants (i.e., halophytes). Succulence occurs also in glycophytes in order to overcome such uncomfortable osmotic stress [19,27,46].

Based on their response to high levels of salinity, plants can be grouped into two broad categories. First, halophytes are plants that grow and complete their life cycle in environments of high salt concentration [47–49]. Second, glycophytes ('sweet plants') are plants that are sensitive to salt and cannot tolerate salt to the same level as halophytes [50,51]. Crop plants vary in their sensitivity to salt levels in soil. For example, corn, bean, lettuce, onion, and citrus plants are considered highly sensitive to salt. In contrast, sugar beet and date palm trees are highly tolerant. Crop plants like cotton, barley, and some tomato cultivars are considered moderately tolerant plants. However, the present study emphasizes that some Palestinian barley cultivars might be considered halophytes, since they can start growth under salt concentration of 175 mM NaCl. These cultivars include ACSAD 1732, ACSAD 1744, ACSAD 1417, and Icarda 1. Moreover, the biochemical, physiological, morphological features of the adaptation mechanisms of other crop plants, as well as barley cultivars, against salinity stress are genotype-specific [1–6,9]. The implications for the further life cycle need to be assessed in detail for the most promising barley cultivars identified here to ensure productivity until harvest.

Soil salt content is critical for plants though their life span. The characteristics of saline soil areas include micro-topography, complicated soil types, and significant differences in local soil conditions and depths based on the plant species root growth [10]. In the present study, soil samples were collected from quarries at different depths and different distances (see Table 2), which corresponded to a basic knowledge of salt distribution [10]. Electrical conductivity in soil is a function of the concentration of charged ions in the soil solution, which are assessed by conducted current. The soil EC values for most samples in this study were close to each other, because all the samples were taken from quarry lands with relatively similar conditions. However, the EC value for each sample was below the normal range of 1100–5700 µScm $^{-1}$ (11–57 $\times$ 10^{-4} dS m^{-1}) of conductivity [10]. This result might contraindicate the hypothesis that quarry land always suffers from salinity stress.

Many factors besides salt content can also affect the EC. Substrates with continuous pore spaces have a higher conductivity due to the continuous water column in the water-filled pores. Therefore, soils with high clay content usually conduct better than sandy soils. An increased water content with more dissolved electrolytes and high cation exchange capacity also increases EC; with increasing depth and decreasing temperature, EC decreases too [52]. The optimal EC levels in the soil for plant growth are 110–570 milliSiemens per meter (mS m^{-1}) [53]. EC is an important indicator for nutrient availability in soil, while, e.g., sandy soils express low EC due to low organic matter and nutrient content, as opposed to higher quality agricultural substrates with high clay content [54]. In this context, quarries substrates are not highly affected by salts but more by seasonal and climatic conditions. This is obvious, since the samples collected directly from the cutting machine had low amounts of solutes and EC. However, the samples collected from the road and/or periphery of the quarries had higher EC and TSS, since their dust and soil mixed with the topsoil surface via vehicles, animals, and winds. Moreover, quarry substrates tend to be sandy rather than high in clay, and dry rather than moist. Therefore, quarry soils showed lower EC values than expected. Further characterization of the local quarry residues in higher spatial resolution is necessary on the large expansions of former quarry lands to decide on the best approach in each case. One of the most common abiotic stresses aside from salinity is drought, affecting large marginal areas of low rainfall that depend on rain-fed water in Palestine. Locally adapted cultivars (landraces), as screened here, would be a valuable solution, since such landraces possess fitting genetic material for required resilience not only against salinity, but other local challenges. Further clarification of the underlying mechanistics will facilitate usage of more marginal areas in the future [1,28].

5. Conclusions

We highly recommend ACSAD1732 cultivation in areas of low precipitation and high soil salt concentration that is at or below 175 mM NaCl. We also recommend the cultivation of the identified resilient barley cultivars in quarries, their landfill, and nearby areas as a means of rehabilitation. Further research is necessary to investigate the homogeneity, salinity, and alkalinity of quarry land substrates and the possible consequences on crop growth and productivity. The capacity and key adaptation features of such resilient cultivars must also be assessed to successfully germinate and grow them in such poor substrates, since the demand for the agricultural use of such areas will increase.

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