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Salicylic Acid Seed Priming: A Key Frontier in Conferring Salt Stress Tolerance in Barley Seed Germination and Seedling Growth

Rim Ben Youssef [1,2,†], Nahida Jelali [1,†], Jose Ramón Acosta Motos [3], Chedly Abdelly [1] and Alfonso Albacete [4,*]

[1] Laboratory of Extremophile Plants, Biotechnology Center of Borj-Cédria, P.O. Box 901, Hammam-Lif 2050, Tunisia; rim.benyoussef@cbbc.rnrt.tn (R.B.Y.); nahida.jellali@cbbc.rnrt.tn (N.J.); chedly.abdelly@cbbc.rnrt.tn (C.A.)
[2] Faculty of Sciences of Tunis, University of Tunis El Manar, Tunis 1060, Tunisia
[3] Plant Biotechnology for Food and Agriculture Group (BioVegA2), Universidad Católica San Antonio de Murcia, Avenida de los Jerónimos 135, Guadalupe, 30107 Murcia, Spain; jracosta@ucam.edu
[4] Institute for Agroenvironmental Research and Development of Murcia (IMIDA), c/Mayor s/n, La Alberca, 30150 Murcia, Spain
* Correspondence: alfonsoa.albacete@carm.es
† These authors contributed equally to this work.

Abstract: The goal of the current study was to investigate the effects of seed priming with salicylic acid (SA) on seed germination parameters, seedling growth traits, nutritional element mobilization, and oxidative stress status in two barley species that were subjected to various salt treatments. The findings demonstrated that salinity reduced a number of germination parameters in unprimed seeds and impacted seedling growth by impeding both species' necessary nutrient mobilization. Under this abiotic stress, a noticeable rise in malondialdehyde and electrolyte leakage was also noted. Interestingly, pretreating seeds with SA improved seed germination and seedling growth performance under either 100 mM or 200 mM NaCl treatments. In fact, SA improved the length and dry weight of stressed seedlings of both barley species in addition to increasing the germination rate and mean daily germination. Additionally, SA increased the content of calcium, iron, magnesium, and potassium while lowering the concentrations of sodium and malondialdehyde and electrolyte leakage. It is significant to note that, in comparison to *Hordeum maritimum*, the positive effects of this hormone were more noticeable in stressed *Hordeum vulgare* species.

Keywords: *Hordeum maritimum*; *Hordeum vulgare*; phytohormone; salinity; pretreatment; improvement; resistance

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1. Introduction

Global food security, threatened by climate change and the increasing population, is one of the most important challenges in the 21st century and must be addressed while coping with an already stressed environment. Salinity is one of many environmental constraints threatening the germination process, which is the crucial step of crop establishment. During the plant life cycle, changes in morphology and physiology activate the embryo during the seed germination and establishment stages. In fact, a variety of physiological and biochemical processes, including seed germination, photosynthesis, respiration, mineral nutrition, and antioxidative enzyme activity, are altered by this abiotic stress [1]. There are two stages to these dangerous effects. The first phase is dominated by the osmotic impact, which causes water stress because the concentration of salt in the soil is higher. It

appears that during this time, variations in water relations are the primary cause of the decline in seedling growth [2–4]. Growth is controlled during the second phase of stress by toxic effects and nutritional imbalances that cause sodium and chloride to be substituted for other crucially important beneficial ions such as potassium and calcium.

In fact, water uptake is reduced during imbibition with rising external osmotic potential. In addition, seed germination could be affected by the toxic impacts of sodium and chloride ions on embryo viability [5]. These impacts lead to a reduction or delay in germination and even to the death of seeds before germination. In this regard, it was confirmed that increasing salt concentration not only prevents seed germination but also extends germination time by delaying the dormancy period [6]. Overcoming this environmental problem and optimizing the use of salt-contaminated water and soil resources has been a scientific goal but has had little success, since only a few significant genetic characteristics related to salt efficiency have been determined [7]. The use of current technology to recover these soils is one option; it presents challenges in its application because of certain limitations, including a low supply of irrigation water and high reclamation and drainage costs. Biological exploitation of these soils via the cultivation of salt-tolerant plant species is the other option. Indeed, halophytes, such as Salicornia and Suaeda species, demonstrate remarkable adaptability to salinity and drought, yet data on their responses under extreme conditions remain limited. Expanding this discussion can highlight the unique survival strategies of halophytes and their potential in saline agriculture. Recent research focuses on seed germination patterns in halophytes, linking their success to seed dormancy mechanisms and hormonal balance under stress conditions. Studies underline the importance of osmolytes (e.g., proline and glycine betaine) and antioxidant enzymes in mitigating oxidative damage during germination under high salinity [8].

Improving salt tolerance in barley genotypes faces challenges, such as low selection efficiency, the complexity of various biological parameters, and inadequate evaluation methods for screening genotypes in breeding programs, despite a more manageable strategy being available [9,10]. Barley is resilient to harsh environments, making it essential to select genotypes that can thrive in saline soils and produce substantial yields [11]. Research shows that salt stress affects barley's antioxidant enzyme activity, with salt-tolerant genotypes exhibiting a higher antioxidant capacity than salt-sensitive ones. Enhancing antioxidant levels can improve barley's salt tolerance, as indicated by a high germination rate under hypersaline conditions and the ability to germinate again after salinity is removed [12]. High salinity hinders seed germination, while low salt concentrations promote it. For example, halophytes show increased germination at low salt levels [13–16]. Conversely, the annual halophyte Cakile maritima faced significant delays in germination and displayed reduced seedling lengths at 200 mmol/L NaCl [17]. With careful observation and extensive experimentation over many years and continents, it was discovered that there are a number of ways to improve the vigor of seedlings as they emerge from the seed, which results in a consistent crop stand. Ultimately, using straightforward techniques leads to a significant increase in yield. Out of a few of these methods, seed priming is a special technique that allows one to either adopt hydro-priming or osmo-priming, among other methods, to stimulate the germination of seedlings. There is plenty of evidence to support the use of particular chemicals or organics and soaking the seeds in various treatments. Hence, this adapted tool was involved to optimize the use of salt-contaminated water and enhance salt tolerance crops without deteriorating soil quality. This technique helps to enhance seed germination under both optimal and stressful conditions [18]. Nevertheless, its advantageous effects may be prominent under unfavorable circumstances [19]. Furthermore, this technique allows salinity problems to be overcome in agricultural lands, as well as glycophyte species to be adapted to this abiotic stress [20]. Many efficient compounds

are used to broaden the application of this technique, such as salicylic acid (SA). SA is a plant hormone more commonly known for its role in human medicine than in the field of plant physiology [21]. However, SA has been recently considered an imperative phenolic signaling molecule regulating the growth of plants growing under both biotic and abiotic stresses [22]. Indeed, this potential endogenous hormone plays a key role in seed germination and plant growth and it is well-known that SA is a key signaling molecule involved in systemic acquired resistance (SAR) [23–25]. Recent works reported a key role for SA in response to salt stress [26] and iron deficiency [27] by inducing and modulating different physiological and metabolic processes including seed germination [28]. Additionally, this phenolic phytohormone plays an imperative role in stimulating catalase, peroxidase, and glutathione reductase activities against different stresses in response to reactive oxygen species (ROS) [29–35]. In contrast, exogenous application of SA does not always have a positive effect on the improvement of oxidative stress under restrictive conditions. Its stimulating effect depends on the applied stress and the species studied [36].

In order to cope with environmental constraints, recent advancements emphasize environmentally friendly materials and techniques to boost seed performance. Seed coating and pelleting are advanced methods that have been used to improve seed performance, facilitate sowing, and enhance crop establishment and seed quality during the past ten years. Additionally, modern seed coating technology involves applying active ingredients such as nutrients, biostimulants, or plant protectants to seeds, improving their resistance to environmental stress. Pelleting increases seed size and weight, making them easier to handle and ensuring even sowing. When combined, seed coating technology has long been utilized as a more cost-effective choice in both developed and developing nations. In this context, the benefits of seed coating and pelleting, such as improved nutrient absorption and stress tolerance, were reported. The use of biodegradable polymers and bio-based materials for sustainable agriculture has been discussed [37]. Furthermore, another study focused on optimizing the pelleting process for small seeds such as red clover, emphasizing critical parameters such as coating thickness and material uniformity for better germination rates [38].

The use of exogenous plant growth regulators to increase plants' tolerance to abiotic stressors has gained a lot of attention in recent years. Furthermore, there is currently a dearth of research examining the effects of pretreatment with SA on wild plants, as the majority of studies to date have concentrated on the impact of pretreatment with SA on cultivated plants. In light of this, the current study was carried out to examine the effect of SA seed priming on wild (Hordeum maritimum) and cultivated (Hordeum vulgare) barley seeds.

2. Materials and Methods

2.1. Plant Material and Growth Conditions

Two barley species, *Hordeum maritimum* and *Hordeum vulgare*, were used throughout the experiment. *H. maritimum* seeds were collected from Sebkha of Sidi Khlif-Kairouan (arid stage); however, *H. vulgare* seeds were provided by the National Institute of Agronomy of Tunis (INAT) (L. Manel). The germination experiment was conducted in the Extremophile Plants Laboratory (LPE) of the Biotechnology Centre of BorjCédria (CBBC), Tunisia. Barley seeds were disinfected for 8 min with sodium hypochlorite (2%, *v*/*v*) and then rinsed three times with distilled water. Then, seeds were soaked in distilled water (unprimed seeds) or in 1250 µM of SA solution for 20 h according to a previous preliminary test [7]. Finally, they were placed in Petri dishes moistened with a double layer of filtered paper (twenty-five seeds in each one). The Petri dishes were irrigated with three different treatments, one treatment consisting of distilled water without salt (0) and two different saline

concentrations consisting of 100 and 200 mM NaCl. Then, they were placed in a germinator at 20 °C, in the dark, for seven days. The experiment was a factorial design with two factors, which were salinity at 3 levels (0, 100, and 200 mM) and seed priming with 2 levels (control and SA priming). From the beginning of the experiment, the number of seeds germinated was recorded daily up to the last day of the germination period.

2.2. Final Germination Percentage

The final germination percentage (FG%) represents the physiological seed germination limit measured on the seventh day and it is expressed according to the following equation [39]:

$$\text{FG\%} = \frac{\text{Germinated seeds}}{\text{Total seeds}} \times 100$$

2.3. Mean Daily Germination Determination

The mean daily germination was calculated according to the following equation [40]:

$$\text{MDG} = \frac{\text{FG\%}}{\text{X}^{\text{th}}\text{ test day}}$$

where the X^{th} test day is the day when the number of seeds germinated reached its maximum for each repetition.

2.4. Seedling Growth

The seedlings were harvested and thoroughly rinsed in five baths of distilled water following seven days of germination under either ideal or stressful conditions. To ascertain the growth parameters, the samples were separated into coleoptiles and radicles after the seed coat was removed, and each sample's length was measured separately. After samples were dried for 48 h at 80 °C, the dry weight (DW) was measured using a precision balance (Mettler type AE100 at 1/100 of mg, Mettler Toledo, Greifensee, Switzerland).

2.5. Nutrient Extraction and Analysis

Twenty mg of vegetal dried material were ground and digested with 10 mL of sulfuric acid (H_2SO_4, 1N) for 1 h at 80 °C and then left overnight at room temperature. This allowed the total extraction of the target elements of samples. The different cations (Fe^{2+}, Mg^{2+}, and $Ca^{2+)}$ were analyzed using an atomic absorption spectrophotometer (Perkin Elmer, Analyst 300, Rodgau, Germany). However, K^+ and Na^+ ions were determined using a flame spectrophotometer (BWB Technologies XP, France). Results were expressed in $\mu g.g^{-1}$ MS for Fe^{2+} and in $mg.g^{-1}$ MS for Mg^{2+}, Ca^{2+}, K^+, and Na^+ [41].

2.6. Measurement of Membrane Stability Index

Using a digital conductivity meter (type Metrohom, BANTE instruments 950, China), the membrane stability index (MSI) was measured in order to estimate the integrity of the membrane. A tube containing 0.2 g of fresh material and 10 mL of distilled water was first heated to 32 °C for 30 min before the electrical conductivity was measured (EC1). After the samples were placed at 100 °C for two hours, the conductivity (EC2) was also measured. The MSI was calculated using the following formula [42]

$$\text{MSI} = \frac{\text{EC1}}{\text{EC2}} \times 100$$

EC1: initial electrical conductivity measured.
EC2: final electrical conductivity measured.

2.7. Measurement of Malondialdehyde

Malondialdehyde (MDA), which can react with β-thiobarbituric acid, was measured to estimate lipid peroxidation [43]. MDA-(TBA), a colored derivative that can be measured spectrophotometrically at 532 nm, is produced when MDA and thiobarbituric acid undergo a condensation reaction. About 1 g of plant material was ground in 10 mL of trichloroacetic acid (0.1%; p/v) to carry out the extraction. For five minutes, the resulting homogenate was centrifuged at 10,000 g. Four milliliters of thiobarbituric acid (0.5%; p/v) made in trichloroacetic acid (20%; p/v) were mixed with 1 mL of supernatant. After 30 min of incubation at 95 °C, the homogenate was cooled in ice to halt the reaction. After that, the samples were centrifuged for 10 min at 1000 g. The absorbance of the supernatant obtained following centrifugation was measured at 532 nm. The non-specific absorbance at 600 nm was then subtracted to adjust the optical density. The following formula was used to determine the concentration of malondialdehyde (MDA) using a molar extinction coefficient of (ε at 532 = 155 $mM^{-1}cm^{-1}$).

$$\mathrm{MDA}\left(\frac{\mathrm{nm}}{\mathrm{gFW}}\right) = \left(\frac{(\mathrm{OD} + \mathrm{O532} - \mathrm{OD600}) \times \mathrm{VS}}{0.155}\right) \times \mathrm{gFW}$$

VS: volume of the supernatant; FW: Fresh weight; OD_{600}: absorbance at 600 nm; OD_{532}: absorbance at 532 nm

2.8. Statistical Analysis

One-way ANOVA was used for the comparison of means. Significant differences were further analyzed using Duncan's test to identify differences between treatments for both barley species. All these tests used an alpha of 0.05 and were carried out with XLSTAT software version 2014 (Addinsoft, Paris, France). For all the growth parameters analyzed, ten replicates (n = 10) were performed. For MDA and ion analyses, three replicates (n = 3) for each treatment and species were performed. A principal component analysis (PCA) was conducted using XLSTAT software, considering variables centered on their means and normalized with a standard deviation of 1.

3. Results

3.1. Final Germination Rate

The results presented in Figure 1 show that salinity caused a significant decrease in the final germination rate in both barley species. This effect was dependent on the applied saline concentration. It is crucial to remember that *H. vulgare* seeds germinated on the medium supplemented with 200 mM NaCl showed the highest reduction percentage. When compared to seeds that germinated under the control medium, this decrease reached 51%. In contrast to seeds that were not pretreated, stressed seeds that were pretreated with SA had a higher germination rate. The species and concentration of salt were the primary determinants of this improvement. It should be noted that *H. vulgare* seeds exhibited a stronger positive impact from SA. In fact, when comparing seedlings from SA-primed seeds exposed to 200 mM NaCl to seedlings from unprimed seeds, the improvement rate was approximately 70% (Figure 1).

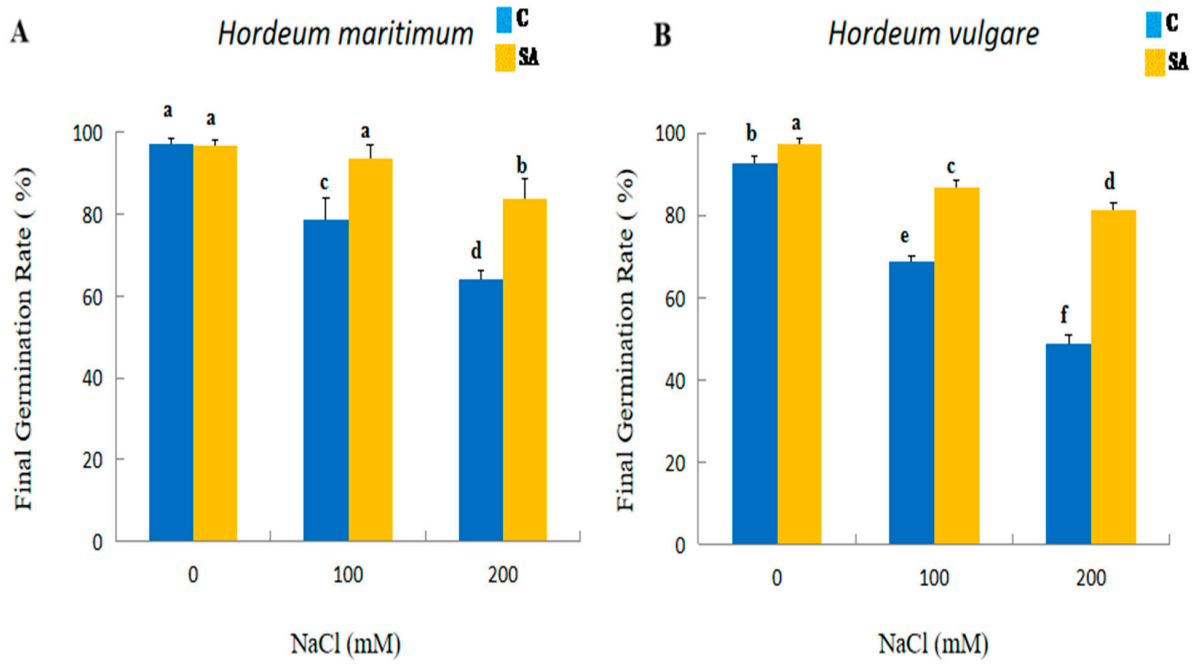
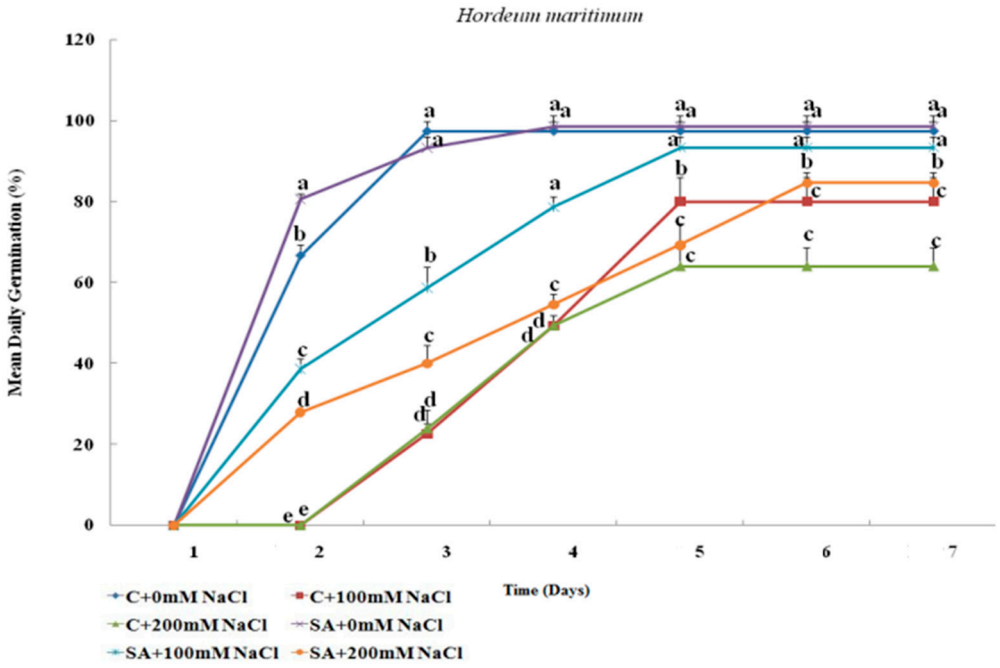


Figure 1. Effect of SA seed priming and no pretreatment (Control: C) on the final germination rate (%) of two barley species, *Hordeum maritimum* (**A**) and *Hordeum vulgare* (**B**), grown under salinity stress. Values are means of five replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

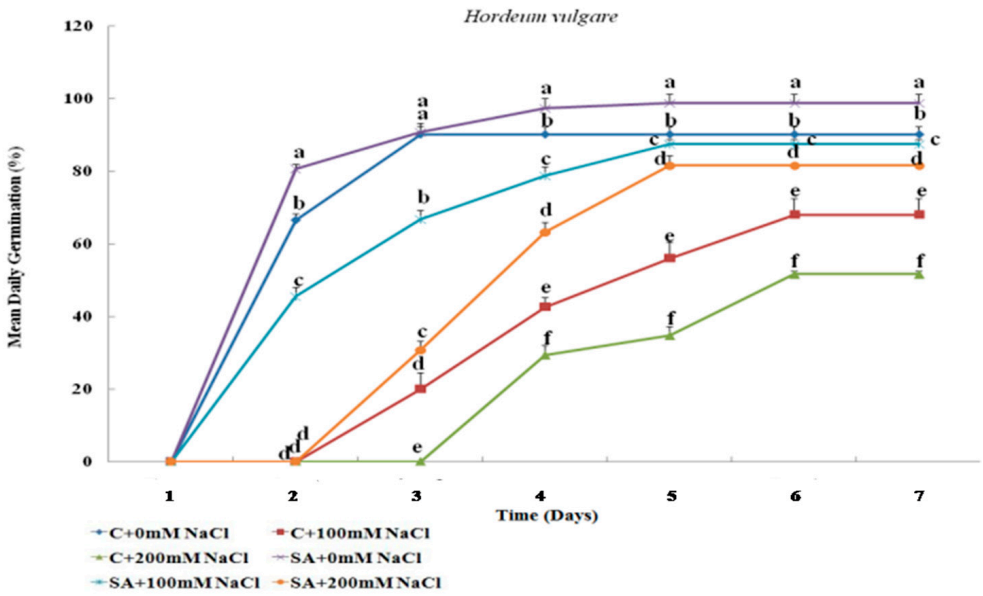
3.2. Mean Daily Germination

According to the results, salinity significantly reduced the daily average germination of both barley species when compared to ideal conditions (Figure 2). The species and the amount of saline that was applied both affected this decline. Pretreating seeds with SA, however, raised this parameter's values in both species. Specifically, this effect was more pronounced in *H. vulgare*.



(**A**)

Figure 2. *Cont.*



(**B**)

Figure 2. Effect of SA seed priming and no pretreatment (Control: C) on the Mean Daily Germination of two barley species, *Hordeum maritimum* (**A**) and *Hordeum vulgare* (**B**), grown under salinity stress. Values are means of three replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

3.3. Growth Parameters

3.3.1. Tissue Length

Figure 3 illustrates how salt stress reduced the length of radicles and coleoptiles from non-pretreated seeds in comparison to control seeds when the pretreatment was not applied. The species and the concentration of applied salt both affected this decline. Indeed, when compared to the control medium, *H. vulgare* seedlings germinated on the medium supplemented with 200 mM NaCl showed the largest reduction percentage in radicle length (65%) and coleoptile length (67%), as shown in Figure 3. In contrast to seedlings from non-pretreated seeds, SA enhanced this parameter in the two species' seedlings under limiting circumstances. The findings demonstrated that, in comparison to their non-pretreated counterparts, *H. vulgare* seedlings exposed to 200 mM NaCl exhibited the greatest increase, with radicles and coleoptiles increasing by 106% and 133%, respectively (Figure 3).

3.3.2. Tissue Dry Biomass

Salinity decreased the dry biomass of the roots and coleoptiles in seedlings of both species when the pretreatment was not applied. In seedlings exposed to 200 mM NaCl, this decrease was more noticeable (Figure 4). In fact, compared to the control salinity treatment, *H. vulgare* and *H. maritimum* showed reductions in radicle biomass of 60% and 37%, respectively, and reductions in coleoptile biomass of 62% and 33%. In line with the length parameter results, seedlings produced from SA-pretreated seeds produced more biomass. The negative effects of salt on the two species' seedling growth were lessened by this phytohormone. Significant evidence of its positive effects was found in *H. vulgare*. In fact, compared to seedlings from non-pretreated seeds, the highest rate of increase in dry biomass production under stress conditions was observed at the radicle level in seedlings exposed to 200 mM NaCl (107%), and at the coleoptile level in those exposed to either 100 or 200 mM NaCl (210%) (Figure 4).

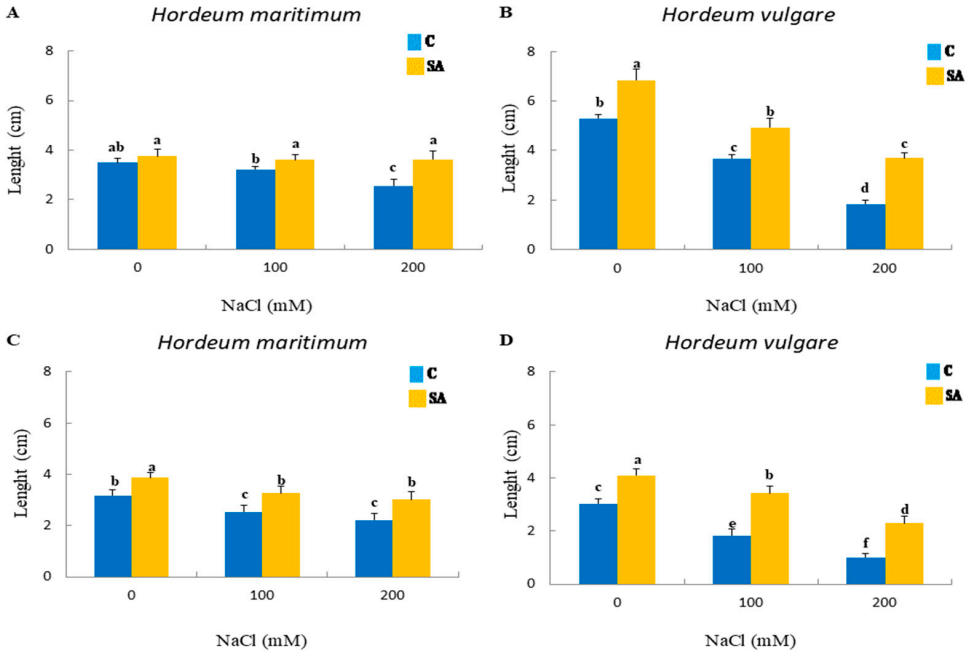


Figure 3. Effect of SA seed priming and no pretreatment (Control: C) on the length of radicles (**A**,**B**) and coleoptiles (**C**,**D**) of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five replicates from three independent experiments ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

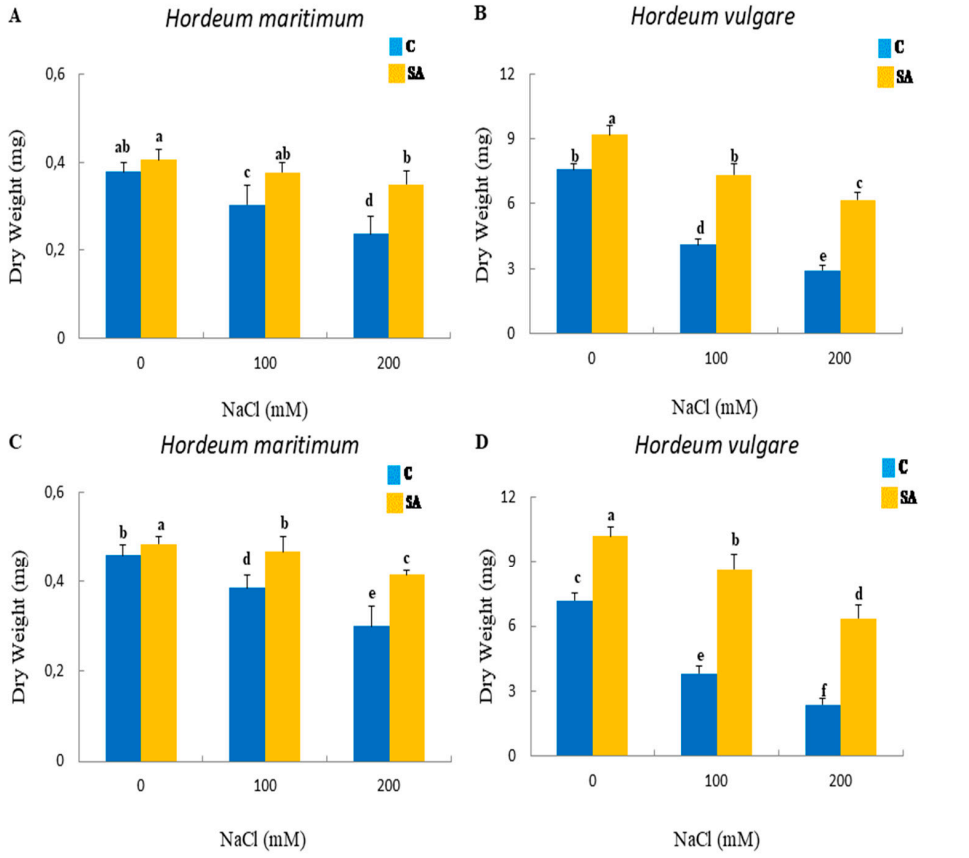


Figure 4. Effect of SA seed priming and no pretreatment (Control: C) on dry weight in radicles (**A**,**B**) and coleoptiles (**C**,**D**) of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five independent replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

3.4. Mineral Nutrition

3.4.1. Iron

The iron content of both species' seedlings from untreated seeds was considerably reduced by salinity. In fact, seedlings exposed to 200 mM NaCl showed a more notable rate of reduction in this nutrient (Table 1). In comparison to the controls, the reductions were approximately 56% and 35% in radicles and 72% and 39% in coleoptiles in *H. vulgare* and *H. maritimum*, respectively. Notably, seedlings of *H. maritimum* and *H. vulgare* from SA-pretreated seeds germinated under stress conditions had higher iron content than seedlings from non-pretreated seeds (Table 1).

Table 1. Effect of SA seed priming and no pretreatment (Control: C) on total Fe, Ca, and Mg content in radicles and coleoptiles of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five independent replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

		Hordeum maritimum			*Hordeum vulgare*		
Treatments		**Fe (µg/g DW)**	**Ca (mg/g DW)**	**Mg (mg/g DW)**	**Fe (µg/g DW)**	**Ca (mg/g DW)**	**Mg (mg/g DW)**
Control	Coleoptile	4994 ± 29 ^{a}	18.25 ± 1.2 ^{a}	22.73 ± 1.5 ^{ab}	1178 ± 34 ^{a}	0.887 ± 0.049 ^{a}	0.228 ± 0.026 ^{a}
	Radicle	2920 ± 45 ^{b}	13.32 ± 1.26 ^{c}	25.15 ± 1.33 ^{ab}	992 ± 24 ^{b}	0.791 ± 0.023 ^{a}	0.217 ± 0.024 ^{ab}
C+100 mM NaCl	Coleoptile	2639 ± 141 ^{d}	11.68 ± 0.59 ^{c}	16.19 ± 1.11 ^{c}	851 ± 26 ^{d}	0.579 ± 0.057 ^{b}	0.187 ± 0.017 ^{b}
	Radicle	1919 ± 161 ^{d}	8.84 ± 1.14 ^{d}	17.58 ± 0.74 ^{c}	921 ± 43 ^{c}	0.314 ± 0.03 ^{c}	0.166 ± 0.009 ^{c}
C+200 mM NaCl	Coleoptile	1414 ± 213 ^{e}	7.60 ± 0.59 ^{d}	10.65 ± 1.11 ^{d}	725 ± 19 ^{e}	0.473 ± 0.057 ^{e}	0.115 ± 0.017 ^{c}
	Radicle	1276 ± 90 ^{e}	5.66 ± 1.14 ^{e}	11.62 ± 0.74 ^{d}	646 ± 33.92 ^{d}	0.481 ± 0.03 ^{b}	0.113 ± 0.009 ^{d}
SA+100 mM NaCl	Coleoptile	3842 ± 251 ^{b}	17.94 ± 0.59 ^{a}	24.21 ± 1.83 ^{a}	1078 ± 50 ^{b}	0.750 ± 0.066 ^{a}	0.212 ± 0.022 ^{a}
	Radicle	3171 ± 102 ^{a}	15.39 ± 0.65 ^{b}	26.81 ± 1.63 ^{a}	1080 ± 27 ^{b}	0.401 ± 0.024 b	0.230 ± 0.011 ^{a}
SA+200 mM NaCl	Coleoptile	3021 ± 253 ^{c}	15.63 ± 0.39 ^{b}	20.83 ± 1.37 ^{b}	1013 ± 39 ^{c}	0.598 ± 0.059 ^{b}	0.228 ± 0.024 ^{a}
	Radicle	2563 ± 121 ^{c}	14.53 ± 1.73 ^{bc}	21.82 ± 3.79 ^{b}	925 ± 31 ^{c}	0.222 ± 0.013 ^{d}	0.197 ± 0.018 ^{b}

3.4.2. Calcium

The calcium content of the two species' seedlings dropped in response to salinity. The seedlings from seeds that germinated on the medium supplemented with 200 mM NaCl showed the biggest decline. Indeed, in *H. vulgare* and *H. maritimum*, the percentage decrease in calcium content was 52% and 39% in radicles and 67% and 47% in coleoptiles, respectively, when compared to the control (Table 1). However, pretreatment with SA increased this nutrient's content, especially in seedlings derived from *H. vulgare* seeds. The applied salt concentration determined this increase. Comparing seedlings derived from non-pretreated seeds to those germinated under 200 mM NaCl, it was found that the radicle and coleoptile sizes of the former were approximately 157% and 102% larger, respectively (Table 1).

3.4.3. Magnesium

Compared to non-salinized conditions, salinity reduced the magnesium content in the two barley species' seedlings (Table 1). In comparison to ideal conditions, this decline was observed in *H. vulgare* and *H. maritimum* seedlings exposed to 200 mM NaCl (by 54% and 48% in radicles and by 53% and 49% in coleoptiles, respectively) (Table 1). Nonetheless, SA seed pretreatment markedly raised the magnesium content of the coleoptiles and radicles of seedlings of both species under stressful conditions (Table 1). In comparison to seedlings originating from non-pretreated seeds, this induction was notably observed in *H. vulgare* seedlings germinated on the medium supplemented with 200 mM NaCl, which was approximately 88% and 96% greater in radicles and coleoptiles, respectively (Table 1).

3.4.4. Sodium

Salinity significantly raised the sodium content in the radicles and coleoptiles of seedlings grown from untreated seeds of both barley species, as Table 2 demonstrates.

The seedlings produced from seeds that germinated on the medium supplemented with 200 mM NaCl showed the most notable accumulation. However, it should be noted that, in comparison to seedlings derived from non-pretreated seeds, those derived from seeds pretreated with SA had significantly lower sodium contents. The species and the salt treatment used determined this reduction (Table 2).

Table 2. Effect of SA seed priming and no pretreatment (Control: C) on Na and K content and Na/K and Ca/Na ratios in radicles and coleoptiles of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five independent replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

		Hordeum maritimum			*Hordeum vulgare*				
Treatments		**Fe (µg/g DW)**	**Ca (mg/g DW)**	**Mg (mg/g DW)**	**Fe (µg/g DW)**	**Ca (mg/g DW)**	**Mg (mg/g DW)**	**Fe (µg/g DW)**	**Ca (mg/g DW)**
Control	Coleoptile	0.066 ± 0.005^{e}	0.900 ± 0.036^{a}	0.073 ± 0.007^{e}	276 ± 17^{a}	0.114 ± 0.015^{e}	1.296 ± 0.056^{a}	0.088 ± 0.013^{d}	160 ± 14^{a}
	Radicle	0.085 ± 0.011^{e}	0.778 ± 0.048^{a}	0.054 ± 0.044^{e}	156 ± 9^{a}	0.134 ± 0.011^{e}	0.963 ± 0.033^{a}	0.139 ± 0.010^{d}	99 ± 6^{a}
C+100 mM NaCl	Coleoptile	0.879 ± 0.049^{b}	0.655 ± 0.024^{d}	1.346 ± 0.116^{c}	13 ± 2^{d}	1.397 ± 0.100^{b}	1.191 ± 0.030^{b}	1.173 ± 0.081^{b}	8 ± 1.6^{d}
	Radicle	0.539 ± 0.023^{c}	0.365 ± 0.021^{c}	1.464 ± 0.157^{c}	16 ± 2^{d}	0.942 ± 0.058^{b}	0.897 ± 0.034^{b}	1.050 ± 0.070^{b}	9 ± 1.2^{d}
C+200 mM NaCl	Coleoptile	1.631 ± 0.042^{a}	0.459 ± 0.13^{e}	3.550 ± 0.058^{a}	4 ± 0.7^{e}	1.963 ± 0.059^{a}	0.871 ± 0.067^{d}	2.265 ± 0.169^{a}	3 ± 0.6^{e}
	Radicle	1.01 ± 0.023^{a}	0.151 ± 0.014^{e}	6.739 ± 0.587^{a}	5 ± 0.9^{e}	1.134 ± 0.058^{a}	0.720 ± 0.040^{d}	1.579 ± 0.091^{a}	4 ± 0.5^{e}
SA+100 mM NaCl	Coleoptile	0.506 ± 0.054^{d}	0.812 ± 0.035^{b}	0.623 ± 0.069^{d}	35 ± 3^{b}	0.792 ± 0.073^{d}	1.262 ± 0.062^{ab}	0.631 ± 0.082^{c}	22 ± 1.5^{b}
	Radicle	0.293 ± 0.015^{d}	0.485 ± 0.018^{b}	0.606 ± 0.044^{d}	52 ± 8^{b}	0.762 ± 0.040^{d}	0.914 ± 0.039^{ab}	0.836 ± 0.070^{c}	20 ± 1.8^{b}
SA+200 mM NaCl	Coleoptile	0.785 ± 0.053^{c}	0.705 ± 0.035^{c}	1.334 ± 0.099^{b}	19 ± 3^{c}	1.181 ± 0.055^{c}	1.023 ± 0.062^{c}	1.158 ± 0.090^{b}	13 ± 0.8^{c}
	Radicle	0.619 ± 0.027^{b}	0.276 ± 0.018^{d}	1.960 ± 0.195^{b}	23 ± 2^{c}	0.846 ± 0.034^{c}	0.780 ± 0.039^{c}	1.088 ± 0.088^{b}	17 ± 1.3^{c}

3.4.5. Potassium

The potassium content of both species' seedlings decreased in response to salinity. With increasing saline concentrations, this decrease became more noticeable (Table 2), increasing by 81% and 25% in *H. vulgare* and *H. maritimum* radicles and 49% and 33% in coleoptiles when exposed to 200 mM NaCl, respectively. On the other hand, pretreating seeds with SA considerably raised the potassium content in both species exposed to salinity, particularly in *H. vulgare* seedlings exposed to 200 mM NaCl. When compared to seedlings grown from untreated seeds, the potassium content of these seedlings was 83% higher in the radicles and 54% higher in the coleoptiles (Table 2).

3.4.6. Sodium/Potassium Ratio

In seedlings grown from untreated seeds, salt stress markedly raised the Na/K ratio. When H. vulgare seedlings were exposed to 200 mM NaCl, this increase was more pronounced. SA treatment led to a decrease in the Na/K ratio in the seedlings of both species because of its critical function in lowering sodium and increasing potassium contents. In comparison to seedlings originating from non-pretreated seeds, this effect was most noticeable in *H. vulgare* seedlings exposed to 200 mM NaCl (Table 2), which decreased the Na/K ratio by 71% in radicles and 62% in coleoptiles, respectively.

3.4.7. Calcium/Sodium Ratio

The Ca/Na ratio in seedlings grown from untreated seeds was considerably reduced by salt stress. Compared to seedlings germinated under ideal conditions, this decrease was more noticeable in *H. vulgare* seedlings exposed to 200 mM NaCl, with radicles and coleoptiles being 96% and 98% smaller, respectively (Table 2). In contrast to seedlings originating from non-pretreated seeds, SA increased the Ca/Na ratio in seedlings of both barley species under restrictive conditions, particularly in *H. vulgare* seedlings exposed to 200 mM NaCl. The values in radicles and coleoptiles, respectively, increased by 319% to 328% (Table 2).

3.5. Membrane Stability Index

In both barley species, salinity dramatically increased electrolyte leakage, as seen in Figure 5. This increase was influenced by the concentration of salt that was applied; *H. vulgare* exposed to 200 mM NaCl showed higher leakage in both radicles (110%) and coleoptiles (73%) in comparison to seedlings that germinated under ideal conditions. Remarkably, SA pretreatment considerably decreased electrolyte leakage in both barley species' seedlings. When comparing seedlings of *H. vulgare* derived from primed seeds and exposed to 200 mM NaCl to seedlings derived from non-pretreated seeds, a significant reduction was observed (Figure 5), with radicles and coleoptiles being reduced by 45% and 55%, respectively.

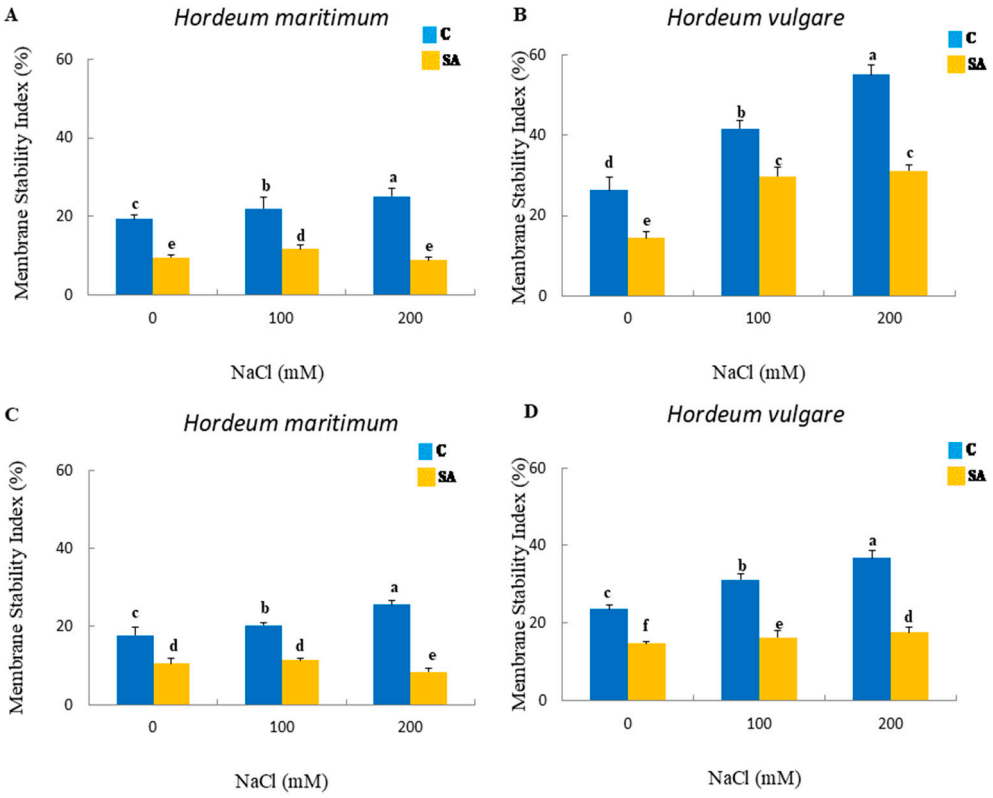


Figure 5. Effect of SA seed priming and no pretreatment (Control: C) on the Membrane Stability Index in radicles (**A**,**B**) and coleoptiles (**C**,**D**) of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five independent replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

3.6. Malondialdehyde Content

In both species, salinity markedly raised MDA levels. However, in seedlings that germinated on the medium supplemented with 200 mM NaCl, this increase was more noticeable. Comparing *H. vulgare* and *H. maritimum* to controls, the stimulation rates were approximately 143% and 100% in coleoptiles and 175% and 60% in radicles, respectively (Figure 6). On the other hand, SA reduced the rise in MDA levels caused by salinity in the seedlings of the two species under investigation. When compared to their counterparts from non-pretreated seeds, the coleoptiles of *H. vulgare* seedlings from pretreated seeds that germinated on the medium supplemented with 200 mM NaCl had the lowest MDA content. The effects of SA on radicles were comparable in seedlings of the two species that germinated at both salt concentrations (Figure 6).

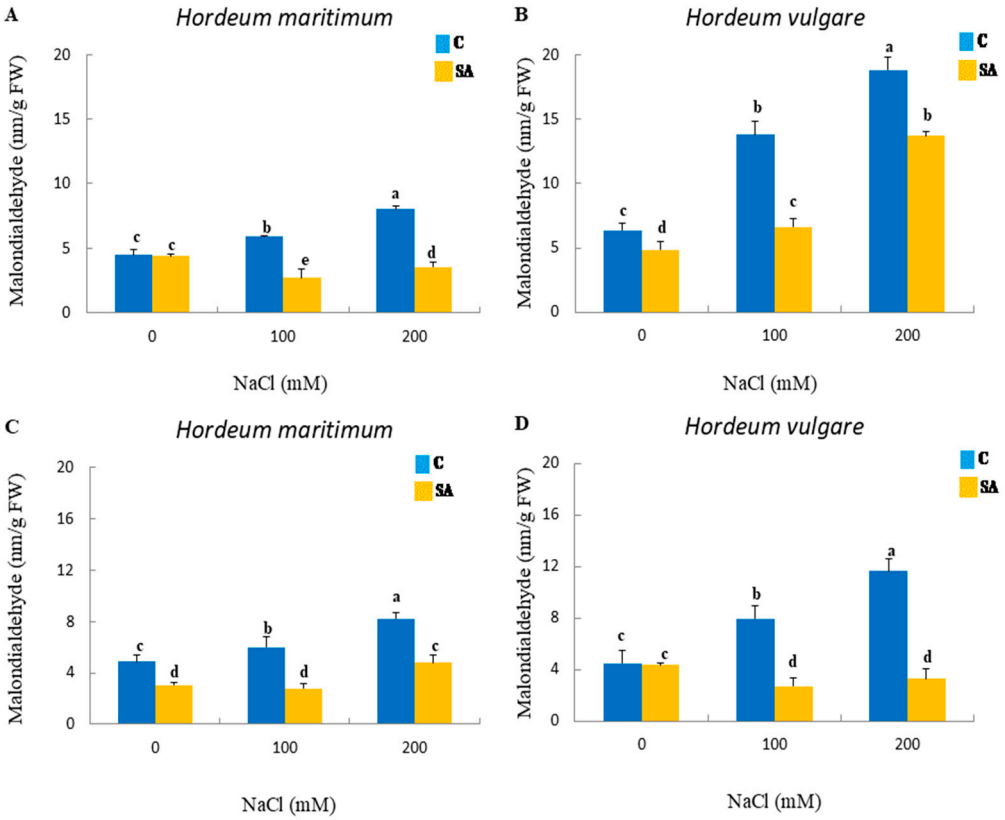


Figure 6. Effect of SA seed priming and no pretreatment (Control: C) on Malondialdehyde content in radicles (**A**,**B**) and coleoptiles (**C**,**D**) of two barley species, *Hordeum maritimum* and *Hordeum vulgare*, grown under salinity stress. Values are means of five independent replicates ± standard error. Data with the same letter are not significantly different at $p < 0.05$ (Duncan's test).

3.7. Principal Component Analysis (PCA)

To study the set of variables that explained the greatest variability in the experiment, as well as how the different treatments were separated, a principal component analysis (PCA) was carried out. Principal component analysis (PCA) is a statistical method that consists of describing the variation produced by the observation of p random variables in terms of a set of new variables that are uncorrelated with each other (called principal components), each of which is a linear combination of the original variables. These new variables are obtained in order of importance, so that the first principal component (PC1) incorporates the greatest possible amount of variation due to the original variables; the second principal component (PC2) is chosen so that it explains the greatest possible amount of variation that remains unexplained by PC1, subject to the condition of being uncorrelated with PC1, and so on. With this in mind, two PCAs for coleoptile and radicle data, followed by a partial least squares discriminant analysis, were conducted to assign the PCs displaying eigenvalues greater than or equal to 1.0, which led to the identification of three PCs (PC1, PC2, and PC3) in coleoptiles, explaining 93.04% of the variation, and two PCs (PC1 and PC2) in radicles that explained 86.50% of the variation within the dataset (at the end of the experiment, after 7 days of germination under optimal or stressful conditions).

The purpose of this analysis was to first obtain a small number of linear combinations of the 12 variables studied (DW, MSI, MDA, Ca, Mg, Fe, K, Na, Na/K, Ca/Na, length, and FG%) that explain the greatest variability in the data. In the case of coleoptiles, three components were extracted, since these three components had eigenvalues greater than or equal to 1.0. These components were principal component 1 (PC1), which explained 48.82% of the variability of the experiment, principal component 2 (PC2), which explained

35.65% of the variability of the experiment, and principal component 3 (PC3), which explained 8.57% of the variability of the experiment. Together, they explained 93.04% of the variability in the original data (Table S1 and Figure S1). Then, for the first two extracted components, the variables that had more weight or were the most important (variables with a higher absolute value) were identified. In PC1, the variables with the most weight, ranked from highest to lowest, were: Na > Fe > MDA > Lenght > DW > Na/K. Therefore, PC1 included all variables related to the absorption of sodium and its effect on the iron accumulated in leaves, then on growth and membrane damage. PC1 was the best, with a value of F = 1025.11***, which allowed us to classify the treatments into seven clusters (Table S2, Figure 7, biographic; Figure S2, Tables S3a and S3b). The first cluster is shaped by the *H. vulgare* seedlings grown under optimal conditions (0 mM NaCl) and *H. vulgare* seedlings primed with SA and subjected to 100 mM NaCl treatments; the second cluster only includes the *H. vulgare* seedlings primed with SA and subjected to 200 mM NaCl treatment; the third cluster is composed of the *H. maritimum* seedlings grown under optimal conditions (0 mM NaCl) and *H. maritimum* seedlings primed with SA and subjected to 100 mM NaCl treatment; the fourth cluster is formed by the *H. vulgare* seedlings subjected to 100 mM NaCl treatment and *H. maritimum* seedlings primed with SA and subjected to 200 mM NaCl treatment; the fifth cluster only includes the *H. maritimum* seedlings subjected to 100 mM NaCl treatment; the sixth cluster only includes the *H. maritimum* seedlings grown under 200 mM NaCl treatment; and the seventh cluster only includes the *H. vulgare* seedlings subjected to 200 mM NaCl (Table S3c). Regarding PC2, the treatments were also very well-separated, with a value of F = 723.09***, which allowed us to once more classify the treatments into seven clusters (Table S3d): the first cluster only consisted of the *H. vulgare* seedlings subjected to 200 mM NaCl treatment; the second cluster included the *H. vulgare* seedlings subjected to 100 mM NaCl and *H. vulgare* seedlings grown under optimal conditions (0 mM NaCl); the third cluster is formed by the *H. vulgare* seedlings primed with SA and subjected to 200 mM NaCl and *H. vulgare* seedlings primed with SA and subjected to 100 mM NaCl treatment; the fourth cluster only includes *H. maritimum* seedlings subjected to 200 mM NaCl treatment; the fifth cluster only includes *H. maritimum* seedlings subjected to 100 mM NaCl treatment; the sixth cluster only includes the *H. maritimum* seedlings primed with SA and subjected to 200 mM NaCl treatment; and the seventh cluster is formed by *H. maritimum* seedlings grown under 0 mM NaCl and *H. maritimum* primed with SA and subjected to 100 mM NaCl treatment. These scores reconfirm the results described in the previous paragraph, which indicated that, in PC1, separation was observed in relation to the species. Meanwhile, in PC2, a separation of the treatments was observed in relation to the effect of salinity intensity in the presence or absence of seed priming (Table S3e).

In the case of radicles, two components were extracted since these two components had eigenvalues greater than or equal to 1.0. These components are principal component 1 (PC1), which explains 49.12% of the variability of the experiment, and principal component 2 (PC2), which explains 37.38% of the variability of the experiment. Together, they explained 86.50% of the variability in the original data (Table S4 and Figure S3). Then, for each extracted component, the variables with greater weights were identified. In PC1, the variables with the highest weights, from highest to lowest, were Fe > DW > Ca > Mg > Length > Ca/Na > Na. Therefore, PC1 included all variables related to mineral nutrition status. Indeed, salt leads to an imbalance generated by the absorption of an excessive amount of sodium. Following the same criteria, in PC2, the variables with the highest weights, from highest to lowest, were MSI > Na/K > MDA > FG%> K. This indicates that PC2 included all variables related to the effect of salinity on membrane damage and competition between sodium and potassium (Table S5).

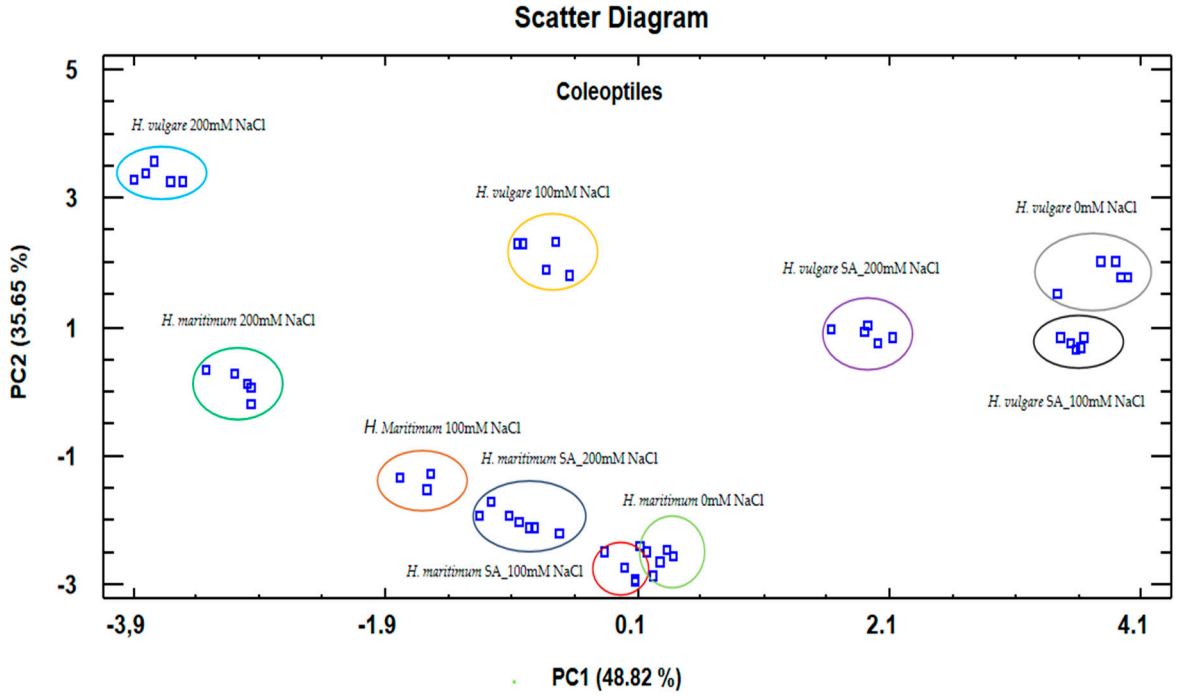


Figure 7. A principal component analysis of coleoptiles for the different treatments (HV_0 mM NaCl, HV_100 mM NaCl, HV_200 mM NaCl, HV_SA_100 mM NaCl, HV_SA_200 mM NaCl, HM_0 mM NaCl, HM_100 mM NaCl, HM_200 mM NaCl, HM_SA_100 mM NaCl, and HM_SA 200 mM NaCl). Two principal components (PC1 and PC2) resulted in a model that explained 84.47% of the total variance.

We again aimed to locate the treatments in a scatter diagram (Figure 8) or biographic (Figure S4). These figures were obtained from the principal component table, where the scores obtained for each component are represented for each treatment (five items of data per 10 treatments, for a total of 50 items of data). In addition, the average score for each of the ten treatments was added (Table S6a). The scatter plot shows that the treatments were well-separated within the two PCs, but PC1 was the best, with a value of F = 1159.63***, which allowed us to classify the treatments into seven clusters (Table S6b). The first cluster is only formed by *H. maritimum* seedlings grown under the 200 mM NaCl treatment; the second cluster is shaped by *H. maritimum* seedlings grown under 100 mM NaCl, *H. maritimum* seedlings primed with SA and subjected to 200 mM NaCl, and *H. maritimum* seedlings primed with SA and subjected to 100 mM NaCl treatment; the third cluster is composed of *H. vulgare* seedlings grown under 200 mM NaCl and *H. maritimum* seedlings grown under 0 mM NaCl treatment; the fourth cluster only contained *H. vulgare* seedlings grown under the 100 NaCl treatment; the fifth cluster only contained *H. vulgare* seedlings primed with SA and subjected to the 200 mM NaCl treatment; the sixth cluster is only formed by *H. vulgare* seedlings primed with SA and subjected to 100 mM NaCl treatment; and the seventh cluster only contained *H. vulgare* seedlings grown under 0 mM NaCl (Table S6c). Regarding PC2, the treatments were well-separated, with a value of F = 716.80***, which allowed us to classify treatments into eight clusters (Table S6d). The first cluster is only formed by *H. vulgare* seedlings grown under 200 mM NaCl treatment; the second cluster is only formed by *H. vulgare* seedlings grown under 100 mM NaCl treatment; the third cluster is composed of *H. vulgare* seedlings primed with SA and subjected to 200 mM NaCl and *H. maritimum* seedlings grown under 200 mM NaCl; the fourth cluster only contained *H. vulgare* seedlings primed with SA and subjected to 100 mM NaCl treatment; the fifth cluster only contained the H. maritimum_100 NaCl treatment; the sixth cluster is shaped by the *H. vulgare*_0 mM NaCl treatment and *H. maritimum*

seedlings primed with SA and subjected to 200 NaCl; the seventh cluster is formed by *H. maritimum* seedlings primed with SA and subjected to 200 mM NaCl and *H. maritimum* primed with SA and subjected to 100 mM NaCl treatment; and the eighth cluster consists of *H. maritimum* primed with SA and subjected to 100 mM NaCl and *H. maritimum* seedlings grown under 0 mM NaCl treatments. These scores reconfirm the results described in the previous paragraph (Table S6e).

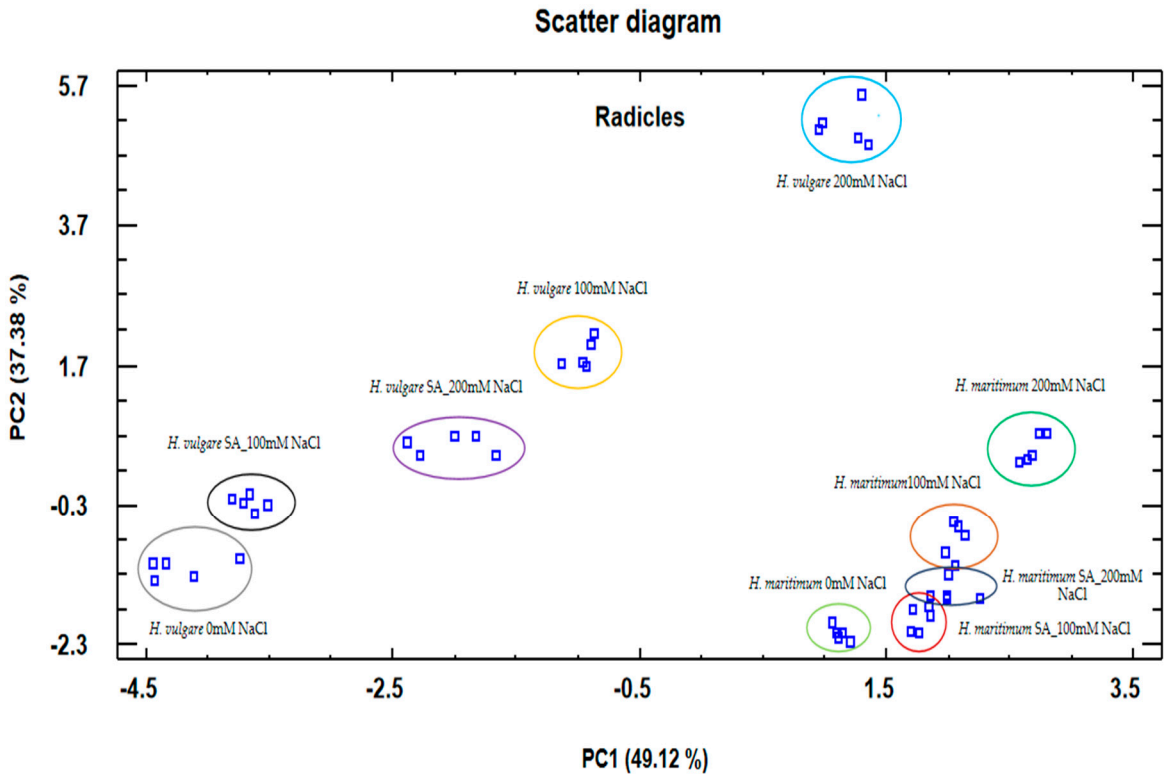


Figure 8. A principal component analysis of radicles for the different treatments (HV_0 mM NaCl, HV_100 mM NaCl, HV_200 mM NaCl, HV_SA_100 mM NaCl, HV_SA_200 mM NaCl, HM_0 mM NaCl, HM_100 mM NaCl, HM_200 mM NaCl, HM_SA_100 mM NaCl, and HM_SA 200 mM NaCl). Two principal components (PC1 and PC2) resulted in a model that explained 84.47% of the total variance.

4. Discussion

One of the most damaging environmental stresses is soil salinity, which reduces the amount of land under cultivation and limits agricultural productivity and quality worldwide [44]. Salt stress affects over 20% of irrigated arable land, or roughly 45 million hectares [45]. According to climate modeling, by 2050, over 50% of arable land will be salinized [46]. The combined effects of xerothermic factors, such as heat and drought, will exacerbate this environmental issue. During the seven days of treatment, seedlings of both barley species germinated in salinity conditions displayed the typical effects of salt stress. Indeed, this environmental restriction reduced both mean daily germination and the final germination rate. Additionally, it reduced the growth characteristics of seedlings in comparison to those grown from seeds germinated under optimal conditions. Regardless of the species and slat concentration, the control and NaCl-treated barley seedlings showed notable differences. Compared to *H. maritimum*, the detrimental effects of salt were more noticeable in *H. vulgare*. Toxic ions may have limited the mobilization of nutritional reserves, which are essential for the embryo's survival and the initiation of the germination process. These findings supported earlier research showing that most plants are more affected by salinity during the germination stage and seedling development [47].

This study showed that by lowering the germination rate, salinity has a negative impact on seed germination and seedling growth. The concentration of salt determines this decline [48]. In the same context, it was demonstrated that all stages of development, but especially the early growth stages, make wheat plants extremely salt-sensitive [49]. Furthermore, salinity stress prevents seed germination through an osmotic effect, which is reflected in the embryo's inability to absorb enough water for tissue hydration and metabolic process activation [50]. Indeed, water scarcity brought on by salinity affects crop stand establishment and germination, which is crucial and the main factor limiting crop production in saline regimes [51]. Excess soluble salts in soils decrease osmotic potential and postpone the onset of seedling germination by blocking the seeds' water uptake or exosmosis and dispersing the processes involved in germination, including the best possible activity of enzymes needed for metabolic activity and the use of seed reserves [52,53].

However, salt stress increased the ratio of Na to K by increasing the absorption of Na content while decreasing the mobilization of K content. Since K transport to coleoptiles has been shown to be proportionate to water transport [54], this behavior could be explained by a decrease in transpiration rate, a reduction in absorption system performance, which would limit K transport [55], or competition for the uptake of K and Na ions [56,57]. Furthermore, antagonism between ions during their uptake under relatively high concentrations of Na^+ and Cl^- causes an essential mineral imbalance that prevents the absorption of available water and essential nutrients such as K^+, Ca^{2+}, and Mg^{2+}. The substitution of Na^+ for Ca^{2+} is also caused by altered mineral distribution, increased ion toxicity, and membrane permeability. Salt stress causes cellular-level osmotic and ionic imbalances that disrupt the entire physiology of plants. For instance, by affecting the root membrane's selectivity mechanism, salinity deprives plants of K^+ [58]. As mentioned, these adverse circumstances may cause metabolic disruptions that result in an excess of reactive oxygen species (ROS) and may lead to oxidative damage to a variety of biomolecules, including proteins, lipids, and nucleic acids [59]. Our study's data demonstrate that salt stress impacted the integrity of the membrane by increasing electrolyte leakage and causing MDA to accumulate, both of which result in oxidative stress. The species of *H. vulgare* showed a notable increase. Salinity, like all other environmental constraints, disrupts the redox system and can cause oxidative stress inside plant cells given that oxidative stress is a platform for any kind of environmental constraint [60]. However, it is well-known that plants also use ROS as signaling molecules during stressful conditions [61]. In fact, salinity-induced oxidative stress throws the pro-oxidant and antioxidant systems out of balance, favoring the former [62]. Generally speaking, these pro-oxidants or ROS are harmful to cells [63]. It is well-known that ROS cause cellular homeostasis to become unbalanced, membranes, proteins, and biomolecules to deteriorate, and that they have mutagenic and post-accumulation effects in the cytoplasm [64]. However, compared to untreated plants, *H. maritimum* plants exposed to various NaCl treatments had lower MDA levels. Pea (*Pisum sativum*) roots subjected to cadmium stress showed comparable outcomes [65]. Interestingly, the substantial increase in the reduced ascorbate (ASC) pool, which is known to be crucial in minimizing membrane damage during environmental stressors, may account for the slight decrease in MDA content in the tissues of *H. maritimum* plants [66]. Similar studies showed that salinity increased ROS production and caused cellular toxicity in a variety of crop plants [67]. Compared to salt-tolerant cultivars, wheat was a sensitive cultivar and exhibited higher levels of lipid peroxidation [68]. For example, salt stress (100 mM NaCl) increased the levels of malondialdehyde (MDA) in wheat seedlings by up to 35% or 68% after 5 or 10 days of exposure, respectively [69]. Overall, *Hordeum maritimum* (wild barley) often exhibits superior salinity tolerance due to its evolutionary adaptations, such as efficient ion compartmentalization and osmotic adjustment mechanisms, whereas *Hordeum*

vulgare (cultivated barley) may prioritize growth under favorable conditions. Indeed, many studies highlight the genetic differences between wild and cultivated barley, emphasizing ion transport systems and root morphology as critical factors in salinity response. Authors discuss how Hordeum maritimum maintains better growth under salinity stress compared to *Hordeum vulgare*, due to a higher capacity for sodium exclusion and maintenance of cellular homeostasis [8,70].

As previously stated, the negative effects of salinity on plant growth and development were lessened and mitigated when SA priming was applied to barley seeds subjected to salt stress. Indeed, SA has been shown to improve the germination of many species under salinity by increasing their tolerance. In our current study, we observed a significant boost in germination and seedling growth in barley seeds due to SA treatment under salt stress conditions. In fact, SA has stimulated Chinese mustard, violet, and wheat seed germination, as well as root and aerial growth in a dose-dependent manner [71]. In this regard, it was verified that active mitotic activity was responsible for the improvement in root growth observed in wheat seedlings cultivated from seeds primed with SA under salinity conditions [72]. Our study's findings were in line with those of other studies conducted in this field. Indeed, a comparison of means revealed that salicylic acid priming improved various germination indices and lessened the detrimental effects of salinity stress on germination traits. For six hours, 0.5 mM was the ideal concentration for salicylic acid priming. Overall, the findings demonstrated that seed priming with salicylic acid can be used to lessen the detrimental effects of salinity stress on triticale seedling growth and seed germination under salinity stress conditions [73].

Similar results showed that SA's beneficial effects result in a significant increase in total biomass when wheat seeds are pretreated with SA [74]. Crucially, SA pretreatment has been shown to increase the length of wheat seedlings cultivated under drought and salt stress conditions, thereby assisting wheat in surviving and competing in stressful environments [75]. These findings corroborated earlier studies that demonstrated the significant positive impact of SA pre-sowing treatment on all assessed growth factors and sweet pepper germination rates [76]. Furthermore, higher levels of cell division in seedlings and roots may be linked to increased germination in stressed seeds, which would boost the growth of wheat seedlings cultivated from SA-primed seeds and minimize membrane damage [77]. Additionally, lettuce's resistance to cadmium toxicity increased when SA seed priming was applied [78]. Regarding this, plants exposed to 5 mM cadmium that were cultivated from seeds primed with SA showed an increase in germination rate and biomass. As was already mentioned, presoaking seeds with SA caused vital nutrients to be transported into the tissues of the seedlings, increasing the amounts of Fe, Mg, Ca, and K. Therefore, the increased H^+-ATPase activity may be the cause of the stimulation of nutrient mobilization in barley seedlings that germinated from primed seeds. Similarly, it was observed that SA markedly enhanced the activity of H^+-ATPase in the roots of peanut plants [79]. Furthermore, SA has been shown to improve cellular ion homeostasis by reducing excess Na^+ influx and promoting K^+ influx in aerial plant parts by bending the affinity of non-specific cation channels towards K^+ [80]. Some authors demonstrated that SA reduced the oxidative stress caused by NaCl, as evidenced by decreased lipid peroxidation levels. On the other hand, it has been acknowledged that seed priming with SA contributes to the improvement of plant resistance and is crucial for boosting antioxidant defense and preventing the buildup of sodium [81]. Baby corn cultivated from SA-primed and salt-treated seeds showed a similar pattern. The higher ionic content was thought to be responsible for this advantageous effect, which raised the K/Na ratio and reduced Na accumulation [82]. Moreover, it has been noted in *Hordeum vulgare* and *Iris pseudacorus* that SA pretreatment strengthened defense systems and lessened the adverse effects of salt

stress [83,84]. SA could also be related to plant acclimation to saline conditions. In this context, NaCl-adapted tomato cells contain a lower concentration of SA than unadapted cells. The adaptation process to NaCl was also related to a higher antioxidative capacity [85].

5. Conclusions

One of the main abiotic factors impeding sustainable agriculture is salinity stress, which prevents barley seedlings from germinating and growing early. Salt did, in fact, lower the rate of seed germination, the average daily germination rate, and the growth of seedlings. Additionally, it caused oxidative stress, marked by elevated MDA and electrolyte leakage, and restricted the absorption of vital mineral elements. The impact of SA pretreatment under salinity stress was examined in this study. The growth of barley seedlings under various salt treatments was significantly enhanced by this plant hormone. Indeed, compared to unprimed seeds, stressed seedlings from SA-primed seeds demonstrated a higher tolerance to NaCl. By raising the content of Fe, Ca, Mg, and K and preventing the buildup of Na, SA provides resistance to salt stress.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy15010154/s1, Table S1. Principal Component Analysis. Table S2. Table of Component Weights. Table S3a. This table shows the scores of the principal components in both barley species: *Hordeum vulgare* and *Hordeum maritimum*. Table S3b. ANOVA table for the component 1 scores according to the treatments. Table S3c. Multiple comparisons test for the component 1 scores by treatments using Tukey HSD method for both barley species Hordeum vulgare and Hordeum maritimum. Table S3d. ANOVA table for the component 2 scores according to the treatments. Table S3e. Multiple comparisons test for the component 2 scores by treatments using Tukey HSD method for both barley species *H. vulgare* and *H. maritimum*. Table S4. Principal Component Analysis. Table S5. Table of Component Weights. Table S6a. This table shows the scores of the principal components. Table S6b. ANOVA table for the component 1 scores according to the treatments. Table S6c. Multiple comparisons test for the component 1 scores by treatments using Tukey HSD method. Table S6d. ANOVA table for the component 2 scores according to the treatments. Table S6e. Multiple comparisons test for the component 2 scores by treatments using Tukey HSD method. Figure S1. Sedimentation graph. Figure S2. Graphical representation of the principal components marking with lines for each variable and wit points for each score. Figure S3. Sedimentation graph. Figure S4. Graphical representation of the principal components marking with lines for each variable and wit points for each score.

Author Contributions: R.B.Y.: Investigation, writing original draft, writing, review and editing. N.J.: writing original draft and conceptualization. J.R.A.M.: writing, review and editing. C.A.: Supervision. A.A.: writing, review and editing, validation. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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