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Determination of germination and seedling characteristics of common grasspea (*Lathyrus sativus* L.) genotypes under salt stress

Yaygın mürdümük (*Lathyrus sativus* L.) genotiplerinin tuz stresi altında çimlenme ve fide özelliklerinin belirlenmesi

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ABSTRACT

Objective: In this study, the aim was to determine the germination and seedling development responses of common grasspea (*Lathyrus sativus* L.) genotypes under salt stress and to identify genotypes sensitive or tolerant to salinity.

Materials and Methods: The research was conducted at the Field Crops Laboratory of the Faculty of Agriculture, Siirt University, under controlled conditions at 25±1°C. The plant material of the study consists of 2 cultivars and 8 genotypes. The study investigated the doses of NaCl at 0, 50, 100, 150, and 200 mM. The laboratory experiment was conducted by a completely randomized factorial design with four replications.

Results: The increase in salt levels significantly ($p<0.01$) affected the germination and seedling characteristics of grasspea genotypes. It was determined that common grasspea genotypes were significantly affected by increasing salt concentrations with regard to germination parameters starting from the 50 mM salt dose. Regarding seedling parameters, grasspea genotypes were affected by salt concentrations beyond 50 mM in relation to seedling length and seedling dry weight, while other seedling parameters were negatively impacted even at the lowest salt dose.

Conclusion: When all examined parameters were considered together, the Sel 668 genotype stood out for its tolerance to salinity and its performance in germination and seedling development.

Keywords: Germination percentage, grasspea, salinity, seedling length, seedling vigor index

ÖZ

Amaç: Bu çalışmada, yaygın mürdümük (*Lathyrus sativus* L.) genotiplerinin tuz stresi altında çimlenme ve fide gelişim tepkilerinin belirlenmesi ve tuzluluğa hassas ya da tolerant genotiplerin ortaya konulması amaçlanmıştır.

Materyal ve Yöntem: Araştırma, Siirt Üniversitesi, Ziraat Fakültesi, Tarla Bitkileri Laboratuvarı'nda, 25±1°C kontrollü şartlar altında yürütülmüştür. Çalışmanın bitkisel materyali 2 çeşit ve 8 genotipten oluşmaktadır. Çalışmada; tuzun (NaCl) 0, 50, 100, 150 ve 200 mM dozları araştırmanın konusunu teşkil etmiştir. Laboratuvar deneyi tesadüf parsellerinde faktöriyel deneme desenine göre 4 tekrarlamalı olarak yürütülmüştür.

Araştırma Bulguları: Tuz seviyesindeki artış, mürdümük genotiplerinin çimlenme ve fide özelliklerini çok önemli ($p<0.01$) derecede etkilemiştir. Yaygın mürdümük genotiplerinin artan tuz konsantrasyonlarına bağlı olarak çimlenme parametreleri açısından 50 mM tuz dozundan itibaren anlamlı olarak etkilediği belirlenmiştir. Fide parametrelerinde ise fide uzunluğu ve fide kuru ağırlığı bakımından 50 mM tuz konsantrasyonundan sonra mürdümük genotipleri etkilenirken, diğer fide parametrelerinin ise kontrolden itibaren en düşük tuz dozunda bile olumsuz yönde etkilendiği belirlenmiştir.

Sonuç: Tüm incelenen parametreler birlikte değerlendirildiğinde ise Sel 668 genotipi tuzluluğu dayanıklılığı ve çimlenme ve fide gelişimi açısından ön plana çıkmıştır.

Anahtar sözcükler: Çimlenme yüzdesi, mürdümük, tuzluluk, fide uzunluğu, fide güç indeksi

INTRODUCTION

Common grasspea (*Lathyrus sativus* L.), which belongs to the Leguminosae family, is a annual legume species of significant economic importance, particularly in developing countries such as India, Bangladesh, Pakistan, Nepal, and Ethiopia, where it is used for both human and animal nutrition (Kumar & Tripathi, 2008; Ahmadi et al., 2015; Xu et al., 2018; Lambein et al., 2019). The grasspea plant is known for containing 65% carbohydrates and 18-34% protein on a dry weight basis, making it recognized as a protein source (Feyzi et al., 2018). It also contains significant amounts of minerals such as phosphorus, magnesium, and calcium (Arshad et al., 2023). Due to its abundant nutrient content and unique characteristics such as low water demand, grasspea is considered a wonderful option for sustainable food production, especially in coping with environmental challenges such as climate change, flooding, and pest diseases, and with the increasing demand for eco-friendly protein sources (Gonçalves et al., 2022).

Climate change and global warming are seen as triggers for significant problems such as drought and soil salinity (Özyazıcı & Açıkbaş, 2021). The stress conditions resulting from climate change affect agriculture differently depending on the regions and agricultural products (Anderson et al., 2020). One of the most significant stress factors that plants encounter throughout their life is salt stress (Omidi et al., 2022). Salinity, especially in arid and semi-arid regions, is one of the most determining environmental stress factors limiting crop productivity (Zörb et al., 2019). In addition to the provided information, salinity adversely affects soil microbial diversity, enzymatic activities, and consequently, carbon and nitrogen dynamics, as well as greenhouse gas emissions from the soil (Fagodiya et al., 2022). Salinity induces various physiological, morphological, and biochemical changes in plant growth and development, affecting processes such as photosynthesis, protein synthesis, lipid metabolism, and energy production (Parida & Das, 2005; Munns & Tester, 2008). Especially during seed germination and early seedling growth stages, which are critical stages for plant development, seed germination phase is the most sensitive period for plants to salinity (Acikbas et al., 2021).

It is important to detect genetic variations for identifying the genotypes that are most tolerant to salinity. Additionally, determining the response of plants to salinity during germination and seedling stages is crucial for achieving optimal yields in salinity-affected areas (Özyazıcı & Açıkbaş, 2021). Salt damage is not only depending on the growth stage, environmental factors, and the structure of salts but also significantly influenced by plant species and variety, as well as the amount of salt (Açıkbaş et al., 2023). In general, *L. sativus* is resilient to environmental stresses and can yield well even under adverse climatic conditions (Cocks et al., 2000). Moreover, it is highly tolerant to negative environmental factors such as periodic flooding, low temperatures, soil salinity, and most importantly, prolonged drought (Tokarz et al., 2020). One of the key ways to cope with this issue is through the cultivation of plants tolerant to salinity, especially considering that both our soils and irrigation waters are becoming increasingly saline due to the impact of global climate change.

The aim of this study is to determine the germination and seedling growth responses of common grasspea (*L. sativus* L.) genotypes under salt stress conditions and to identify sensitive or tolerant genotypes to salinity.

MATERIALS and METHODS

Materials

The research was conducted at the Field Crops Department Laboratory of Siirt University (Türkiye), Faculty of Agriculture (37°58'13.20"N - 41°50'43.80"E). In the study, a total of 10 common grasspea (*L. sativus* L.) genotypes, 8 lines (IFLS 349, IFLS 257, Sel 706, Sel 668, Sel 702, Sel 1794, ETH-24 and ETH WIR-70) obtained from ICARDA (International Center for Agricultural Research in the Dry Areas), and 2 cultivars (GAP Mavisi and Gürbüz-2001) bred in Türkiye, were used as plant material. Sodium chloride (NaCl) was used as the salt form.

Research Subject and Germination Experiment

Laboratory experiments were included ten different grasspea genotypes and five different concentrations (0- 50-100-150 and 200 mM) of salt (NaCl). They were established in randomized plots in factorial design with four replications. For each replication, 20 seeds were used. Seeds were surface sterilized with 70% ethanol for one minute and then rinsed three times with sterile water. Then, to remove the microorganisms on the seed surface, a subsequent step of surface sterilization was carried out by covering the seeds with a 10% sodium hypochlorite (NaOCl) + 0.01% tween20 solution for 10 minutes. The sterilized seeds were placed between two layers of Whatman No.2 filter paper in petri dishes (90 mm x 15 mm). Five ml of salt solutions were applied to each petri dish. Petri dishes were left to germinate in an incubator (BINDER, GmbH, Germany) setting at 25±2°C temperature. Until the end of the study, 5 ml of salt dose was added to the petri dishes according to the trial subjects for every 48 hours (according to the humidity levels of the seeds in the petri dishes).

Germination controls were applied for every 24 hours during the experiment and the germination test was completed on the 10th day. The observation of at least 2 mm radicle was the germination criterion of the seeds (Scott et al., 1984; Soleymani & Shahrajabian, 2018). Measurements were conducted on ten randomly selected seedlings in each petri dish, and on all germinated plants in petri dishes that did not contain adequate number of seedlings due to salt stress.

Germination and Seedling Growth Assessments

In the study, germination parameters such as germination percentage (GP), mean germination time (MGT), germination index (GI), coefficient of uniformity of germination (CUG), germination energy (GE), and seedling growth parameters such as seedling length (SL), seedling fresh weight (SFW), seedling dry weight (SDW) and seedling vigor index (SVI) were examined.

Equation 1 of Scott et al. (1984) was used for the determination of the GP parameter.

$$GP= (NGS/TS)x100 \quad (1)$$

In the equation, *NGS* is the number of normal germinated seeds, *TS* is the total number of utilized seeds.

Mean germination time is used to determine the germination day of seeds and was calculated by Equation 2 (Ellis & Roberts, 1981).

$$MGT= \Sigma (N_i T_i / N_i) \quad (2)$$

N_i is the number of seeds germinated on the T_i day; T_i refers to the number of days from the beginning of germination.

Germination index was calculated with the help of Equation 3 (Wang et al., 2004), CUG by Equation 4 (Bewely & Black, 1994), and GE by Equation 5 (Li et al., 2020).

$$GI= \Sigma (G_i/T_t) \quad (3)$$

G_i is the germination percentage at the i^{th} day, and T_t is the days of germination test duration.

$$CUG= \sum n / \sum[(MGT-t)^2 n] \quad (4)$$

t is the time in days starting from day 0, the day of sowing, and n is the number of seeds completing germination on day t.

$$(T_1/N) \times 100 \quad (5)$$

In the equation, T_1 represents the number of seeds germinated on the first day, and N represents the total number of seeds.

Seedling length (SL) (cm): At the end of the study, the lengths of seedling were scanned in color with a random selection using an Iscan Color Mini Portable Scanner with a resolution of 600 dpi. The SL parameter was precisely and meticulously measured using (Acikbas et al., 2021) the ImageJ image analysis software (Rueden et al., 2017).

Seedling fresh weight (SFW) and dry weight (SDW) (mg): The SFW was determined at the end of the study by weighing ten randomly selected seedlings from each Petri dish and calculating the average fresh weight of seedlings. Following that, the fresh seedlings were dried in an oven at 70 ºC for 48 hours to determine the average SDW.

Seedling vigor index (SVI): It was calculated using Equation 6 as reported by Kalsa & Abebie (2012).

$$SVI= GP\text{x}SDW \ \ \text{(gr)} \qquad (6)$$

Statistical Analysis

The obtained data were subjected to analysis of variance according to the completely randomized factorial design. The differences between the means were checked with the TUKEY's HSD multiple comparison test (Açıkgöz & Açıkgöz, 2001). The JMP Pro 14 software was used for statistical calculations.

RESULTS

The variance analysis results for the GP, MGT, CUG, GI, GE, SL, SFW, SDW, and SVI values of the grasspea genotypes considered in the study according to salt stress are presented in Table 1.

Table 1. The variance analysis of the parameters examined in the study

Çizelge 1. *Araştırmada incelenen parametrelerin varyans analizi*

Factors/Traits	TUKEY value/F probability								
	GP	MGT	CUG	GI	GE	SL	SFW	SDW	SVI
Genotypes (G)	7.57/**	0.63/ns	9.07/**	1.65/**	11.78/**	0.71/**	52.75/**	2.14/**	5.65/**
Salinity (S)	4.57/**	0.38/**	5.48/**	1.00/**	7.14/**	0.44/**	31.99/**	1.29/**	3.41/**
G x S	21.42/**	1.81/**	25.54/**	4.69/**	33.66/**	2.07/**	150.46/**	6.09/**	16.11/**

GP: Germination percentage, MGT: Mean germination time, CUG: Coefficient of uniformity of germination, GI: Germination index, GE: Germination energy, SL: Seedling length, SFW: Seedling fresh weight, SDW: Seedling dry weight and Seedling vigor index, **: p<0.01, ns: no significant difference.

The differences among genotypes for all parameters (except MGT) were found to be statistically significant at the p<0.01 level. Similarly, the differences among salinity levels and genotype × salinity interaction for all parameters were also found to be statistically significant at the p<0.01 level (Table 1).

As a result of the study, increasing salt concentrations were found to decrease germination rates; however, the difference between the control treatment (0 mM) and the 50 and 100 mM salt doses was statistically insignificant, significant decreases occurred from the 150 mM salt dose onwards. Accordingly, the highest germination rate, as the average of genotypes, was determined to be 99.0% and 98.5% in the control (0 mM) and 50 mM applications, respectively, while the lowest value was observed at the highest dose of salt, 200 mM salt concentration (43.2%). When the average results of grasspea genotypes were examined, the highest germination rate was found to be 92.0% in the Sel 668 genotype, on average across salt concentrations, and the difference between Sel 668 genotype and other genotypes except Sel 706, ETH WIR-70, and Gürbüz-2001 genotypes was statistically insignificant in terms of germination rate. The lowest germination rate was determined to be 77.7% on average across salt concentrations in the Gürbüz-2001 cultivar (Table 2).

In the study, it was observed that germination was more delayed with increasing salt concentrations than untreated ones. In this regard, germination occurred on average in 1.35 and 1.38 days in 0 and 50 mM environments, respectively, while in the 100 mM salt concentration, it took 2.19 days, and in 200 mM, the average germination time was 2.98 days (Table 2).

Table 2. Some germination parameters of grasspea genotypes at different salt concentrations

***Çizelge 2.** Mürdümük genotiplerinin farklı tuz konsantrasyonlarındaki bazı çimlenme parametreleri*

Genotypes	Salt concentration (mM, NaCl)					
	0 mM	50 mM	100 mM	150 mM	200 mM	Average
	Germination percentage (%)					
IFLS 349	100.0±0.0^{a}	100.0±0.0^{a}	96.7±2.9^{a}	85.0±18.0^{abc}	60.0±5.0^{de}	88.3^{AB}
IFLS 257	100.0±0.0^{a}	98.3±2.9^{a}	93.3±11.5^{a}	96.7±2.9^{a}	50.0±10.0^{def}	87.7^{AB}
GAP Mavisi	98.3±2.9^{a}	98.3±2.9^{a}	96.7±5.8^{a}	96.7±2.9^{a}	36.7±7.6^{f}	85.3^{ABC}
Gürbüz-2001	96.7±5.8^{a}	98.3±2.9^{a}	98.3±2.9^{a}	86.7±7.6^{ab}	8.3±2.9^{g}	77.7^{D}
Sel 706	100.0±0.0^{a}	98.3±2.9^{a}	96.7±2.9^{a}	96.7±2.9^{a}	10.0±5.0^{g}	80.3^{CD}
Sel 668	100.0±0.0^{a}	98.3±2.9^{a}	96.7±2.9^{a}	100.0±0.0^{a}	65.0±13.2^{cd}	92.0^{A}
Sel 702	98.3±2.9^{a}	98.3±2.9^{a}	96.7±2.9^{a}	95.0±5.0^{a}	55.0±13.2^{def}	88.7^{AB}
Sel 1794	100.0±0.0^{a}	96.7±5.8^{a}	91.7±7.6^{a}	95.0±5.0^{a}	66.7±2.9^{bcd}	90.0^{AB}
ETH-24	100.0±0.0^{a}	100.0±0.0^{a}	98.3±2.9^{a}	86.7±18.9^{ab}	43.3±12.6^{ef}	85.7^{ABC}
ETH WIR-70	96.7±5.8^{a}	96.7±2.9^{a}	96.7± 2.9^{a}	93.3±2.9^{a}	36.7±5.8^{f}	84.3^{BCD}
Average	99.0^{A}	98.5^{A}	96.2^{AB}	93.2^{B}	43.2^{C}	
	Mean germination time (day)					
IFLS 349	1.17±0.1^{e}	1.37±0.1^{cde}	2.51±0.7^{b-e}	2.77±0.6^{b-e}	3.11±0.6^{a-d}	2.18
IFLS 257	1.33±0.2^{de}	1.32±0.1^{de}	1.96±0.4^{b-e}	2.35±0.2^{b-e}	3.21±0.3^{ab}	2.03
GAP Mavisi	1.44±0.2^{b-e}	1.62±0.2^{b-e}	2.81±0.4^{b-e}	2.55±0.7^{b-e}	3.17±0.9^{abc}	2.32
Gürbüz-2001	1.64±0.3^{b-e}	1.59±0.2^{b-e}	2.27±0.2^{b-e}	2.52±0.1^{b-e}	2.17±0.3^{b-e}	2.04
Sel 706	1.22±0.0^{e}	1.39±0.1^{cde}	1.93±0.1^{b-e}	2.09±0.3^{b-e}	2.94±0.6^{b-e}	1.91
Sel 668	1.23±0.2^{e}	1.17±0.0^{e}	2.31±0.1^{b-e}	2.03±0.3^{b-e}	4.81±1.1^{a}	2.31
Sel 702	1.45±0.2^{b-e}	1.25±0.1^{e}	1.48±0.1^{b-e}	2.07±0.3^{b-e}	2.67±0.8^{b-e}	1.79
Sel 1794	1.23±0.2^{e}	1.25±0.2^{e}	1.69±0.4^{b-e}	2.32±0.3^{b-e}	3.12±0.3^{a-d}	1.92
ETH-24	1.20±0.1^{e}	1.42±0.2^{b-e}	2.74±0.3^{b-e}	2.34±0.5^{b-e}	2.14±0.4^{b-e}	1.97
ETH WIR-70	1.60±0.3^{b-e}	1.37±0.2^{cde}	2.25±0.4^{b-e}	2.31±0.4^{b-e}	2.50± 0.9^{b-e}	2.01
Average	1.35^{C}	1.38^{C}	2.19^{B}	2.34^{B}	2.98^{A}	
	Germination index					
IFLS 349	18.11±1.2^{a}	16.44±1.2^{ab}	9.83±2.3^{h-l}	7.53±1.6^{k-p}	4.73±0.2^{m-q}	11.33^{ABC}
IFLS 257	16.78±1.8^{a}	16.50±1.0^{ab}	11.67±2.4^{c-k}	9.77±1.2^{h-l}	3.79±0.7^{opq}	11.70^{ABC}
GAP Mavisi	15.73±1.1^{a-d}	13.97±0.8$^{a-ı}$	8.16±1.1^{k-o}	9.41±2.6$^{ı-m}$	3.17±0.7^{pq}	10.09^{C}
Gürbüz-2001	15.12±1.0^{a-f}	14.17±1.4^{a-h}	10.91±0.5^{e-k}	8.81±0.7^{j-n}	1.50±0.5^{q}	10.10^{C}
Sel 706	17.83±0.3^{a}	16.06±1.3^{abc}	11.81±1.0^{b-k}	11.56±1.5$_{c-k}$	1.39±1.2^{q}	11.73^{ABC}
Sel 668	17.78±2.1^{a}	18.11±0.7^{a}	9.64±0.9^{h-l}	11.69±1.7^{c-k}	4.47±0.8^{n-q}	12.34^{AB}
Sel 702	15.28±1.6^{a-e}	17.28±0.8^{a}	14.78±1.3^{a-g}	11.25±2.1^{d-k}	4.50±0.0^{n-q}	12.62^{AB}
Sel 1794	17.67±1.5^{a}	17.22±2.2^{a}	13.48±0.9^{a-j}	10.19±0.8^{g-l}	5.69±0.4^{l-q}	12.85^{A}
ETH-24	17.67±1.2^{a}	15.94±1.6^{a-d}	9.04±0.9^{j-n}	9.41±2.9$^{ı-m}$	4.53±1.1^{n-q}	11.32^{ABC}
ETH WIR-70	14.83±2.3^{a-g}	16.44±1.4^{ab}	10.44±1.7^{f-k}	9.53±1.7^{h-l}	3.56±0.7^{opq}	10.96^{BC}
Average	16.68^{A}	16.21^{A}	10.98^{B}	9.91^{C}	3.73^{D}	

Values within a group denoted by different letters are significantly different at $p \leq 0.01$.

Salinity significantly reduced the germination index, germination uniformity coefficient, and germination energy. Significant decreases in the mentioned germination parameters occurred from the 100 mM salt dose onwards, and differences between the 0 mM and 50 mM salt concentration treatments were found to be statistically insignificant. The highest values for germination index, germination uniformity coefficient, and germination energy were observed at these two salt concentrations (respectively, 16.68 and 16.21 for GI; 74.9 and 72.7 for CUG; 69.7 and 64.7 for GE). When differences among grasspea genotypes were examined, the Sel 1794 genotype stood out with the highest values for germination index and germination energy, while the Sel 668, Sel 702, and Sel 1794 genotypes excelled on germination uniformity coefficient. Generally, increasing salt concentration reduced the GI, CUG, and GE values in all genotypes compared to the control (0 mM) and 50 mM (Tables 2 & 3).

The highest seedling length values, as the average of genotypes, were determined in the control (0 mM) and 50 mM salt concentration treatments (9.22 cm each), while the lowest values were observed at the highest dose of salt (200 mM) (1.15 cm). Regarding seedling length, it was found that the Sel 702 genotype had the longest measurement at 7.33 cm. It was grouped with the IFLS 257 and Sel 668 genotypes for seedling length (Table 3).

Table 3. Some germination and seedling length values of grasspea genotypes at different salt concentrations

Çizelge 3. *Mürdümük genotiplerinin tuz konsantrasyonlarındaki bazı çimlenme ve fide uzunluğu değerleri*

Genotypes	Salt concentration (mM, NaCl)					
	0 mM	50 mM	100 mM	150 mM	200 mM	Average
	Coefficient of uniformity of germination					
IFLS 349	84.2±6.3^{a}	73.5±5.8^{a-d}	40.9±6.7^{g-p}	31.2±7.0^{k-s}	19.6±2.5^{n-s}	49.9^{ABC}
IFLS 257	75.9±10.3^{abc}	74.5±5.3^{a-d}	48.9±5.7^{d-k}	41.5±5.4^{g-o}	15.7±3.8^{o-s}	51.3^{AB}
GAP Mavisi	68.8±7.4^{a-f}	60.8±4.7$^{\text{a-ı}}$	34.9±6.2$^{\text{ı-r}}$	39.6±3.8^{h-q}	12.3±4.2^{rs}	43.3^{BC}
Gürbüz-2001	59.8±8.1^{a-j}	62.3±6.7^{a-h}	43.5±2.3^{f-n}	34.5±2.8^{j-r}	7.2±2.5^{s}	41.4^{C}
Sel 706	82.2±1.9^{a}	71.3± 5.9^{a-e}	50.3±4.6^{c-k}	46.8±3.0^{e-l}	6.3±2.2^{s}	51.4^{AB}
Sel 668	83.0±9.7^{a}	84.1±4.9^{a}	42.0±1.8^{g-n}	49.9±3.7^{d-k}	14.3±2.4^{qrs}	54.7^{A}
Sel 702	68.6±9.1^{a-f}	78.6± 4.6^{ab}	65.6±6.1^{a-g}	46.6±4.3^{e-m}	20.8±1.4^{m-s}	56.1^{A}
Sel 1794	81.9±9.8^{a}	78.7± 4.2^{ab}	55.6±5.9^{b-k}	41.0±2.2^{g-p}	21.5±1.2^{l-s}	55.7^{A}
ETH-24	82.1±7.7^{a}	71.3±8.8^{a-e}	36.1±3.2$^{\text{ı-r}}$	39.1±3.1^{h-q}	20.4±2.7^{n-s}	49.8^{ABC}
ETH WIR-70	62.3± 5.8^{a-h}	72.3± 9.9^{a-e}	44.1±2.4^{f-n}	41.1±6.3^{g-p}	15.5±2.3^{p-s}	47.1^{ABC}
Average	74.9^{A}	72.7^{A}	46.2^{B}	41.1^{B}	15.4^{C}	
	Germination energy					
IFLS 349	83.3±10.4^{a}	65.0±8.8^{abc}	15.0±2.7^{g-j}	5.3±1.3^{j}	6.7±2.9^{j}	35.1^{ABC}
IFLS 257	68.3±7.6^{abc}	66.7±7.6^{abc}	30.0±3.2^{d-j}	13.3±2.6$^{\text{hıj}}$	3.3±0.9^{j}	36.3^{ABC}
GAP Mavisi	60.0±8.7^{a-e}	43.3±7.6$^{\text{c-ı}}$	5.3±2.0^{j}	13.3±2.5$^{\text{hıj}}$	5.0±0.0^{j}	25.4^{C}
Gürbüz-2001	63.3±7.6^{a-d}	45.0±3.2^{b-h}	23.3±5.3^{f-j}	15.0±4.0^{g-j}	6.7±2.9^{j}	30.7^{BC}
Sel 706	78.3±2.9^{ab}	63.3±6.1^{a-d}	28.3±5.8^{e-j}	28.3±5.8^{e-j}	5.0±1.0^{j}	40.7^{AB}
Sel 668	78.3±3.6^{ab}	83.3±2.9^{a}	13.3±4.6$^{\text{hıj}}$	25.0±5.2^{f-j}	3.7±1.8^{j}	40.7^{AB}
Sel 702	55.0± 2.8^{a-f}	75.0±8.7^{abc}	51.7±6.6^{a-f}	28.3±5.6^{e-j}	1.7±0.5^{j}	42.3^{AB}
Sel 1794	76.7±5.3^{abc}	76.7±4.4^{abc}	48.3±4.4^{b-g}	21.7±4.8^{f-j}	6.7±2.9^{j}	46.0^{A}
ETH-24	78.3±10.4^{ab}	60.0±5.0^{a-e}	10.0±2.0$^{\text{ıj}}$	15.0±4.0^{g-j}	6.7±2.9^{j}	34.0^{BC}
ETH WIR-70	55.0±7.5^{a-f}	68.3±7.4^{abc}	16.7±2.6^{g-j}	15.0±4.0^{g-j}	3.3±0.9^{j}	31.7^{BC}
Average	69.7^{A}	64.7^{A}	24.2^{B}	18.0^{B}	4.9^{C}	
	Seedling length (cm)					
IFLS 349	7.08±0.6^{h-n}	9.87±0.4^{a-e}	6.23±0.3^{l-o}	4.00±1.0^{pq}	1.20± 0.1^{r}	5.68^{EF}
IFLS 257	11.37±0.7^{ab}	8.81±1.1$^{\text{c-ı}}$	6.80±0.6$^{\text{ı-n}}$	4.60±0.5^{op}	2.06±0.1^{qr}	6.73^{ABC}
GAP Mavisi	8.98±1.3^{c-h}	8.46±0.8^{d-k}	5.74±0.6^{m-p}	3.87±0.5^{pq}	1.08±0.1^{r}	5.62^{EF}
Gürbüz-2001	7.68±0.7^{f-m}	9.32±0.0^{b-g}	5.91±0.5^{m-p}	3.96±0.5^{pq}	0.56±0.1^{r}	5.49^{F}
Sel 706	10.24±0.5^{a-d}	8.94±0.8^{c-h}	6.48±1.0^{k-o}	6.16±1.2^{l-o}	0.71±0.1^{r}	6.51^{BCD}
Sel 668	11.40±0.7^{a}	9.30±1.1^{b-g}	8.73±0.3^{c-j}	5.36±0.6^{nop}	1.25±0.0^{r}	7.21^{AB}
Sel 702	9.62±0.9^{a-f}	10.73±0.9^{abc}	8.49±0.1^{d-k}	6.38±0.3^{l-o}	1.42±0.0^{r}	7.33^{A}
Sel 1794	8.00±0.2^{e-l}	9.43±0.7^{a-f}	7.00±0.4^{h-n}	5.42±0.1^{nop}	1.34±0.1^{r}	6.24^{CDE}
ETH-24	8.60±0.6^{d-j}	9.53±0.3^{a-f}	6.72±0.3^{j-n}	6.28±0.1^{l-o}	1.21±0.1^{r}	6.47^{CD}
ETH WIR-70	9.27±1.3^{c-g}	7.80±0.6^{e-m}	7.35±0.9^{g-n}	4.08±0.1^{pq}	0.65±0.0^{r}	5.83^{DE}
Average	9.22^{A}	9.22^{A}	6.94^{B}	5.01^{C}	1.15^{D}	

Values within a group denoted by different letters are significantly different at $p \leq 0.01$.

The values for seedling fresh and dry weights and seedling vigor index are given in Table 4. When Table 4 is examined, the highest values for seedling fresh weight and seedling vigor index, as the average of genotypes, were determined in the control group (521.8 mg and 51.5, respectively), while the lowest values were observed at the highest dose of salt (200 mM) (202.1 mg and 9.1, respectively). It was found that IFLS

257 and ETH WIR-70 genotypes had the highest values for seedling fresh weight and seedling vigor index, on average across salt concentrations. When seedling dry weight was evaluated, the highest dry weights were reached at 0 and 50 mM concentrations as the average of genotypes, while the lowest dry weight values were observed when reaching the 200 mM dose. When their genotypes examined, the highest seedling dry weight values were found in the ETH WIR-70 genotype with 18.2 mg. The lowest values were determined in the IFLS 349 (13.1 mg), GAP Mavisi (12.9), and Gürbüz-2001 (12.6 mg) genotypes (Table 4).

Table 4. Some seedling development parameters of grasspea genotypes at different salt concentrations

Çizelge 4. *Mürdümük genotiplerinin farklı tuz konsantrasyonlarındaki bazı fide gelişim parametreleri*

Genotypes	Salt concentration (mM, NaCl)					
	0 mM	50 mM	100 mM	150 mM	200 mM	Average
	Seedling fresh weight (mg)					
IFLS 349	494.8±43.3^{a-h}	380.2±32.1^{f-n}	391.7±9.5^{e-n}	335.4±33.4$^{ı-o}$	268.1±18.7^{m-s}	374.0^{BC}
IFLS 257	555.6±31.6^{abc}	475.5±21.2^{a-j}	490.0±23.0^{a-h}	386.1±40.0^{f-n}	327.4 ±32.2^{j-p}	446.9^{A}
GAP Mavisi	439.7±6.0^{c-l}	441.3±36.9^{b-l}	409.4±34.1^{c-m}	372.5±16.2^{g-n}	156.7 ±16.1^{s}	363.9^{BC}
Gürbüz-2001	483.4±14.8$^{a-ı}$	527.8±49.8^{a-f}	381.9±33.8^{f-n}	380.1±28.5^{f-n}	172.0 ±33.4^{qrs}	389.1^{BC}
Sel 706	543.5±8.8^{a-d}	382.4±30.6^{f-n}	364.7±28.4^{g-n}	349.7±31.2^{h-o}	178.0±20.0^{p-s}	363.7^{BC}
Sel 668	591.0±38.7^{ab}	475.4±44.5^{a-j}	427.1±58.9^{c-l}	333.9±17.2$^{ı-o}$	246.4 ±28.3^{n-s}	414.8^{AB}
Sel 702	512.5±42.0^{a-g}	542.2±57.7^{a-e}	402.1±33.0^{d-m}	354.5±18.7^{h-o}	145.7±18.8^{s}	391.4^{BC}
Sel 1794	495.6±13.0^{a-h}	390.5±54.1^{f-n}	387.2±37.7^{f-n}	308.3±32.9^{l-r}	146.0± 21.0^{s}	345.5^{C}
ETH-24	497.1±26.5^{a-h}	457.8±52.7^{a-l}	321.9±42.3^{k-q}	385.7±3.5^{f-n}	166.7± 12.9^{rs}	365.8^{BC}
ETH WIR-70	605.2±31.4^{a}	555.4±63.1^{abc}	463.6±31.5^{a-k}	412.7±41.9^{c-m}	213.9±33.4^{o-s}	450.2^{A}
Average	521.8^{A}	462.9^{B}	404.0^{C}	361.9^{D}	202.1^{E}	
	Seedling dry weight (mg)					
IFLS 349	18.9±1.4^{a-j}	18.8±3.1^{a-j}	13.1±2.7^{j-p}	9.9±0.6^{n-s}	4.8±0.4^{q-t}	13.1^{E}
IFLS 257	24.7±1.3^{a}	18.6±1.3^{a-j}	15.4±2.7^{f-n}	13.3±2.1$^{ı-p}$	7.5±0.8^{p-t}	15.9^{BCD}
GAP Mavisi	16.9±2.0^{d-l}	17.2±2.4^{c-k}	14.0±2.3^{h-o}	10.7±1.6^{m-r}	5.5±0.5^{q-t}	12.9^{E}
Gürbüz-2001	19.3±3.7$^{a-ı}$	16.2±1.2^{e-m}	12.0±2.0^{k-p}	10.8±1.2^{l-q}	4.7±0.3^{v-t}	12.6^{E}
Sel 706	22.3±1.0^{a-e}	22.5±3.0^{a-d}	15.7±2.0^{f-n}	12.2±1.8^{k-p}	4.6±0.7st	15.5^{BCD}
Sel 668	24.3±0.7^{a}	24.1±0.9^{a}	16.4±3.1^{d-m}	13.8±0.7^{h-o}	3.6±0.4^{t}	16.4^{ABC}
Sel 702	23.2±2.0^{abc}	23.7±3.3^{ab}	17.7±0.3^{b-k}	14.6±2.1^{f-n}	7.6±0.7^{p-t}	17.4^{AB}
Sel 1794	17.4±0.9^{c-k}	18.0±1.4^{b-k}	14.0±2.2^{h-o}	12.4±0.6^{k-p}	8.4±1.3^{o-t}	14.0^{DE}
ETH-24	20.4±1.5^{a-g}	20.6±1.5^{a-f}	14.4±3.6^{g-o}	13.5±0.6$^{ı-p}$	3.8±0.2^{t}	14.5^{CDE}
ETH WIR-70	24.6 ±2.7^{a}	23.8±1.6^{ab}	19.8±0.2^{a-h}	14.4±2.3^{g-o}	8.5±1.1^{o-t}	18.2^{A}
Average	21.2^{A}	20.4^{A}	15.3^{B}	12.6^{C}	5.9^{D}	
	Seedling vigor index					
IFLS 349	48.8±2.2$^{a-ı}$	38.0±1.2^{e-l}	37.9±2.1^{e-l}	28.4±2.8^{lm}	16.1±2.4^{mn}	33.8^{BC}
IFLS 257	55.6±3.2^{ab}	46.7±1.9^{a-j}	46.0±2.7^{a-j}	37.2±2.4^{e-l}	16.3±3.3^{mn}	40.4^{A}
GAP Mavisi	43.3±1.8^{a-l}	43.5±2.8^{a-l}	39.7±3.2^{b-l}	36.0±1.2^{f-l}	5.7±1.1^{n}	33.6^{C}
Gürbüz-2001	46.8±3.9^{a-j}	52.0±2.8^{a-f}	37.6±4.1^{e-l}	32.8±1.6$^{ı-l}$	1.5±0.7^{n}	34.1^{BC}
Sel 706	54.4±0.9^{a-d}	37.5±1.9^{e-l}	35.2±2.8^{g-l}	33.8±2.8^{h-l}	1.8±1.1^{n}	32.6^{C}
Sel 668	59.1±2.9^{a}	46.7±5.0^{a-j}	41.3±3.4^{b-l}	33.4±1.7^{h-l}	16.3±2.9^{mn}	39.3^{AB}
Sel 702	50.5±4.5^{a-g}	53.3±6.0^{a-e}	38.8±2.9^{c-l}	33.6±0.6^{h-l}	8.1±2.6^{n}	36.9^{ABC}
Sel 1794	49.6±1.3^{a-h}	37.8±4.6^{e-l}	35.3±3.0^{g-l}	29.2±1.6^{klm}	9.7±1.4^{n}	32.3^{C}
ETH-24	48.9±2.2$^{a-ı}$	45.8±5.3^{a-j}	31.6±3.3^{j-m}	33.4±2.1$^{ı-l}$	7.1±1.6^{n}	33.4^{C}
ETH WIR-70	58.4±2.0^{a}	54.7±4.7^{abc}	44.8±1.8^{a-k}	38.4±2.9^{d-l}	8.1±2.3^{n}	40.9^{A}
Average	51.5^{A}	45.6^{B}	38.8^{C}	33.6^{D}	9.1^{E}	

Values within a group denoted by different letters are significantly different at $p \leq 0.01$.

It was determined that genotype x salinity interactions had significant effects on all germination and seedling parameters investigated (Table 1). According to these examined germination and seedling development parameters, it is believed that the interaction arises from the differential effects of salt concentrations on genotypes, with some genotypes being more affected than others by this effect, while some genotypes are more resistant to salt. Additionally, another reason is that as salt concentrations increase, there was a decreasing trend in the examined parameters across all genotypes in general. However, some genotypes exhibited fluctuating trends and significant increases compared to the control, which contributed to the significance of the interaction (Tables 2-4).

DISCUSSION

Salinity, particularly among abiotic stresses, significantly limits crop productivity and causes economic losses to farmers (Garg et al., 2016; Ahanger et al., 2017). Salinity exhibits its adverse effects on plants in several ways; among these, high salt concentration in the soil severely affects the water uptake capacity of plant roots, rendering the plant more vulnerable (Saxena et al., 2019). This leads to the suppression of many physiological and biochemical processes within plants, diminishing nutrient uptake and assimilation, growth, development, and production, thereby demonstrating its toxic effect (Hasegawa et al., 2000; Munns & Tester, 2008). Understanding plant responses under different stress conditions and developing stress-tolerant plants are crucial for sustainable agriculture. It has been reported that salt-tolerant crops would be a significant avenue in achieving sustainability goals in the current agricultural system (Flowers, 2004; Munns & Tester, 2008; Ali et al., 2019).

In the study, significant decreases were observed in all germination parameters examined, both in all investigated grasspea genotypes and in the average results of genotypes, with increasing salt concentrations. Researchers have reported that the decreases in germination parameters due to salt concentration are attributed to the prevention of seed water uptake at high salt concentrations and embryo poisoning due to the toxic effects of some ions (Dan & Brix, 2007; Tavili & Biniaz, 2009; Ceritoğlu et al., 2020; Chen et al., 2020; Dere, 2021; Açıkbaş et al., 2023). The findings obtained for germination parameters, especially germination rate, are consistent with studies conducted on grasspea plants subjected to salt stress (Mahdavi & Sanavy, 2007; Fallahi et al., 2015; Arslan & Aydınlıoğlu, 2018; Moghaddam et al., 2020; Tokarz et al., 2020; Açıkbaş & Özyazıcı, 2021). Significant differences were observed among grasspea genotypes for all examined germination parameters in the study. This variation is attributed to the genotypic structure of the varieties, as indeed, numerous studies have found high genotypic variation among genotypes in terms of salt tolerance in their species, and different responses of genotypes concerning of germination parameters (Ahmed et al., 2014; Shakeri & Emam, 2017; Arslan & Aydınlıoğlu, 2018; Rajabi Dehnavi et al., 2020).

Average germination time is a parameter indicating how quickly seeds germinate (Bijanzadeh & Egan, 2018), and in the study, it was found that the average germination time increased with increasing salt content in all investigated grasspea genotypes, showing significant variations among genotypes. Some studies with different plant species and genotypes have also reported that salt doses extend the germination time, and there are differences among genotypes regarding average germination time (Okçu et al., 2005; Almodares et al., 2007; Rajabi Dehnavi et al., 2020).

The evaluated seedling parameters, including seedling length, seedling fresh and dry weights, as well as germination rate and seedling vigor index calculated based on seedling fresh weight, showed a decrease in response to increasing salt concentrations. There were differences in the responses of genotypes to salt stress (Tables 3 & 4). Although some varieties exhibited high germination rates, the effects of salt stress on seedling development characteristics-particularly on the affected organs-became more pronounced. This provided clearer insight into the developmental trajectory related to salt tolerance. Many studies conducted with leguminous forage crops exposed to salt stress (Okçu et al., 2005; Kondetti et al., 2012; Day & Uzun, 2016; Arslan & Aydınlıoğlu, 2018; Ivani et al., 2018; Ahmed et al., 2023) have also reported results supporting the negative impact of increasing salt concentrations on seedling development parameters and the differential effects observed in the genotypes used in the study.

CONCLUSION

In conclusion, it was determined that common grasspea genotypes were significantly affected by increasing salt concentrations in terms of germination parameters from 50 mM salt dose onwards. Regarding seedling parameters, grasspea genotypes were affected after 50 mM salt concentration in regard to seedling length and seedling dry weight, while other seedling parameters were adversely affected even at the lowest salt dose.

It was observed that genotypes exhibited different responses regarding salt tolerance and resilience across all examined germination and seedling development parameters. Generally, it was found that some of the used genotypes were more resilient in germination and seedling development parameters under salt stress compared to varieties, indicating promising genotypes. While different genotypes stood out in the examined parameters individually, when all parameters were considered together, the Sel 668 genotype is predicted to be a potential new variety candidate due to its resilience to salinity and its performance in germination and seedling development. In this regard, salinity is becoming an increasingly problematic issue, and it is necessary to define the performance of salt-tolerant grasspea genotypes under field conditions.

Data Availability

All data related to the study are presented within the manuscript.

Author Contributions

Conception and design of the study: SA; sample collection: SK; analysis and interpretation of data: SK, SA; statistical analysis: SA; visualization: SK, SA; writing manuscript: SA.

Conflict of Interest

The authors have no conflicts of interest to declare.

Ethical Statement

We declare that there is no need for an ethics committee for this research.

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