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THE EFFECTS OF SEAWEED APPLICATIONS ON THE GERMINATION RATE AND SPEED OF CARROT (*Daucus Carota* Var. *Sativus*) SEEDS UNDER SALT STRESS

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Abstract: In this study, the effects of commercial seaweed extract (Maxicrop®) applications on germination percentage, germination index, and germination time of carrot seeds were investigated under different salt concentrations in laboratory conditions using Petri dishes. The experiments were conducted with 16 different combinations of 4 salt doses (T1: 0 mM, T2: 50 mM, T3: 100 mM, T4: 150 mM) and 4 seaweed extract doses (D1: 0, D2: 1:250, D3: 1:500, D4: 1:1000) in three replicates. According to the results, seaweed extract applications increased germination percentage and shortened germination time. The highest germination percentage was observed in the combinations T2D4 (45.18%) and T2D1 (45.00%), while the lowest was in T4D1 (36.61%). The germination index reached its highest value in the T1D1 (20.80) combination, while the lowest was recorded in T4D1 (7.42). In terms of germination time, the shortest time was observed in T1D1 (1.50 days), and the longest in T4D1 (3.70 days). Increased salt concentration negatively affected germination performance, whereas seaweed extract partially alleviated these effects. It was determined that seaweed applications supported seed metabolism and improved germination under stress conditions through an osmotic priming effect. These findings highlight the positive effects of seaweed-based products on seed germination and support their potential use in agricultural practices.

Keywords: Seaweed extract, Carrot, Germination time, Germination percentage

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1. Introduction

Climate change and the world's growing population have exacerbated a number of environmental stress factors that endanger agricultural output. Many plants ideal growing circumstances are upset by abiotic stressors such as high temperatures, droughts, and salinities, which result in large losses in agricultural output (Bray et al., 2000; Rockström and Falkenmark, 2000). Salinity is regarded as one of the most important stressors for agricultural land's sustainability (Altun and Arslan, 2022).

Due to uncontrolled fertilization and irrigation practices, salt problems currently affect about 23% of agricultural lands and 33% of irrigated regions. This percentage is rising quickly. By the mid-twenty-first century, it is projected that 50% of agricultural fields worldwide will face saline stress (Zaman et al., 2018). Salinity restricts plant growth and productivity by negatively influencing basic physiological functions such as seed germination, vegetative growth, and reproductive development (Bolton, 2019).

Plant development is particularly vulnerable to environmental stress during seed germination and early seedling growth (Jones, 1986). By limiting water intake through osmotic potential and negatively impacting embryo viability through ion toxicity, salinity inhibits seed germination (Kaymakanova, 2009). When salt builds up in soil water, the osmotic potential is reduced, which prevents seeds from absorbing water. Furthermore, dry seeds cannot absorb water due to high environmental salt concentrations, specifically sodium (Na^+) and chloride (Cl^-) ions (Uçarlı, 2020). One of the most notable effects of salinity on seed germination is its ability to slow germination rates and, at higher levels, reduce the percentage of germination. At lower concentrations, only the germination rate is affected, with no significant impact on the total percentage of germinated seeds (Shannon and Grieve, 1999). Therefore, studies aimed at understanding plant tolerance to salinity stress are critical for achieving agricultural sustainability.

The Apiaceae family includes the widely grown and extensively consumed carrot (*Daucus carota* L.), a cool-season vegetable (Rubatzky et al., 1999). In terms of market value and area under cultivation, carrots are one of the most commercially important vegetables in the world. Because of their high α- and β-carotene content, which is transformed into retinol (vitamin A), carrots are

an essential source of nutrients for immune system support and eye health (Klimek-Chodacka et al., 2015). One of the vegetables most susceptible to salinity is the cultivated carrot (*Daucus carota* var. *sativus*) (Bernstein and Ayers, 1953; Mann et al., 1961). Carrots' ability to withstand salt during the germination stage has not been thoroughly studied up to this point (Schmidhalter and Oertli, 1991; Kahouli et al., 2014).

Vegetable seeds are often subjected to various pre-sowing treatments to ensure optimal germination and emergence under adverse conditions. One such treatment involves soaking seeds in natural osmotic solutions like seaweed extracts (Demirkaya, 2010). According to Shukla et al. (2018), seaweed extracts have several positive impacts, such as better seed germination, greater plant output, improved tolerance to biotic and abiotic stressors, and longer post-harvest seed shelf life. Numerous bioactive substances, including betaines, cytokinins, and auxins, are found in seaweed (Zhang and Ervin, 2008). Therefore, this study aimed to investigate the effects of seaweed extract, an organic material, on seed germination in carrots under saline conditions.

2. Materials and Methods

This study was carried out in the Department of Horticulture laboratory at the Faculty of Agriculture, Sakarya University of Applied Sciences, in 2024. The plant material used in the study was the Nantes Scarlet carrot (*Daucus carota* var*. sativus*) variety, sourced from Bursa Seed Industry Interventional studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

2.1. Seed Sterilization and Experimental Design

The carrot seeds used in the trials were sterilized by soaking them in a 1% sodium hypochlorite (NaOCl) solution for 5 minutes, followed by rinsing with sterile distilled water to complete the sterilization process. After sterilization, a stock solution of the commercial seaweed extract Maxicrop (*Ascophyllum nodosum*) (Maxicrop USA Inc.) containing plant growth-promoting substances such as cytokinins, auxins, enzymes, amino acids, trace elements, and nutrients (pH: 7.33, EC: 0.75 mS, N: 0.75%, P_2O_5: 0.05%, K_2O: 19.28%) was prepared by dissolving 10 g of the extract in 100 ml of distilled water at a 1:10 ratio. The stock solution was diluted further to prepare solutions with concentrations of 1:250, 1:500, and 1:1000. Seeds were soaked in these prepared solutions at 25±2 °C for 24 hours.

For germination trials, two layers of filter paper were placed in each Petri dish, and 50 carrot seeds were evenly distributed on the paper. Four different salt concentrations (T1:0 mM, T2:50 mM, T3: 75 mM, and T4:100 mM NaCl) were prepared, and 5 ml of the respective solution was added to each Petri dish based on the treatments. The trials were conducted using 16 different combinations of four salt concentrations and four seaweed extract dilutions (D1: 0, D2: 1:250, D3: 1:500, D4: 1:1000) in a completely randomized design with three replicates per treatment (Table 1). The prepared Petri dishes were kept in germination cabinets at 25±2 °C for 10 days (ISTA, 1996).

Table 1. Combinations of salt dose and seaweed extract dose used in the experiments

T1*D1	T2*D1	T3*D1	T4*D1
T1*D2	T2*D2	T3*D2	T4*D2
T1*D3	T2*D3	T3*D3	T4*D3
T1*D4	T2*D4	T3*D4	T4*D4

Each Petri plate was lined with two layers of filter paper, and then 50 seeds were added. NaCl solutions with concentrations of 0 mM, 50 mM, 75 mM, and 100 mM were made for the salt treatments, and 5 ml of each solution was added to each Petri dish in accordance with the treatments.

The Petri dishes were checked every 24 hours, and the number of germinated seeds was counted. The counting continued until the 10th day. The germinated seeds were removed from the environment for counting, and the data was recorded.

2.2. Evaluated Traits and Calculations

Germination Rate (%): The number of germinated seeds was counted on the 10th day, and the germination rate was calculated using the following formula:

Germination Rate (%)=(Number of Germinated Seeds /Total Number of Seeds)×100 (Yıldırım and Güvenç, 2005).

Germination Index (GI): The daily number of germinated seeds (Gi) was divided by the corresponding day number (Tt), and the total of these values was calculated:

$GI = \Sigma(Gi / Tt)$ (Wang et al., 2004).

Mean Germination Time (MGT): The sum of the products of the number of germinated seeds (f) and the corresponding days (x) was divided by the total number of germinated seeds:

$MGT = \Sigma(fx) / \Sigma f$ (Ellis and Roberts,1980).

2.3. Statistical Analysis

The research data were analyzed using the *JUMP* 13 software program (SAS Institute, Cary, NC, USA). Parameters such as germination rate, germination index, and mean germination time were evaluated using two-way analysis of variance (Two-Way ANOVA). The statistical significance of factors and their interactions was examined at a 5% significance level. LSMeans Differences the Tukey HSD test was used for comparison (SAS Institute, Cary, NC, USA). In the analyses of germination percentages, arc Sin p 1/2 angular transformation values were used.

3. Results

The results of the germination trials, including the effects of seaweed extract applications on carrot seed germination rates under different salt concentrations, are presented in table 2. Germination rates were generally highest on the first day. The average germination rate across all treatments was around 10–11 seeds, indicating that the seeds quickly absorbed water and began germinating. The control group (0 mM NaCl) and the 1:500 seaweed extract application showed the highest germination rates on the first day. As the days progressed, germination rates decreased across all treatments. Notably, after the fourth day, a significant decline in germination rates was observed, indicating that most of the germination occurred within the first few days.

Table 2. Effects of seaweed applications under saline conditions on germination percentage, index, and duration of nantes scarlet carrot variety

	Treatments	Germination Percentage	Germination Index	Germination Duration
	Saline Applications			
	T1	43.17 a	18.62 a	18.62 a
	T2	43.00 a	16.66 b	16.66 b
	T3	42.65 a	16.27 b	16.27 b
	T4	39.07 a	11.04 c	11.04 c
	Seaweed Applications			
	D1	41.61 a	13.97 b	16.11 a
	D2	41.05 a	16.11 a	13.97 b
	D3	42.28 a	16.18 a	16.18 a
	D4	42.95 a	16.33 a	16.33 a
	T X D (Interactions)			
T1	D1	43.46 ab	20.80 a	1.50 g
T1	D2	43.23 ab	17.00 abcde	1.72 efg
T1	D3	42.68 ab	17.70 abcd	1.62 fg
T1	D4	43.30 a	18.98 ab	1.87 defg
T2	D1	45.00 ab	18.66 abc	2.23 cde
T2	D2	40.37 ab	13.89 def	2.13 cdef
T2	D3	40.05 ab	14.92 bcde	1.92 cdefg
T2	D4	45.18 ab	19.18 ab	1.82 defg
T3	D1	41.38 ab	17.55 abcd	1.91 cdefg
T3	D2	43.46 ab	15.27 bcde	2.0 cdefg
T3	D3	44.72 ab	18.07 abcd	1.96 cdefg
T3	D4	42.43 ab	14.21 cdef	2.35 bcd
T4	D1	36.61 b	7.42 g	3.70 a
T4	D2	37.13 ab	9.74 fg	2.80 b
T4	D3	41.66 ab	14.05 def	2.43 bc
T4	D4	40.87 ab	12.95 ef	2.43 bc
	Significance			
	Salt doses	0.1793	<.0001*	<0.0001*
	Seaweed extract	0.8174	0.0014*	0.0823
	T X D (Interactions)	0.8354	<0.0001*	0.0036*

T1= 0, T2= 50, T3= 75, T4= 100 Mm NaCl; D1= 0, D2= 1:250, D3= 1:500, D4= 1:1000 seaweed applications

Statistical differences were found for the germination index and germination time of carrot seeds under different salt concentrations (Table 2). As salt concentration increased, the germination index decreased significantly. The germination index in T1 was 18.62, while it dropped to 11.04 in T4. Similarly, germination time increased as salt concentration increased. The value in T1 was 18.62, while it was 11.04 in T4. The salt doses did not have a statistically significant effect on germination percentage; however, as salt concentration increased, germination percentage decreased (Table 2).

Regarding the effect of seaweed extract on carrot seed germination, statistical differences were found for both the germination index and germination time (Table 2). Seaweed extract did not have a statistically significant effect on the germination percentage. When examining the effect on the germination index, the D1 treatment (13.97) showed a slightly lower index compared to other treatments. There were no significant differences between D2, D3, and D4 treatments. The germination time was shorter in D2 (13.97) compared to other

treatments, where it ranged between 16.11 and 16.33 days. The D2 treatment shortened the germination time, allowing the seeds to germinate faster than other treatments.

When evaluating the interaction between different salt concentrations and seaweed extract applications (T*D), the highest germination percentage was observed in the T2D4 (45.18%) and T2D1 (45.00%) combinations. The lowest germination percentage was observed in the T4D1 (36.61%) combination. The highest germination index was measured in the T1D1 (20.80) combination, while the lowest germination index was found in the T4D1 (7.42) combination. As salt concentration increased (T4), the germination index showed a significant decline. However, seaweed extract applications, especially in the T1 and T2 groups, maintained a high index. The shortest germination time was observed in the T1D1 (1.50 days) combination, demonstrating the positive effects of both low salt concentration and seaweed extract. The longest germination time was found in the T4D1 (3.70 days) combination, highlighting the negative impact of high salt concentration (Table 2).

4. Discussion and Conclusion

Ensuring tolerance to external challenges at the crucial initial stage of plant development, seed germination, is essential. In this study, applying seaweed extract to carrot seeds considerably boosted their rate and speed of germination in saline circumstances as compared to the control, and it also lessened the adverse effects of salinity stress. The treatments with seaweed extract worked very well at moderate dosage (1:250 and 1:500). Although there was an early favorable effect at lower doses (1:1000), no discernible contribution was noted in the days that followed (Table 2).

Osmotic conditioning with seaweed extract has been reported in several studies to increase germination rate and shorten germination time (Sivritepe, 2000; Yıldırım and Güvenç, 2005; Demirkaya, 2010). The natural growth regulators (such as hormonal compounds, amino acids, and micronutrients) and antioxidant properties contained in seaweed extracts can support seed metabolism, improving germination even under stress conditions (Demirkaya, 2010). The shorter the average germination time for a group of seeds, the higher the germination potential of that seed group. As the average germination time increases, the seed group's strength decreases. Osmotic conditioning with seaweed extract reduced both germination time and enhanced germination in carrot seeds.

Möller and Smith (1998) found that applying seaweed extract to lettuce seeds for 24 hours positively affected germination under both normal and high temperatures. In other study on leeks, Yıldırım and Güvenç (2005) observed that 1:250 and 1:500 seaweed extract concentrations significantly improved both germination rate and germination index compared to other treatments. A study conducted by Demirkaya (2010) demonstrated that osmotic conditioning with seaweed extract increased the germination rate and reduced average germination time in pepper and onion seeds.

Based on the results of this study, it is recommended to soak carrot seeds in seaweed extract or water for 24 hours before planting to enhance germination rate and speed under both salt stress and normal conditions. Given that osmotic conditioning with seaweed extract is an organic, environmentally friendly substance that does not cause pollution, its use is recommended to minimize the reliance on chemicals.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	N.K.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

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