Journal of Agricultural Sciences (Belgrade)
Vol. 68, No. 2, 2023
Pages 141-154

https://doi.org/10.2298/JAS2302141K
UDC: 631.415
Original scientific paper

# A COMPARATIVE STUDY ON SALT STRESS RESPONSE OF *CAMELINA SATIVA* AND *CARTHAMUS TINCTORIUS* DURING GERMINATION

**Teodora N. Kukrić[1*], Ana M. Marjanović Jeromela[2], Zorica T. Nikolić[2] and Dušica D. Jovičić[2]**

[1]University of Novi Sad, Faculty of Agriculture,
Trg Dositeja Obradovića 1, 21000 Novi Sad, Serbia
[2]Institute of Field and Vegetable Crops Novi Sad,
Maksima Gorkog 30, 21000 Novi Sad, Serbia

**Abstract:** Soil salinization is one of the most significant global problems, leading to reduced agricultural productivity potential and biodiversity. The main salt commonly found on the surface of soils and in water is NaCl, which directly impacts plant growth and land degradation. Therefore, this study was conducted to examine the morpho-physiological characteristics of two genotypes of *Camelina sativa* ('NS Slatka'; 'NS Zlatka') and two genotypes of *Carthamus tinctorius* ('NS Lana'; 'NS Una'), which potentially characterize them as salt-tolerant crops. The levels of salinity tolerance were compared under five NaCl treatments, ranging from 0 mM to 200 mM. Based on the obtained results, seeds of all four genotypes germinated at the highest salt concentration (200mM NaCl), but the germination percentage declined at all salt concentrations. Moreover, lower salt concentrations induced root elongation and reduced shoot length of seedlings of all four genotypes. Salt stress tolerance indexes showed the importance of converting the plant parameters into mathematical indexes, and the significance of comparing all the tolerance indexes according to salt stress.

**Key words:** NaCl, salinity, tolerance indexes.

## Introduction

Agricultural areas take up 38% of the global land surface, of which one-third is used as cropland (FAO STAT, 2020). Human-induced saline and sodic soils have drastically raised the total percentage of globally salt-affected lands. The current percentage of salinated land, estimated at 50%, appears to be rising according to recent studies carried out by the United Nations Environmental Program (UNEP). This increase in salt-affected lands has both natural and human causes (Kumar, 2017; Shahid et al., 2018).

[*]Corresponding author: e-mail: teodora.kukric@polj.uns.ac.rs

Despite researching this globally rising problem for decades and implementing sustainable management of salt-affected soils, the issue of salinization is ubiquitous and concerning (Shrivastava and Kumar, 2015; Mukhopadhyay et al., 2021; Singh, 2022). Therefore, soil salinization is recognized as one of the most significant problems at a global level, leading to reduced agricultural productivity potential and biodiversity, which is directly connected with substantial financial losses (FAO and ITPS, 2015).

Crops are measurably affected by soil salinization. NaCl is the salt most commonly found on the soil surface and in irrigation water (Ashraf et al., 2010). $Na^+$ and $Cl^-$ ions in solutions associated with other abiotic and biotic factors negatively impact plant growth and land degradation (Corwin, 2021). As a medium for seed germination – the most sensitive stage in the plant life cycle – and root growth, soil supplies plants with nutrients and water (Zuffo et al., 2020; Li et al., 2019). Soil, as a medium for seed germination, provides plants with nutrients and water. The soil surface layer is predominated by salt in saline conditions, limiting germination. Saline soil limits germination. Furthermore, plant establishment is negatively impacted by decreased soil water potential, which induces difficulties for a plant to uptake water and nutrients. Consequently, ionic imbalance and cytotoxicity occur with oxidative stress in plant cells (Hanslin and Eaggen, 2005). Salt-tolerant plants withstand high salinity through processes entrenched on cellular and tissue levels that are directed by physiological and molecular mechanisms. The primary defence mechanisms are osmotic tolerance, ionic tolerance, tissue tolerance, and cell antioxidant systems (Hasegawa et al., 2000; Wang et al., 2009).

Comparatively advantaged are crops with the capacity to accommodate salinity and adjustable crops produced on marginalized and poor-quality lands. Crops that can tolerate salinity and crops that can be grown on poor-quality lands have an advantage over other types of crops. *Camelina sativa* (false flax) and *Carthamus tinctorius* (safflower) are oil crops that belong to the Brassicaceae and Asteraceae families, respectively. Both crops have been used as a source of edible oil for centuries. Their agronomic characteristics present them as favorable cultivars, and they benefit agricultural production in terms of demand for renewable oil sources and crop rotation requirements (Ashri et al., 1974; Ekin, 2005). The short growth cycle of *C. sativa* and tolerance to cold and drought stress distinguish it as a prospective agricultural crop. *C. tinctorius* is also well known for its adaptability to varied growing conditions (Singh and Nimbkar, 2006).

The objective of this comparative study was to assess the response of two genotypes of *C. sativa* and two genotypes of *C. tinctorius* to salt stress during germination and early seedling growth stages under controlled conditions. Using different concentrations of NaCl solutions to simulate salt stress, we provided the responses of the genotypes based on germination performance and shoot and root elongation rates.

## Material and Methods

The experiment was carried out at the Laboratory for Seed Testing at the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The research material consisted of four genotypes obtained from the breeding program of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The two plant species tested under saline conditions were *Camelina sativa* (L.) Crantz, genotypes: 'NS Zlatka' and 'NS Slatka', as well as *Carthamus tinctorius*, genotypes: 'NS Una' and 'NS Lana'. The seeds used for this experiment were randomly taken from seed lots obtained from the crops of the same field and under the same conditions for all genotypes.

The experiment was laid out in a completely randomized design with three replications. One hundred seeds per replication were placed between filter papers in glass Petri dishes of 12 cm in diameter. Moistened filter papers were used as a growing medium. Distilled water was used as a control. Four levels of NaCl concentration were applied to induce salt stress. On the first day of the experiment, 10 ml of each treatment solution: 50, 100, 150, or 200 mM NaCl were added.

The salt stress effect on experimented seeds was investigated by a standard germination test established by ISTA (2019) for each plant species. The germination percentage (G) was determined by counting the number of seeds that produced seedlings whose radicle size was >3mm. The first count was made on the fourth day of the experiment, which was germination energy (GE). Besides seed energy and germination percentage, the length of seedlings (mm) was also determined. Shoot and root lengths (SL; RL) were measured on the sixth and tenth days of the experiment. The root/shoot ratio of the seedlings (R/S) was calculated by dividing the root and shoot lengths of the seedlings. For ease of comparison, these values were converted into root elongation rate (RER) and shoot elongation rate (SER), as explained by Channaoui et al. (2019):

$$\mathrm{RER} = \frac{(\mathrm{RLE}-\mathrm{RLS})}{(\mathrm{TE}-\mathrm{TS})} \qquad \mathrm{SER} = \frac{(\mathrm{SLE}-\mathrm{SLS})}{(\mathrm{TE}-\mathrm{TS})} \tag{1}$$

where RLE/SLE and RLS/SLS (mm) are the root and shoot lengths at the end and the start of a measurement period, respectively, and TE – TS is the time difference (d) from the start to the end of the measurement period.

Atypical seedlings (A) were also counted as undeveloped or damaged seedlings during the experiment. Germination stress tolerance index (GSTI), shoot length stress tolerance index (SLSTI), root length stress tolerance index (RLSI), and total seedling length stress tolerance index (TLSI) were calculated using the equations given by Partheeban et al. (2017):

$$\text{GSTI} = \frac{\text{Germination of stressed seeds}}{\text{Germination of control seeds}} \times 100 \quad (2)$$

$$\text{SLSTI} = \frac{\text{Shoot length of stressed plants}}{\text{Shoot length of control plants}} \times 100 \quad (3)$$

$$\text{RLSTI} = \frac{\text{Root length of stressed plants}}{\text{Root length of control plants}} \times 100 \quad (4)$$

$$\text{TLSTI} = \frac{\text{Total length of stressed plants}}{\text{Total length of control plants}} \times 100 \quad (5)$$

The recorded data were statistically analyzed, followed by two-way ANOVA using SPSS Statistic Version 25. Statistically significant differences were determined at the 0.05 probability level, and significant differences between treatments were determined using post hoc analysis – the Tukey test.

## Results and Discussion

The ability of seeds to germinate and seedlings to emerge is affected by salinity as an environmental factor. These two phases of plant growth characterize different salt tolerance mechanisms essential for a plant successful establishment (Almodares et al., 2007). Therefore, it is necessary to evaluate both growth stages under stress conditions, and to understand the link between germination failures followed by seedling emergence. This is especially important for plants most sensitive at the germination stage (Hamdy et al., 1993). In this study, the results of two-way ANOVA (Table 1) showed that genotype and salt stress significantly affected the germination and R/S ratio of *Camelina* seeds. The interaction between genotype and salt stress had no significant effect on germination, indicating that the genotypes responded similarly to the stress treatments. In contrast, all sources of variation affected GE and GSTI. *Camelina* genotypes also responded differently to the stress levels for the following parameters: RL, SL, RER, and SER. When only the effect of salt stress was observed, SLSTI and TLSTI were affected, whereas A and RLSTI were affected by the interaction between salt stress and genotype. Regarding *Carthamus* seeds and according to the results of two-way ANOVA (Table 2), G, GE, and GSTI were significantly affected by all sources of variation, indicating that genotypes responded differently to stress treatments. In contrast, all other parameters (A, RL, SL, RER, SER, RLSTI, SLSTI, TLSTI and R/S) were affected only by salt stress.

The germination percentage of *Camelina* seeds was the highest in optimal conditions (0 mM NaCl) (Table 3). While ‘NS Slatka’ had a higher germination percentage when salt was lacking in the medium only in the control, ‘NS Zlatka’ showed a better germination percentage with an increasing concentration of NaCl. Germination decreased by 0.6%, 10%, 24% and 54% for ‘NS Slatka’, at 50, 100, 150 and 200 mM NaCl while for ‘NS Zlatka’ germination decreased by 2% and

31% at 150 mM and 200 mM NaCl, respectively. It should be emphasized that 'NS Zlatka' germination declined less under the highest salt treatment in comparison with 'NS Slatka', and that it was able to germinate unhindered at 150 mM NaCl.

Table 1. Results of ANOVA (sum squares) of the *Camelina* traits determined.

| *Camelina sativa* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | df | G | GE | A | RL | SL | RER | SER |
| G | 1 | 169.00** | 215.10** | 0.11 | 2.78 | 0.44 | 0.30 | 0.04 |
| conc | 5 | 25660.00** | 31849.60** | 696.88** | 2234.22 | 731.88 | 16.74 | 8.55 |
| G x conc | 5 | 980.70 | 1207.60** | 84.55** | 119.56** | 11.55** | 2.27** | 0.20** |
| error | 24 | 251.30 | 216.70 | 142.00 | 233.33 | 78.00 | 6.75 | 1.68 |
| | df | RLSTI | SLSTI | GSTI | TLSTI | R/S | | |
| G | 1 | 83.30 | 17.80 | 1625.80** | 48.50 | 619.26 | | |
| conc | 4 | 38116.2** | 14876.00* | 36019.20** | 24201.60* | 219349.39* | | |
| G x conc | 4 | 3262.00* | 314.50 | 433.20* | 1130.20 | 815.76 | | |
| error | 20 | 5158.40 | 3697.50 | 558.70 | 3211.20 | 13588..98 | | |

*P < 0.05, **P < 0.01; GE – germination energy, G – germination percentage, A – atypical seedlings, SL – shoot length, RL – root length, SER – shoot elongation rate, RER – root elongation rate, RLSTI – root length stress tolerance index, SLSTI – shoot length stress tolerance index, GSTI – germination stress tolerance index, TLSTI – total seedling length tolerance index, R/S – root/shoot ratio.

Table 2. Results of ANOVA (sum squares) of the *Carthamus* traits determined.

| *Carthamus tinctorius* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | df | G | GE | A | RL | SL | RER | SER |
| G | 1 | 246.50** | 653.33** | 56.03 | 38.53 | 4.80 | 4.80 | 0.03 |
| Conc | 4 | 7010.00** | 8762.33** | 3093.20 | 9949.13** | 3304.87** | 3304.87** | 13.33** |
| G x conc | 4 | 521.50** | 988.33** | 604.80 | 175.13 | 23.53 | 23.53 | 0.91 |
| error | 20 | 354.70 | 312.67 | 791.3 | 1516.67 | 72.00 | 72.00 | 2.85 |
| | df | RLSTI | SLSTI | GSTI | TLSTI | R/S | | df |
| G | 1 | 6.90 | 13.41 | 559.50** | 8.60 | 320.79 | G | 1 |
| conc | 3 | 20710.70** | 16119.47** | 7079.10** | 18641.80** | 18015.25* | conc | 3 |
| G x conc | 3 | 532.80 | 163.73 | 720.80** | 297.30 | 1846.95 | G x conc | 3 |
| error | 16 | 3893.00 | 586.40 | 668.70 | 1637.90 | 346955.89 | error | 16 |

*P < 0.05, **P < 0.01; GE – germination energy, G – germination percentage, A – atypical seedlings, SL – shoot length, RL – root length, SER – shoot elongation rate, RER – root elongation rate, RLSTI – root length stress tolerance index, SLSTI – shoot length stress tolerance index, GSTI – germination stress tolerance index, TLSTI – total seedling length tolerance index, R/S – root/shoot ratio.

In various studies investigating the effect of salt stress on oilseed crops, increasing salinity at the germination stage reduced seed vigor. Moreover, among the four different salt types found in the soil (NaCl, $Na_2SO_4$, $CaCl_2$, MgCl), NaCl

had the most significant negative impact on the seed germination of *Brassica sp*. (Mohammed et al., 2002; Hosseini et al., 2002; Jovičić et al., 2014).

Regarding 'NS Zlatka', with increasing salt concentration, there was no consistent decline, but germination increased by 2% and 3% at 50 mM and 100 mM NaCl stress levels, respectively. This specific result is consistent with the *Camelina* genotypes examined in the study carried out by Matthees et al. (2018). They explained that the higher the quantity of accumulated organic solutes in the seedlings, the more tolerance they showed at low salt concentrations compared to the control.

As for the *Camelina* seed, the germination percentages of *Carthamus* seeds (Table 4) in optimal conditions (0 mM NaCl) were the highest for both genotypes, and as the salt concentration increased, the germination percentage decreased. The strongest reduction of germination was recorded at the highest NaCl concentration (200 mM). The 'NS Lana' genotype had a higher germination percentage in optimal conditions than the 'NS Una' genotype, but showed a higher germination decline under the treatment solutions. Germination decreased by 13%, 9%, 30% and 41% for 'NS Una', and by 11%, 10%, 55% and 55.5% for 'NS Lana' at 50, 100, 150 and 200 mM NaCl, respectively. Soheilikhah et al. (2011) studied several safflower genotypes on this subject with the same salt concentrations and found that a concentration of NaCl decreased germination (14% and 74% at 50 and 200 mM NaCl, respectively). While their result shows 50 mM as the critical value, our results show that *Carthamus* seeds can germinate well up to 100 mM NaCl. Our findings are supported by Ghorashy et al. (1972), who found that concentrations higher than 100 mM NaCl decreased the germination of *Carthamus* seeds.

Examining the germination percentage in this study shows that the seeds of four genotypes germinated were still able to germinate at the highest concentration of NaCl (200 mM). However, they were prevented from developing their full germination potential at higher salt concentrations (150 and 200 mM). The critical value was 150 mM, except for 'NS Zlatka' – 200 mM NaCl, where there was a significant reduction in germination, indicating the high tolerance of these species to a moderate stress level.

At the highest concentration of NaCl (200 mM NaCl), atypical seedlings occurred two or three times more often than in optimal conditions (0 mM NaCl). Seedling abnormalities were reflected in the fact that some of the following structures: cotyledons, primary root, hypocotyl, and first leaves were damaged, atrophied, or absent. In addition to the fact that the highest salt level suspended the germination process, it influenced the formation of atypical seedlings, indicating the toxic effect of Na ions. Demiral and Tukan (2005) reported that seeds that remained undeveloped were a consequence of a weak antioxidant defense system and lipid peroxidation in cell membranes.

Regarding the seedling parameters (Tables 3 and 4), SL was the longest for *Camelina* and *Carthamus* seedlings in the absence of stress. Other treatments with salt ions gradually decreased the SL of seedlings. SER values were the highest within the control treatment for both 'NS Slatka' and 'NS Zlatka' and decreased with each higher salt treatment. *Carthamus* SER values for 'NS Una' were in the following order: 2.7 > 2.3 > 1.6 > 1.5 > 0.7 under the following treatments: 50, 100, 0, 150, 200 mM, and for 'NS Lana' were in the following order: 2.4 > 2.2 > 2.2 > 1.0 > 0.7 under the following treatments: 50, 0, 100, 150, 200. When observing an RL (Figure 1), the low amount of NaCl stimulated the growth of *Camelina* seedlings – both genotypes had a short length in optimal conditions, which followed the seedlings at the salt treatment of 200 mM, while a salt treatment of 50 mM NaCl induced the highest RL. RER values were the highest at 200 mM and the lowest at 100 mM NaCl. When observing the RL (Figure 2) of *Carthamus* seedlings, it was found that only the treatment of 50 mM NaCl stimulated longer root growth of both genotypes than the RL of the control in both genotypes, then the RL gradually decreased up to the highest salt conditions and shortness of RL. The RER values were the highest at 100 mM and the lowest at 200 mM of NaCl for 'NS Una', whereas the highest values of RER for 'NS Lana' were at 50 mM and the lowest at 200 mM of NaCl.

Table 3. The effect of different salinity levels on a seedling characteristic of *Camelina* genotypes.

| Treatment NaCl [mM] | GE | G | A | SL | RL | SER | RER | R/S |
|---|---|---|---|---|---|---|---|---|
| NS Slatka | | | | | | | | |
| 0 | 87.3±3.79$^{a}$ | 88.6±3.21$^{a}$ | 5.0±3.21$^{c,d}$ | 20.3±1.53$^{a}$ | 19.3±0.58$^{d}$ | 2.3±0.19$^{a,b}$ | 1.7±0.35$^{a,b,c}$ | 0.95±0.08$^{b,c}$ |
| 50 | 86.6±3.79$^{a,b}$ | 88.0±2.65$^{a}$ | 6.3±3.06$^{c,d}$ | 20.0±2.58$^{a}$ | 43.0±3.61$^{a}$ | 1.2±0.54$^{c}$ | 1.6±0.83$^{a,b,c}$ | 2.10±0.43$^{a}$ |
| 100 | 78.3±2.89$^{b,c}$ | 79.6±4.04$^{a,b}$ | 2.3±1.53$^{d}$ | 19.0±1.00$^{a}$ | 34.6±3.79$^{a,b}$ | 1.4±0.19$^{c}$ | 0.4±0.63$^{c}$ | 1.83±0.23$^{a,b}$ |
| 150 | 63.3±2.89$^{d}$ | 66.6±2.08$^{c}$ | 10.3±2.52$^{b,c}$ | 16.0±0.00$^{a,b}$ | 34.3±3.51$^{a,b}$ | 1.5±0.10$^{c}$ | 1.8±0.44$^{a,b,c}$ | 2.15±0.22$^{a}$ |
| 200 | 19.6±1.53$^{e}$ | 40.6±4.04$^{d}$ | 20.0±3.61$^{a}$ | 11.0±1.00$^{b,c}$ | 30.0±1.00$^{a,c}$ | 1.2±0.01$^{b,c}$ | 3.0±0.17$^{a}$ | 2.74±0.16$^{a}$ |
| NS Zlatka | | | | | | | | |
| 0 | 67.0±3.46$^{d}$ | 70.0±4.58$^{c}$ | 6.6±3.06$^{c,d}$ | 20.3±2.08$^{d}$ | 19.3±0.58$^{d}$ | 2.4±0.10$^{a}$ | 1.7±0.35$^{a,b,c}$ | 0.96±0.09$^{b}$ |
| 50 | 70.3±4.04$^{c,d}$ | 71.6±3.06$^{b,c}$ | 8.3±1.53$^{b,c,d}$ | 19.0±1.00$^{a,b}$ | 37.6±3.51$^{a,b}$ | 0.8±0.17$^{c}$ | 1.0±0.92$^{b,c}$ | 1.97±0.44$^{a}$ |
| 100 | 70.0±4.36$^{c,d}$ | 72.6±4.04$^{b,c}$ | 5.3±2.08$^{c,d}$ | 19.3±1.59$^{a}$ | 36.0±1.73$^{a,b}$ | 1.4±0.51$^{c}$ | 0.2±0.35$^{c}$ | 1.87±0.07$^{a}$ |
| 150 | 65.0±1.73$^{d}$ | 68.6±3.51$^{c}$ | 6.6±2.08$^{c,d}$ | 17.6±0.58$^{a}$ | 36.0±2.00$^{a,b}$ | 1.6±0.10$^{b,c}$ | 1.5±0.44$^{a,b,c}$ | 2.04±0.41$^{a}$ |
| 200 | 33.6±3.21$^{e}$ | 48.0±2.65$^{d}$ | 15.3±3.51$^{a,b}$ | 12.0±12.00$^{b,c}$ | 29.3±2.52$^{b,c}$ | 1.2±0.35$^{c}$ | 2.2±0.51$^{a,b}$ | 2.80±0.93$^{a}$ |

GE – germination energy; G – germination percentage; A – atypical seedlings; SL – shoot length; RL – root length; SER – shoot elongation rate; RER – root elongation rate; R/S – root/shoot ratio.

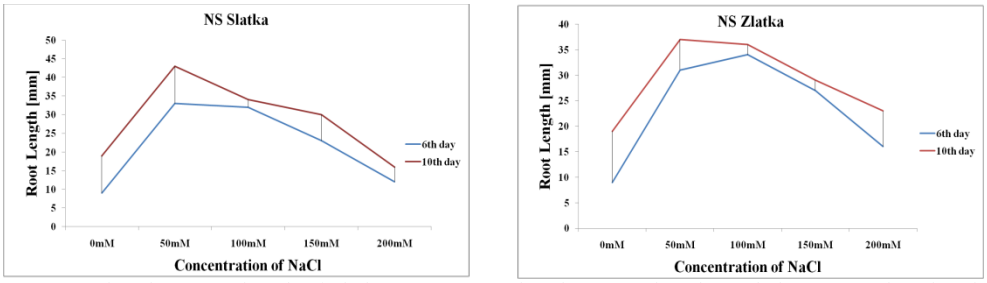
Apart from the interplay of several physiological processes, the morphological ones reflect the plant response to salinity (Julkowska and Testernik, 2015). Reducing the shoot length and lengthening the roots represent morphological adaptations to stress conditions. During salinity exposure, the energy used for plant

growth is relocated to defense mechanisms, and due to decreasing photosynthesis and leaf area, the total available energy for usage is reduced (Bandehagh and Taylor, 2020). Mostafavi (2011) presented that the shoot was proportionally reduced due to the additional contact with salt stress, which was achieved through the evaporation of salt from the medium. Moreover, in the same study, in all investigated *Carthamus* genotypes, both SL and RL decreased due to salinity, unlike in our study. Ashraf et al. (2010) suggested that inhibition of cellular enzymes and hormonal imbalance reduced cell elongation. These disturbances may explain the shoot/root growth obtained in our study. In order to increase tolerance and also avoid the largest accumulation of salt on the top of the soil, plant roots elongate towards the deeper soil layer. According to Kage et al. (2004), the distribution balance of assimilates is disturbed in favor of the roots. In small-diameter seeds, such as *Camelina* seeds, increasing the total contact area of the root with the medium can be crucial for plant establishment under stress conditions. However, there is a risk of excessive elongation leading to a thin and fragile root (Sun et al., 2008). Furthermore, the R/S ratio, as a morphological marker, is a good indicator of the plant response to salinity (Agathokleous et al., 2019). The higher R/S ratio at higher salt concentration is an adaptation that allows plants to survive under salinity conditions (Munns and Tester, 2008). The results show that the R/S ratio changed in all *Camelina* and *Carthamus* genotypes as a function of concentration. The approximate values of the R/S ratio between *Camelina* genotypes indicate their adaptability to the same levels of salt stress, which does not coincide with the values of the other parameters that showed significant differences between species and genotypes.

Table 4. The effect of different salinity levels on a seedling characteristic of *Carthamus* genotypes.

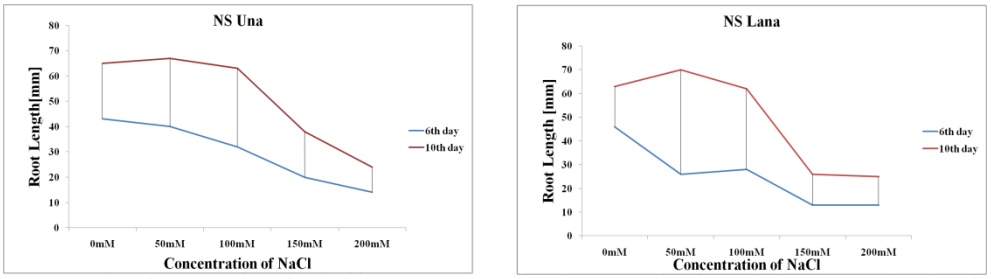
| Treatment NaCl [mM] | GE | G | A | SL | RL | SER | RER | R/S |
|---|---|---|---|---|---|---|---|---|
| NS Una | | | | | | | | |
| 0 | 72.3±4.93$^{a,b}$ | 79.6±5.50$^{a}$ | 19.0±4.00$^{c,d}$ | 37.0±1.73$^{a}$ | 65.3±3.51$^{a}$ | 1.6±0.28$^{b,c}$ | 3.6±0.16$^{b,c}$ | 0.95±0.08$^{b,c}$ |
| 50 | 63.3±5.03$^{b,c}$ | 68.6±5.13$^{a}$ | 20.6±3.51$^{c,d}$ | 36.3±2.52$^{a}$ | 67.3±3.79$^{a}$ | 2.7±0.63$^{a}$ | 4.5±1.41$^{a,b,c}$ | 2.10±0.43$^{a}$ |
| 100 | 66.3±4.72$^{b,c}$ | 72.0±6.24$^{a}$ | 22.6±2.08$^{b,c,d}$ | 25.3±1.15$^{b}$ | 63.0±3.43$^{a,b}$ | 2.3±0.16$^{a,b}$ | 5.1±1.75$^{a,b,c}$ | 1.83±0.23$^{a,b}$ |
| 150 | 49.6±2.08$^{d,e}$ | 55.6±4.04$^{b}$ | 33.0±4.55$^{a,b,c}$ | 15.6±2.52$^{c}$ | 38.0±3.71$^{b,c}$ | 1.5±0.33$^{b,c}$ | 2.8±2.03$^{b,c}$ | 2.15±0.22$^{a}$ |
| 200 | 40.0±5.29$^{e}$ | 46.6±3.51$^{b,c}$ | 31.6±5.03$^{b,c}$ | 10.6±1.53$^{c}$ | 24.3±3.06$^{c}$ | 0.7±0.25$^{c}$ | 1.6±0.44$^{c}$ | 2.74±0.16$^{a}$ |
| NS Lana | | | | | | | | |
| 0 | 78.0±1.00$^{a}$ | 80.0±4.35$^{a}$ | 12.3±0.057$^{d}$ | 36.6±0.58$^{a}$ | 63.0±1.73$^{a,b}$ | 2.2±0.09$^{a,b}$ | 2.7±0.91$^{b,c}$ | 0.96±0.09$^{b}$ |
| 50 | 63.0±2.64$^{b,c}$ | 70.6±2.51$^{a}$ | 19.3±3.21$^{c,d}$ | 34.0±3.61$^{a}$ | 70.0±3.00$^{a}$ | 2.4±0.78$^{a,b}$ | 7.2±0.83$^{a}$ | 1.97±0.44$^{a}$ |
| 100 | 59.0±4.00$^{c,d}$ | 71.6±2.51$^{a}$ | 18.3±5.77$^{c,d}$ | 26.0±1.73$^{b}$ | 62.0±3.41$^{a,b}$ | 2.2±0.09$^{a,b}$ | 5.6±1.74$^{a,b}$ | 1.87±0.07$^{a}$ |
| 150 | 25.0±4.35$^{f}$ | 36.0±2.64$^{c}$ | 50.3±4.50$^{a}$ | 12.3±0.58$^{c}$ | 26.6±2.31$^{c}$ | 1.0±0.19$^{c}$ | 2.1±0.33$^{b,c}$ | 2.04±0.41$^{a}$ |
| 200 | 20.0±3.00$^{f}$ | 35.6±3.78$^{c}$ | 40.3±5.50$^{a,b}$ | 12.0±0.00$^{c}$ | 25.0±3.91$^{c}$ | 0.7±0.25$^{c}$ | 1.8±0.83$^{c}$ | 2.80±0.93$^{a}$ |

GE – germination energy; G – germination percentage; A – atypical seedlings; SL – shoot length; RL – root length; SER – shoot elongation rate; RER – root elongation rate; R/S – root/shoot ratio.




RL 6 – root length measured on the sixth day; RL 10 – root length measured on the tenth day; SL 6 – shoot length measured on the sixth day; SL 10 – shoot length measured on the tenth day.

Figure 1. The root length of *Camelina* genotypes under different NaCl concentrations.




RL 6 – root length measured on the sixth day; RL 10 – root length measured on the tenth day; SL 6 – shoot length measured on the sixth day; SL 10 – shoot length measured on the tenth day.

Figure 2. The root length of *Carthamus* genotypes under different NaCl concentrations.

Based on the individual parameters of all four genotypes investigated in our study, it would be possible to predict the pattern of plant behavior in certain stages of development, which could be reflected in the yield later. Moreover, mathematical equations can precisely evaluate plant tolerance by correlating the obtained data of selected parameters of plants under non-stress and stress conditions (Jamshidi and Javanmard, 2018). To clarify the salinity tolerance mechanisms, Zuffo et al. (2020) suggested that identifying genotypes tolerant to salinity based on a single parameter or index may be ineffective. Therefore, in our study, the measured parameters were calculated as stress tolerance indexes. The stress tolerance indexes are among the most valuable tools for evaluating the plant response under stress (Živčak et al., 2008). To our knowledge, this is the first study where salt stress indexes were calculated for *Camelina* and *Carthamus*. In this way, all calculated parameters were considered, making one complex representing the plant as a whole during germination and early growth. All tolerance indexes are presented in Figure 3 for the *Camelina* genotypes and in Figure 4 for the *Carthamus* genotypes.

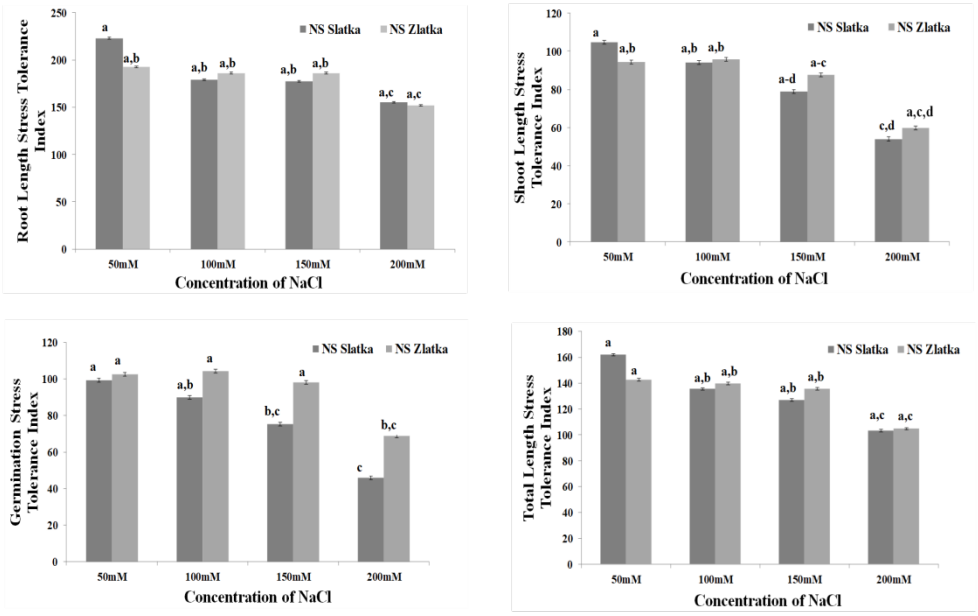



Figure 3. Stress tolerance indexes of *Camelina* genotypes.

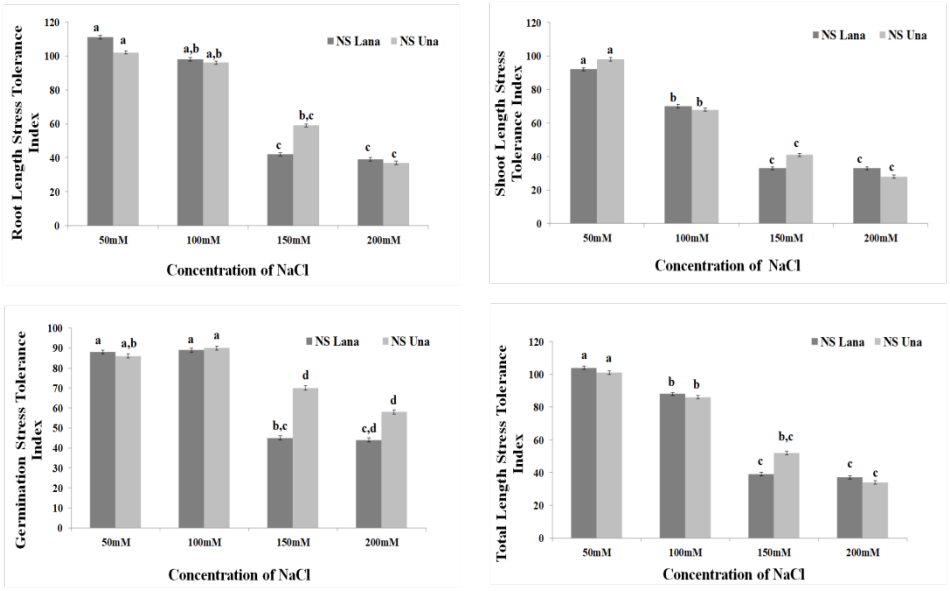



Figure 4. Stress tolerance indexes of *Carthamus* varieties.

The GSTI for *Camelina* ranged from 45 to 104%, and for *Carthamus* from 44 to 90%. The four groups were differentiated, and 'NS Slatka' and 'NS Una' had the highest tolerance indexes. The SLSTI of *Camelina* ranged from 54 to 104%, allowing differentiation into four groups, while *Carthamus* ranged from 28 to 98%, allowing differentiation into three groups. Among the genotypes, 'NS Slatka' and 'NS Una' had the highest SLSTI. Then, RLSTI ranged from 152 to 222% and from 37 to 111% for *Camelina* and *Carthamus*, respectively. The three groups were differentiated, and 'NS Slatka' and 'NS Lana' showed the highest RLSTI. When observing the TLSTI of the genotypes, the highest tolerance was detected for 'NS Slatka' and 'NS Lana' under 50 mM salinity treatment. On the other hand, the lowest TLSTI was observed in 'NS Slatka' and 'NS Una' under 200 mM salinity treatment. The obtained results indicate the difference in the tolerance to salt stress between these two plant species and between the examined genotypes. These differences occur due to various mechanisms of adaptation to a stressful environment, such as insufficient water osmotic pressure and the toxic effect of salt ions (Zuffo et al., 2020).

## Conclusion

In the present study, a significant variation in salt tolerance was observed among all tested genotypes. The salt stress differentiates all genotypes by affecting germination energy, germination percentage, root length, shoot length, root elongation rate, and shoot elongation rate. The critical value of salt stress was 150 mM, except for 'NS Zlatka' – 200 mM NaCl, where there was a significant reduction in germination, indicating the tolerance of these species to salt stress. Moreover, seeds of all tested genotypes can be expected to germinate at 200 mM NaCl in laboratory-controlled conditions. The reduced shoot length and the elongated roots represent morphological adaptations to salinity, which can be more expected in *Camelina* genotypes. Salt stress tolerance indexes showed the importance of converting the plant parameters into mathematical indexes, and the significance of comparing all the tolerance indexes according to salt stress. Consequently, the salt stress tolerance indexes defined in this experiment might be a useful tool in selecting plant genotypes for cultivation in saline areas.

## Acknowledgments

This research was financially supported by the Ministry of Education, Science and Technological Development, Republic of Serbia (Project No. 451–03–68/2022–14/200032) and by the Provincial Secretariat for Higher Education and Scientific Research of APV Vojvodina (Project No. 142-451-2609/2021-01/02). It was conducted as a part of activities of the Center of Excellence for Innovations in Breeding of Climate Resilient Crops—Climate Crops, Institute of Field and Vegetable Crops, Novi Sad, Serbia.

## References

Agathokleous, E., Belz, R.G., Kitao, M., Koike, T., & Calabrese, E.J. (2019). Does the root to shoot ratio show a hormetic response to stress? An ecological and environmental perspective. *Journal of Forestry Research*, *30* (5), 1569-1580.

Almodares, A., Hadi, M.R., & Dosti, B. (2007). Effects of salt stress on germination percentage and seedling growth in sweet sorghum cultivars. *Journal of Biological Sciences, 7* (8), 1492-1495.

Ashraf, M.Y., Ashraf, M., Mahmood, K., Akhter, J., Hussain, F., & Arshad, M. (2010). Phytoremediation of saline soils for sustainable agricultural productivity. In M. Ashraf., M. Ozturk & M.S.A. Ahmad (Eds.), *Plant adaptation and phytoremediation*, *Chapter 15*, (pp. 335-355). Dordrecht: Springer.

Ashri, A., Zimmer, D.E., Urie, A.L., Cahaner, A., & Marani, A. (1974). Evaluation of the World Collection of Safflower, Carthamus tinctorius L. IV. Yield and Yield Components and Their Relationships 1. *Crop Science*, *14* (6), 799-802.

Bandehagh, A., & Taylor, N.L. (2020). Can alternative metabolic pathways and shunts overcome salinity induced inhibition of central carbon metabolism in crops? *Frontiers in Plant Science*, *11*, 1072.

Channaoui, S., El Idrissi, I.S., Mazouz, H., & Nabloussi, A. (2019). Reaction of some rapeseed (*Brassica napus* L.) genotypes to different drought stress levels during germination and seedling growth stages. *Oilseeds and fats, crops and lipids*, 26, 23.

Corwin, D.L. (2021). Climate change impacts on soil salinity in agricultural areas. *Euopean Journal of Soil Sci*ence *72* (2), 842-862.

Demiral, T., & Türkan, I. (2005). Comparative lipid peroxidation, antioxidant defense systems and proline content in roots of two rice cultivars differing in salt tolerance. *Enviromental and Experimental Botany, 53* (3), 247-257.

Ekin, Z. (2005). Resurgence of safflower (*Carthamus tinctorius* L.) utilization: *A global view. Journal of Agronomy, 4* (2), 83-87.

FAO and ITPS (2015). Status of the World's Soil Resources (SWSR)—Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

FAOSTAT (2020). Statistical Database. Food and Agriculture Organization of the United Nations, Rome.

Ghorashy, S.R., Sionit, N., & Kheradnam, M. (1972). Salt tolerance of safflower varieties (*Carthamus tinctorius* L.) during germination. *Agronomy Journal*, *64*, 256-257.

Hamdy, A., Abdul-Dayem, S., & Abu-Zeid, M. (1993). Saline water management for optimum crop production. *Agricultural Water Management, 24*, 189-203.

Hanslin, H.M., & Eggen, T. (2005). Salinity tolerance during germination of seashore halophytes and salt-tolerant grass cultivars. *Seed Science Research, 15* (1), 43-50.

Hasegawa, P.M., Bressan, R.A., Zhu, J.K., & Bohnert, H.J. (2000). Plant cellular and molecular responses to high salinity. *Annual Review of Plant Biology, 51* (1), 463-499.

Hosseini, M.K., Powell, A.A., & Bingham, I.J. (2002). Comparison of the seed germination and early seedling growth of soybean in saline conditions. *Seed Science Research, 12* (3), 165-172.

Jamshidi, A., & Javanmard, H.R. (2018). Evaluation of barley (*Hordeum vulgare* L.) genotypes for salinity tolerance under field conditions using the stress indices. *Ain Shams Engineering Journal, 9* (4), 2093-2099.

Jovičić, D., Nikolić, Z., Zorić, M., Marjanović-Jeromela, A., Petrović, G., Milošević, D., & Ignjatov, M. (2014). Viability of oilseed rape (*Brassica napus* L.) seeds under salt stress. *Genetika-Belgrade, 46* (1), 137-148.

Julkowska, M.M., & Testerink, C. (2015). Tuning plant signaling and growth to survive salt. *Trends in Plant Science, 20* (9), 586-594.

Kage, H., Kochler, M., & Stützel, H. (2004). Root growth and dry matter partitioning of cauliflower under drought stress conditions: measurement and simulation. *European Journal of Agronomy, 20* (4), 379-394.

Kumar, A. (2017). Germination behaviour of soybean varieties under different salinity stress. *International Journal of Applied Agriculture Research, 12*, 69-76.

Li, Q., Yang, A., & Zhang, W.H. (2019). Higher endogenous bioactive gibberellins and α-amylase activity confer greater tolerance of rice seed germination to saline-alkaline stress. *Environmental and Experimental Botany. 162,* 357-363.

Matthees, H.L., Thom, M.D., Gesch, R.W., & Forcella, F. (2018). Salinity tolerance of germinating alternative oilseeds. *Industrial Crops Products, 113*, 358-367.

Mostafavi, K. (2011). An evaluation of safflower genotypes (*Carthamus tinctorius* L.), seed germination and seedling characters in salt stress conditions. *African Journal of Agricultural Research, 6* (7), 1667-1672.

Mohammed, M.E., Benbella, M., & Talouizete, A. (2002). Effect of sodium chloride on sunflower (*Helianthus annuus* L.) seed germination. *Helia, 25* (37), 51-58.

Mukhopadhyay, R., Sarkar, B., Jat, H.S., Sharma, P.C., & Bolan, N.S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management, 280*, 111736.

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

Partheeban, C., Chandrasekhar, C.N., Jeyakumar, P., Ravikesavan, R., & Gnanam, R. (2017). Effect of PEG induced drought stress on seed germination and seedling characters of maize (Zea mays L.) genotypes. *International Journal of Current Microbiology and Applied Sciences*, *6* (5), 1095-1104.

Shahid, S.A., Zaman, M., & Heng, L. (2018). M. Zaman, S.A. Shahid & L. Heng (Eds.), *Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques, Chapter 2*: *Soil salinity: historical perspectives and a world overview of the problem*. (pp. 43-53). Edinburgh: Springer, Cham.

Sun, F., Zhang, W., Hu, H., Li, B., Wang, Y., Zhao, Y., & Li, X. (2008). Salt modulates gravity signaling pathway to regulate growth direction of primary roots in Arabidopsis. *Plant physiology, 146* (1), 178-188.

Shrivastava, P., & Kumar, R. (2015). Soil salinity: A serious environmental issue, and plant growth promoting bacteria as one of the tools for its alleviation. *Saudi Journal of Biological Sciences, 22* (2), 123-131.

Singh, A. (2022). Soil salinity: A global threat to sustainable development. *Soil Use and Management, 38* (1), 39-67.

Singh, V., & Nimbkar, N. (2006). R.J. Singh (Ed.), Genetic Resources Chromossome Engineering, and Crop Improvement: Oil Crops, *Chapter 6*: Safflower (*Carthamus tinctorius* L.). (pp. 168-194). New York: CRC Press.

Soheilikhah, Z., Ghasmpour, H.R., & Zebarjadi, A. (2011). Effect of salinity stress on germination and early seedling growth of different safflower (*Carthamus tinctorius* L.) genotypes. *Journal of Ecobiotechnology,* FAO.

Wang, W.B., Kim, Y.H., Lee, H.S., Kim, K.Y., Deng, X.P., & Kwak, S.S. (2009). Analysis of antioxidant enzyme activity during germination of alfalfa under salt and drought stresses. *Plant Physiology and Biochemistr, 47* (7), 570-577.

Zuffo, A.M., Steiner, F., Aguilera, J.G., Teodoro, P.E., Teodoro, L.P.R., & Busch, A. (2020). Multi-trait stability index: A tool for simultaneous selection of soya bean genotypes in drought and saline stress. *Journal of Agronomy and Crop Science, 206* (6), 815-822.

Živčák, M., Brestič, M., Olšovská, K., & Slamka, P. (2008). Performance index as a sensitive indicator of water stress in *Triticum aestivum* L. *Plant Soil and Environment, 54* (4), 133-139.

Received: January 12, 2023
Accepted: April 27, 2023

# UPOREDNI PREGLED UTICAJA STRESA SALINITETA TOKOM KLIJANJA *CAMELINA SATIVA* I *CARTHAMUS TINCTORIUS*

**Teodora N. Kukrić[1*], Ana M. Marjanović Jeromela[2], Zorica T. Nikolić[2] i Dušica D. Jovičić[2]**

[1]Univerzitet u Novom Sadu, Poljoprivredni fakultet,
Trg Dositeja Obradovića 1, 21000 Novi Sad, Srbija
[2]Institut za ratarstvo i povrtarstvo Novi Sad,
Maksima Gorkog 30, 21000 Novi Sad, Srbija

R e z i m e

Zaslanjenost zemljišta kao jedan od najznačajnijih problema u svetu dovodi do smanjene poljoprivredne proizvodnje i smanjenja biodiverziteta. Najčešće zastupljena so u zemljištu i vodi je NaCl koja direktno utiče na rast biljaka i degradaciju zemljišta. Zbog navedenog problema, tokom ovog rada, ispitane su agronomske karakteristike dva genotipa *Camelina sativa* („NS Slatka"; „NS Zlatka") i dva genotipa *Carthamus tinctorius* („NS Lana"; „NS Una"), koje ih potencijalno izdvajaju kao tolerantne useve na soni stres. Ispitano je pet tretmana NaCl od 0 mM do 200 mM. Na osnovu dobijenih rezultata seme svih ispitivanih genotipova je klijalo pri najvećem tretmanu (200 mM NaCl), međutim pri svim tretmanima zaslanjenosti procenat klijanja se smanjio. Takođe, došlo je do produžavanja korena i smanjenja dužine izdanka klijanaca kod svih ispitivanih genotipova. Korišćeni indeksi tolerancije na soni stres su pokazali značajnost preračunavanja dobijenih biljnih parametara preko matematičkih indeksa, kao i značajnost uporednog pregleda svih indeksa tolerancije na soni stres.

**Ključne reči:** NaCl, zaslanjenost, indeksi tolerancije.

Primljeno: 12. januara 2023.
Odobreno: 27. aprila 2023.

[*]Autor za kontakt: e-mail: teodora.kukric@polj.uns.ac.rs