

DETERMINING GERMINATION RESPONSES OF ANNUAL HONEYBEE PLANT (*Phacelia tanacetifolia* Benth.) UNDER SALT AND DROUGHT STRESS UNDER *In vitro* CONDITIONS

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ABSTRACT

Salinity and drought are two of the most important factors limiting global agricultural productivity. The aim of the study was to examine effects of salinity and drought on *P. tanacetifolia* genotypes. The seeds of three *P. tanacetifolia* genotypes were used as materials [Saglamtimur (A₁), Stala (A₂), Enton (A₃)]. The seeds were germinated at room temperature with 12-h photoperiod and 12-h dark period to screen and evaluate the effects of sodium chloride (NaCl) and polyethylene glycol (PEG 6000) based drought on the seed germination process of the *P. tanacetifolia*. Three NaCl (0, 50, 100 mM) and PEG 6000 (0, 5%, 10%) doses were applied to the seeds. Germination energy (GE) and germination percentage (GP) were recorded on 3th and 8th day. Root length (cm), shoot length (cm), fresh weight (g), and dry weight (g) were measured on the 8th day by randomly selecting 15 seeds per replication. Also, promptness index (PI), germination stress tolerance index (GSTI) and simple vigour index (SVI) were calculated. All data obtained in the study were subjected to analysis of variance in accordance with the completely randomized design as triplicate. Salinity was affected more negatively than drought in all genotypes. Enton (A₃) was inferred as more resistant genotype among all genotypes.

KEYWORDS:

Abiotic stress, salinity, germination indexes, resistant, PEG 6000

INTRODUCTION

Salinity and drought are the very important environmental stress factors that suppress plant growth and yield in agricultural production [1]. Drought and salinity are rapidly increasing due to many malpractices globally and currently affect more than 10 % of arable land World over, resulting in more than ~ 50 % reduction in average yields of major crops [2]; [3]; [4]. It is estimated that the climate change due to greenhouse gasses could also lead to extreme

changes in temperatures that may end up in inducing high drought in several areas around the World [5]. Besides drought, salinity is another major problem limiting the productivity of crops, which affects about 7% of the World arable lands [6].

Seed germination is the initial and the most critical stage in the plant life. Germination and seedling growth is decreased due to many factors including drought and salt stress that disrupt cell regulation and limit seedling growth [7]; [8]. Salinity, affect seed germination due to toxic effects of specific ions like Na, Cl, SO₄ and inducing osmotic pressure which obstruct seed water uptake [9]. Salts around the roots have an instantaneous effect on cell growth and associated metabolisms [10]. In the seed germination stage, tolerance against drought is very crucial. Drought leads to weak seed germination and, sometimes damages to the crops. Generally, drought decreases nutrient uptake by the roots and transport from the roots to the shoots, due to restricted transpiration and impaired active transport and membrane permeability [11]. Sodium chloride (NaCl) and polyethylene glycol (PEG) are used in salt and drought stress study experiments by many researchers [12]; [13]; [14]. NaCl and PEG compounds have also been used to stimulate osmotic stress effects in Petri dishes, rolling papers (*in vitro*) for plants to maintain uniform water potential during the experimental periods [15]; [16].

The *Phacelia tanacetifolia* Benth. is native to the United States and Mexico, and has North American origin. It is extensively used as cover crops [17]; [18] and has been listed among top 20 plants considered the most suitable for honey bee farming in Europe [19]; [20]. This study aims to screen three 3 genotypes of *P. tanacetifolia* using drought and salt stress tolerance tests by testing their germination.

MATERIALS AND METHODS

Seed Material. The seeds of three *P. tanacetifolia* genotypes were used as materials. The seeds were obtained from the local market of Ankara, Turkey. The seeds were dry-stored in cloth bags at room temperature for further use. *P. tanacetifolia* genotypes (Saglamtimur, Stala, Enton) were labeled as A₁,

A₂, A₃.

Salt and Drought Stress Treatments. The seeds were germinated at room temperature with 12-h photoperiod (cool white fluorescent lamps, 200 μ mol m⁻² s⁻¹, 400-700 nm) and 12-h dark period to screen and evaluate the effects of sodium chloride (NaCl) (Merck, Germany) and polyethylene glycol (PEG 6000) (Merck, Germany) based drought on the seed germination process of the *P. tanacetifolia*. 0 (distilled water), %5 and 10% PEG 6000 and 0, 50, 100 mM – NaCl are concentrations to screen the seeds. Salt treated and PEG 6000 treated seed groups were labeled as S₀, S₁, S₂ and P₀, P₁, P₂ in the same order.

Germination Experiments. The seeds were first sterilized with 1% sodium hypochlorite solution for five minutes, then rinsed with distilled water before treating with respective NaCl and PEG 6000 concentrations. The seeds in each treatment were sandwiched in equally distanced rows using moist germination papers (Anchor Corp, 5 × 10 cm). These sandwiched papers were rolled and put into the sealed polythene bags to avoid moisture loss. The Seeds were considered germinated with the emergence of the radicle (≥ 2 mm). The germination experiments were repeated three times with 25 seeds per treatment.

Germination energy (GE) and germination percentage (GP) were recorded on 3th and 8th day. Root length (cm), shoot length (cm), fresh weight (g), and dry weight (g) were measured on the 8th day by randomly selecting 15 seeds per replication. To calculate the dry weight, the fresh shoots were dried for 72 hours at 60 °C [21].

$$PI = nd1 (1.00) + nd3 (0.75) + nd5 (0.50) + nd7 (0.25)$$

$$GSTI (\%) = [P.I \text{ of stressed seeds} / P.I \text{ control seeds}] \times 100$$

$$SVI = GP (\%) \times DW \text{ of Seedling}$$

Statistical Analysis. All data obtained in the study were subjected to analysis of variance in accordance with the completely randomized design as triplicate using JMP-12 [22], using a two factorial ANOVA ($p \leq 0.05$). The genotypes were considered as the main factor and the salt or drought treatments were considered as sub factor during analysis of variance. Germination data were arcsine transformed before the analysis of variance. Simple correlation coefficients were calculated to evaluate the correlation of the experimental parameters with the germination percentage.

RESULTS

Interactive Effects of Salinity Stress on Seed Germination of *P. tanacetifolia* genotypes. Two factorial ANOVA results showed that all parameters were affected by salt stress ($p \leq 0.01$, Table 1.) The highest germination percentage and germination energy of all genotypes were obtained under non-stressed conditions (distilled water), and significant differences were observed under salt stress (S), genotypes (A), and their interaction (S×A) [exp. from A for GP ($p \leq 0.05$), S×A for GP(ns)] (Table 1). Germination percentage and germination energy were decreased with the increasing salt stress. For all genotypes, similar trends were found between germination percentage and germination energy. A₁, A₃ had maximum germination percentage and germination energy (%92.78 and %36.11), in the same order (Table 2.).

Germination index (GRI) was affected by salt stress ($p \leq 0.01$), genotypes ($p \leq 0.01$), and their interaction ($p \leq 0.05$). GRI decreased among 0 mM to 100 mM salt stress levels. GRI was greater under non-stressed conditions (16.27). When the salt stress reached 100 mM, the GRI decreased (12.33). For all genotypes, GRI was noted between 13.25-14.56 (Table 2). In addition, A₃ had the highest and A₂ had the lowest GRI (Figure 2.).

TABLE 1
The experimental results of the Two-factorial ANOVA for the effects of genotype (A), salinity (S), drought (P) on seed germination test of *P. tanacetifolia*

Independent variables	GE	GP	GRI	RL	SL	FW	DW	GSTI	PI	SVI
S	29.89**	14.89**	50.05**	31.32**	98.67**	90.43**	32.25**	188.52**	90.54**	75.51**
A	7.32**	4.22*	6.75**	1.51	0.22	15.17**	29.15**	16.19**	6.12**	0.03
S × A	7.64**	0.56	2.79*	1.73	2.08	0.39	4.54*	7.37**	2.00	0.93
P	1.50	48.69**	14.35**	30.34**	98.75**	94.12**	32.25**	11.04**	29.56**	127.05**
A	5.65*	3.00*	7.25**	1.38	0.16	15.87**	29.15**	1.20	6.55**	0.42
P × A	0.23	1.15	0.61	1.71	2.01	0.42	4.54*	0.68	0.80	2.38

(S: Salinity, P: PEG 6000, A: Fiddleneck genotypes, GE: Germination energy, GP: Germination percentage, GRI: Timson germination index, RL: Root length, SL: Shoot length, FW: Fresh weight, DW: Dry weight, GSTI: Germination stress tolerance index, PI: Promptness index, SVI: Simple vigour index, **factors are significant $p \leq 0.01$, *factors are significant $p \leq 0.05$).

TABLE 2
Seed germination test parameters of *P. tanacetifolia* genotypes

Salinity										
Treatment	GE(%)	GP(%)	GRI	RL(cm)	SL(cm)	FW(g)	DW(g)	GSTI(%)	PI	SVI
S ₀	40.00AA	96.11A	16.27A	4.51A	3.77A	0.341A	0.024A	100.00A	14.07A	358.51A
S ₁	33.89AA	88.33A	13.70A	3.55A	2.32AB	0.269A	0.016A	84.60B	11.44AB	205.14AB
S ₂	25.56AB	86.11A	12.33A	2.64B	1.60B	0.211AB	0.012B	75.82B	10.05B	137.20B
A ₁	34.44A	92.78A	14.49A	3.32	2.49	0.297A	0.021A	90.83A	12.12A	235.10
A ₂	28.89B	87.22A	13.25A	3.71	2.59	0.280A	0.021A	84.60A	11.24A	230.66
A ₃	36.11A	90.56A	14.56A	3.67	2.55	0.244A	0.011B	75.81A	12.20A	235.09
PEG 6000										
P ₀	27.22A	97.22A	14.97A	5.80A	4.86A	0.405A	0.033A	100.00A	13.67A	473.06A
P ₁	24.44A	88.33AB	13.19A	4.83A	3.44AB	0.331AB	0.025A	89.57A	11.62A	304.13B
P ₂	23.33A	81.11B	12.36A	3.95AB	2.72AB	0.274B	0.021B	84.06AB	10.64A	220.87B
A ₁	20.56B	88.33A	12.64A	4.63	3.63	0.360A	0.030A	91.65	11.30A	328.03
A ₂	26.67A	87.22A	13.36A	4.99	3.71	0.342AB	0.030A	88.35	11.88A	328.86
A ₃	27.78A	91.11A	14.52A	4.94	3.70	0.307B	0.020A	93.63	12.74A	341.2

S: Salinity, P: PEG 6000, A: Fiddleneck genotypes Capital letters were used for comparison of stress levels and genotypes in subgroups ($P < 0.01$)

Root length and shoot length showed significantly on different salt stress ($p \leq 0.01$), on genotypes and their interactions were not significant (Table 1.). Root length and shoot length decreased, with salt stress level up to 100 mM. Root length and shoot length were the longest under non-stressed conditions (4.51cm, 3.77 cm). 100 mM salt stress level affected negatively to root and shoot development. Also, the minimum root and shoot length were observed under 100 mM (2.64cm and 1.60 cm). For all genotypes, root and shoot length were very close to each other ($A_2 > A_3 > A_1$). Root and shoot lengths ranged 3.32-3.71 cm and 2.49-2.59 cm, respectively (Table 2, Figure 1.). A_2 was the least affected genotype under different salt stress conditions.

Fresh weight and dry weight were affected by salt stress ($p \leq 0.01$) and genotypes ($p \leq 0.01$). Unlike salt stress and genotype, their interaction was not significant except dry weight ($p \leq 0.05$) (Table 1). Fresh and dry weights ranged 0.211-0.341 g and 0.012-0.024g, in the same direction (Table 2, Figure 1.). When the salt stress level increased, fresh and dry weight decreased. The maximum fresh and dry weight was obtained under non-stressed conditions, while the minimum fresh and dry weights were determined using 100 mM salt stress. The fresh weight and dry weight of the three genotypes lined $A_1 > A_2 > A_3$ when the salt stress level gradually reached non-stress conditions (distilled water) to 100 mM (Figure 1.).

Germination stress tolerance index (GSTI), promptness index (PI), and simple vigour index (SVI) were affected by salt stress ($p \leq 0.01$). GSTI and PI were found to be significant by genotypes ($p \leq 0.01$) except SVI. Besides, GRI was affected by salt stress $\times$ genotypes interaction ($p \leq 0.05$), except PI and SVI (Table 1.). GSTI decreased when the salt stress was high levels (0 to 100 mM). GSTI was ranged %75.82-100.00 (Table 2.). The most tolerant

genotype in accordance with salt stress levels is A_1 (90.83). A_2 , A_3 was followed A_1 (Figure 1.). Similar trends were determined in PI. PI were decreased by increasing salt stress level (0 to 100 mM). PI ranged 10.05-14.07. PI of genotypes was very close to each other and noted among 11.24-12.20. A_3 had highest PI in all genotypes (12.20). SVI sharply decreased by salt stress level reached between 0 to 100 mM. The most highest SVI was obtained under non-stressed conditions (distilled water) (358.51). Similar to PI, SVI of genotypes results showed that SVI was very close to each other and ranged 230.66-235.10 (Table 2, Figure 1.).

Interactive Effects of Drought Stress and on Seed Germination of *P. tanacetifolia* genotype.

Two factorial ANOVA results showed that all parameters analyzed were affected by drought (P) except for germination energy ($p \leq 0.01$, Table 1.) The highest germination percentage and germination energy of all genotypes was obtained under non-stressed conditions (distilled water), and significant differences were individually observed in drought (P), genotypes (A) ($p \leq 0.05$, Table 1.). Germination percentage and germination energy decreased with increasing drought level using PEG 6000 (%81.11-97.22 and %23.33-27.22). A_3 had maximum germination percentage and germination energy in all genotypes (%91.11 and %27.78) (Table 2, Figure 2.).

Germination index (GRI) was affected by drought ($p \leq 0.01$), genotypes ($p \leq 0.01$) except their interaction (Table 1.). GRI decreased between 0% to 10% PEG induced stress. GRI was greater under non-stressed conditions (14.97). When the drought stress increased (0 to 10% PEG), GRI decreased (14.97-12.36). For all genotypes, GRI was noted among 12.64-14.52 (Table 2.). In addition, A_3 had the highest and A_1 had the lowest GRI (Figure 2.).

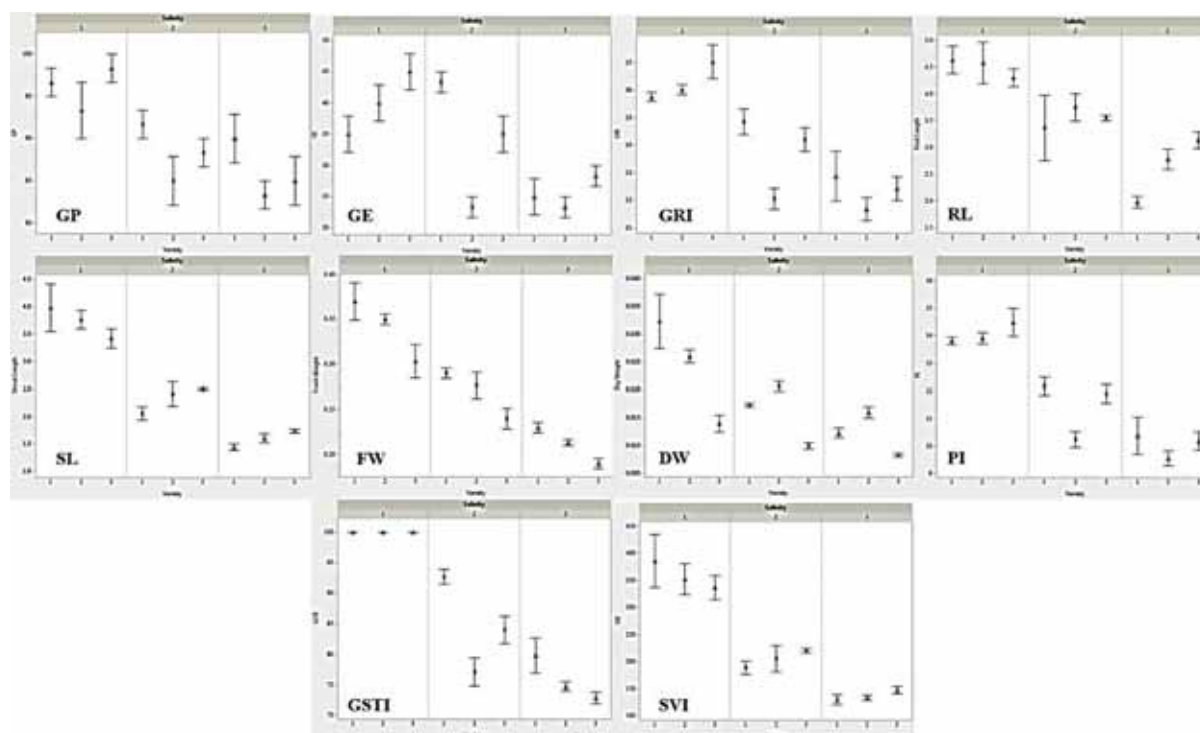


FIGURE 1
Effect of salt stress and genotypes on *P. tanacetifolia*

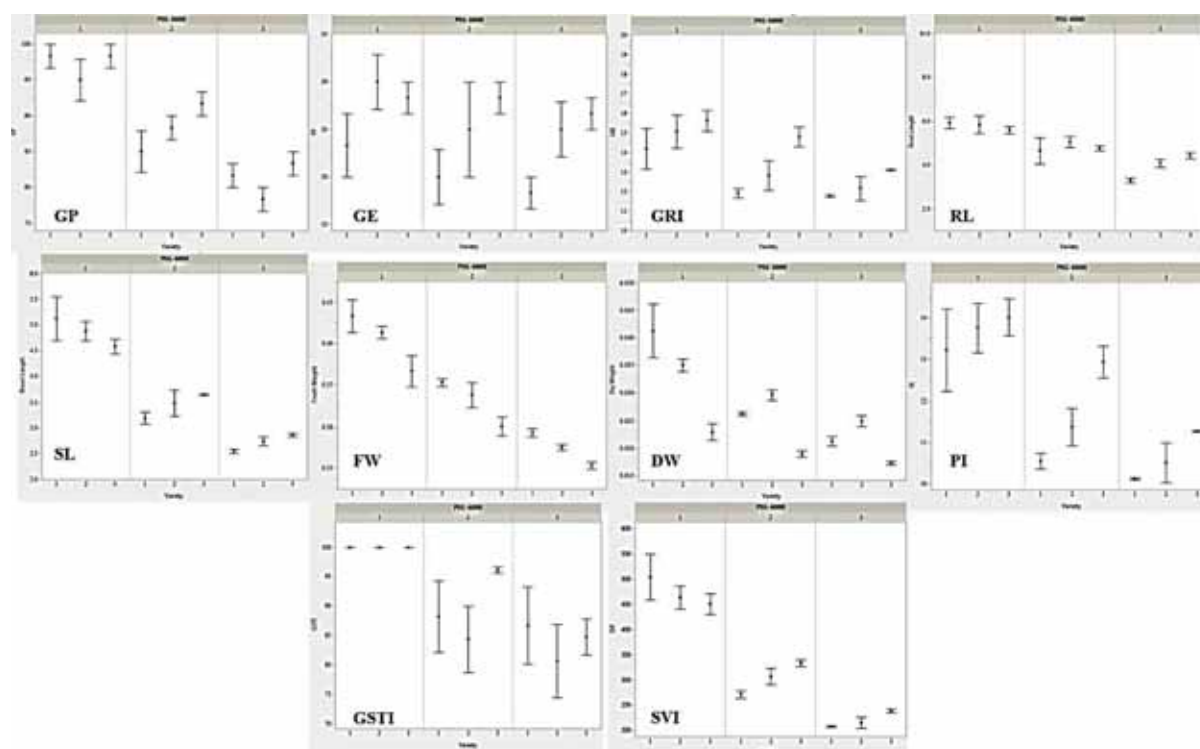


FIGURE 2
Effect of PEG 6000 and genotypes on *P. tanacetifolia*

Root length and shoot length showed significantly different affects by drought ($p \leq 0.01$), genotypes and their interactions were not significant (Table 1). Root length and shoot length decreased, when the drought level was up to 10%. Root length and shoot length were the longest under non-stressed

conditions (5.80 cm and 4.86 cm). 10% PEG induced stress affected root and shoot length negatively. Also, the minimum root and shoot length were observed under 10% PEG induced stress (3.95 cm, 2.72 cm). Root and shoot length were very close to each other for all genotypes, similar to the salt stress stress

TABLE 3
Correlation coefficients of measured traits

	Salt stress									
	GP	GE	GRI	AvRL	AvSL	AvFW	AvDW	PI	GSTI	SVI
GP		-0.02	-0.38	-0.13	-0.47	0.28	-0.52	0.38	0.23	0.93
GE	-0.02		0.07	0.36	0.06	-0.02	-0.22	-0.07	0.39	0.01
GRI	-0.38	0.07		-0.34	-0.99	-0.48	0.12	0.99	-0.10	0.21
AvRL	-0.13	0.36	-0.34		-0.32	-0.13	0.13	0.34	-0.34	0.001
AvSL	-0.47	0.06	-0.99	-0.33		-0.43	0.05	0.99	-0.07	0.32
AvFW	0.28	-0.02	-0.48	-0.13	-0.43		0.67	0.48	-0.06	-0.38
AvDW	-0.52	-0.22	0.11	0.13	0.05	0.68		-0.11	0.49	0.56
PI	0.38	-0.07	0.99	0.34	0.99	0.48	-0.11		0.11	-0.21
GSTI	0.23	0.39	-0.10	-0.34	-0.07	-0.06	0.49	0.11		-0.27
SVI	0.93	0.01	0.21	0.001	0.32	-0.38	0.56	-0.22	-0.27	

	Drought									
	GP	GE	GRI	AvRL	AvSL	AvFW	AvDW	PI	GSTI	SVI
GP		-0.15	-0.50	0.52	-0.58	0.36	-0.46	0.50	0.27	0.88
GE	-0.15		-0.20	0.36	-0.18	-0.02	0.25	0.20	0.45	-0.16
GRI	-0.51	-0.20		0.45	-0.99	0.40	-0.43	0.99	0.13	0.43
AvRL	0.52	0.36	0.45		0.47	-0.15	0.13	-0.45	-0.53	-0.29
AvSL	-0.58	-0.18	-0.99	0.47		0.41	-0.45	0.99	0.15	0.52
AvFW	0.36	-0.02	0.40	-0.15	0.42		0.59	-0.39	0.16	-0.28
AvDW	-0.46	0.25	-0.43	0.13	-0.45	0.59		0.43	-0.14	0.48
PI	0.50	0.20	0.99	-0.45	0.99	-0.40	0.43		-0.13	-0.42
GSTI	0.27	0.45	0.13	-0.53	0.15	0.16	-0.14	-0.13		-0.10
SVI	0.88	-0.16	0.43	-0.29	0.52	-0.28	0.48	-0.42	-0.10	

group in the shown order of $A_2 > A_3 > A_1$. Root and shoot length ranged 4.63-4.99 cm and 3.63-3.71 cm, respectively (Table 2, Figure 2.). A_2 was the least affected genotype under different drought stress conditions.

Fresh weight and dry weight were affected by drought stress ($p \leq 0.01$) and genotype ($p \leq 0.01$). Their interaction showed significantly different results for the dry weight ($p \leq 0.05$) (Table 1). Fresh and dry weight ranged 0.247-0.405 g and 0.021-0.033g, in the same order (Table 2.). When the PEG induced stress increased, the fresh and dry weights decreased. The maximum fresh and dry weights were obtained under non-stressed conditions, while the minimum fresh and dry weight was determined in %10 PEG. The fresh weight and dry weight of the three genotypes lined $A_1 > A_2 > A_3$ and $A_1 = A_2 > A_3$, when the PEG induced stress reached 0% to 10%, in the same order (Figure 2.).

Germination stress tolerance index (GSTI), promptness index (PI), and simple vigour index (SVI) were affected by drought stress ($p \leq 0.01$). GSTI and SVI did not show any significant differences among genotypes except for PI ($p \leq 0.01$, Table 1.). Also, GRI, PI, and SVI were not affected by drought $\times$ genotypes interaction. GSTI decreased when the drought stress was at high levels (0 to 10%) (Table 2, Figure 2.). GSTI ranged 84.06-100.00%. The most stress-tolerant genotype in accordance with PEG induced stress is A_3 (93.63). Similar trends were determined in PI. PI that decreased by increasing the PEG induced stress (%0 to 10%). PI ranged 10.64-13.67.

PI of genotypes were very close to each other and noted showed range of 11.30-12.74. A_3 had the highest PI in all genotypes (12.74). SVI sharply decreased by PEG induced stress was up to 0% to 10% (220.87-473.06). The most highest SVI was obtained under non-stressed conditions (distilled water) (473.06). Similar to PI, SVI of genotypes results showed that SVI was very close to each other and ranged 328.03-341.20 (Table 2, Figure 2.).

DISCUSSION

The present study investigated that the seed germination responses of 3 *P. tanacetifolia* genotypes. If it is mentioned about applied stress conditions in this study, salt stress is more influential than drought stress to the seeds at the germination stage. Sufficient production of plants are highly related to the seed germination phase, particularly under drought-salt stress conditions [3]. The results showed that the *P. tanacetifolia* had high germination percentage and germination energy under non-stressed conditions (distilled water). Considering both stress factors (salt stress and drought), when the stress level reached the maximum, germination percentage the germination energy decreased. Similar results were also found in of *Borago officinalis* L. [23], and *P. secunda* [24]. Also, [25]; [26] agreed that increasing salt stress and drought stress levels result in decreasing germination responses. It was observed that a decrease in germination percentage and

germination energy was shown in drought conditions more than under salt stress conditions in genotypes. It was understood that these genotypes are more sensitive to drought.

Salt stress and drought stress have adverse effects on germination. Drought and salinity based stresses might have limited germination responses by decreasing the water uptake [27]. It was observed that increasing salt stress, root and shoot development, fresh and dry weight decreased more than in drought stress conditions in this study, Roots, which acted as an interface between plant to the soil, are more exposed to many abiotic stresses; for example drought, salt stress, and waterlogging [28]. Also, roots affected much more by abiotic stresses in comparison to shoots/ aerial parts [29]. Nonetheless, the influence of these stresses on root development has been less studied compared to shoots, especially for the *P. tanacetifolia*. Besides this, there is a lack of knowledge about the responses of the seed germination stage on this plant. Root length, shoot length, fresh and dry weight of *P. tanacetifolia* declined with increasing stress levels. Also, these decreases in length and weight were more pronounced in salt treated seeds compared to those treated for drought stress. It was determined that inhibition in root length, shoot length, fresh and dry weight at equivalent water potentials of NaCl and PEG was mainly due to salt toxicity rather than osmotic stress. It is known that *P. tanacetifolia* is more resistant to drought than salt stress. [30]; [31]; [32]; [33] demonstrated that increasing stress levels affected negatively on root length, shoot length, fresh and dry weight. It is well known that salt stress reduces the productivity of several crops [34]; [35].

Salt stress and drought are considered important stress factors affecting the germination index of the *P. tanacetifolia*. When the stress levels reached the maximum; GRI, GSTI, PI, and SVI reduced, similar to the findings of [27]; [36]. For all genotypes, results showed that germination indices were in the same Duncan group, except SVI. [37] Proposed that the speed and uniformity of seedling emergence were crucial components of seed performance as they can directly influence stand establishment in the field. Higher timson germination index (GRI), was noted that inferred obtaining of more rapid germination. Under salt stress conditions, the *P. tanacetifolia* had more rapid germination compared to drought conditions and, it germinated rapidly. On the basis of GSTI; salt stress is more effective than drought. Also, *P. tanacetifolia* is more resistant to drought than salt stress. As mentioned earlier, it was inferred that it was genotype dependent. Higher salt stress and drought stress levels, the seeds retarded germination and root development were mainly due to the osmotic effect which is deleterious and prevents the plants from maintaining their proper nutritional requirements necessary for their healthy growth [34].

Correlation coefficients of measured traits were displayed and it showed various results in accordance with salt stress and drought levels in Table 3. Traits of PI, GE, GP, and GE, GP indicated a significant positive correlation with GSTI under salt stress and drought conditions, respectively (Table 3.). Also, correlation coefficients of GSTI for GP, GE was higher in drought levels than salt stress levels. High germination stress index value is criteria for evaluation salt stress and drought resistance, and the traits that correlate with GSTI, that are suitable for selection under stress conditions, and the selections based on these traits is suitable for drought resistance [38].

CONCLUSION

It is concluded that salt stress and drought declines growth responses like germination energy (GE) and percentage (GP), Timson germination index (GRI), fresh (FW) and dry weights (DW) and other germination indices were inversely related to increasing levels of NaCl and PEG 6000. All germination responses were decreased with increasing stress levels. All genotypes showed more pronounced effects of salt stress compared to drought. Enton (A_3) was inferred as more resistant genotype among all genotypes.

REFERENCES

- [1] Khan, A., Anwar, Y., Hasan, M., Iqbal, A., Ali, M., Alharby, H.F., Hakeem, K.R. and Hasanuzzaman, M. (2017) Attenuation of drought stress in *Brassica* seedlings with exogenous application of Ca^{2+} and H_2O_2 . *Plants*. 6(2), 20.
- [2] Wang, W.B., Kim, Y.H., Lee, H.S., Kim, K.Y., Dengand, X.P., Kwak, S.S. (2009) Analysis of antioxidant enzyme activity during germination of alfalfa under salt and drought stresses. *Plant Physiol Biochemical*. 47, 570–577.
- [3] Li, R., Shi, F., Fukuda, K., Yang, Y. (2010) Effects of salt and alkali stresses on germination, growth, photosynthesis and ion accumulation in alfalfa (*Medicago sativa* L.). *Soil Sci. Plant Nutrition*. 56, 725–733.
- [4] Ouzounidou, G., Ilias, I.F., Giannakoula, A., Theocharidou, I. (2014) Effect of water stress and NaCl triggered changes on yield, physiology, biochemistry of broad bean (*Vicia faba* L.) plants and on quality of harvested pods. *Biologia*. 69, 1010–1017.
- [5] Zhang, G., Cai, M. and Hu, A. (2013) Energy consumption and the unexplained winter warming over Northern Asia and North America. *Nat. Clim. Chang*. 3(5), 466–470.

- [6] Rozema, J. and Flowers, T. (2008) Crops for a salinized world. *Science*. 322, 1478–1480.
- [7] Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S.M.A. (2009) Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Development*. 29, 185–212.
- [8] Farooq, M., Hussain, M., Wakeel, A. and Siddique, K.H.M. (2015) Salt stress in maize: effects, resistance mechanisms and management. A review. *Agron. Sustain. Development*. 35, 461–481.
- [9] Shaikh, F., Gul, B., Li, W.Q., Liu, X.J. and Khan, M.A. (2007) Effect of calcium and light on the germination of *Urochondra setulosa* under different salts. *J. Zhejiang Univ. Sci. B*. 8, 20–26.
- [10] Geilfus, C.M., Zörb, C., Neuhaus, C., Hansen, T., Lüthen, H. and Mühling, K.H. (2011) Differential transcript expression of wall-loosening candidates in leaves of maize cultivars differing in salt resistance. *Journal of Plant Growth Regulation*. 30, 387–395.
- [11] Alam, S.M. (1999) Nutrient uptake by plants under stress conditions. *Handbook of plant and crop stress*. 2, 285–313.
- [12] Benlioglu, B. and Ozkan, U. (2021) The Influence of Salinity and Drought Stress on Some Oat Cultivars (*Avena Sativa* L.) by Determining Some Stress Indices and Growth Performances at The Germination Stage. *Tekirdag Agriculture Faculty Journal*. 17(3), 318–328.
- [13] Chen, X., Zhang, R., Xing, Y., Jiang, B., Li, B., Xu, X. and Zhou, Y. (2021) The efficacy of different seed priming agents for promoting sorghum germination under salt stress. *Plos One*. 16(1), e0245505.
- [14] Pereira, I.C., Catão, H.C. and Caixeta, F. (2020) Seed physiological quality and seedling growth of pea under water and salt stress. *Revista Brasileira de Engenharia Agrícola e Ambiental*. 24(2), 95–100.
- [15] Kulkarni, M. and Deshpande, U. (2007) In vitro screening of tomato genotypes for drought resistance using polyethylene glycol. *Afr. J. Biotechnol.* 6(6), 691–696.
- [16] Khayatnezhad, M., Gholamin, R., Jamaatie-Somarin, S.H. and Zabihi-Mahmoodabad, R. (2010) Effects of peg stress on corn cultivars (*Zea mays* L.) at germination stage. *World Appl. Sci. J.* 11(5), 504–506.
- [17] Emery, D.E. (1988) Seed Propagation of Native California Plants. Santa Barbara Botanic Garden, Santa Barbara, CA. 115.
- [18] Ozkan, U. (2020). Forage Yield and Nutritive Values of *Phacelia (Phacelia tanacetifolia* Benth.) as affected by different nitrogen doses under warm temperate type climate in Turkey. *J. Anim. Plant Sci.* 46(2), 8175–8186.
- [19] Gilbert, L. (2003) *Phacelia tanacetifolia*: what we know about its suitability as an insectary plant and cover crop in the Mid-Atlantic region. Small Farm Success Project, Sustainable Agricultural Systems Lab. USDA, USA.
- [20] Petanidou, T. (2003) Introducing plants for bee-keeping at any cost?—Assessment of *Phacelia tanacetifolia* as nectar source plant under xeric Mediterranean conditions. *Plant Systematics and Evolution*. 238(1), 155–168.
- [21] Yıldız, M. and Ozgen, M. (2004) The effect of a submersion pretreatment on in vitro explant growth and shoot regeneration from hypocotyls of flax (*Linum usitatissimum*). *Plant Cell, Tissue and Organ Culture*. 77(1), 111–115.
- [22] SAS, Institute Inc. (2015) JMP® Statistical Discovery Software, version 12.0; SAS Institute Inc., Cary, NC, USA.
- [23] Ahmadi, G., Akbarabadi, A., Kahrizi, D., Rezaizad, A. and Gheytooli, M. (2012) Study of drought tolerance of bread wheat (*Triticum aestivum* L.) genotypes in seedling stage. *Biharean Biologist*. 6(2), 77–80.
- [24] Ailin Chichizola, G., Edit Rovere, A. and Gonzalez, S.L. (2019) Germination of *Phacelia secunda* (Boragina-ceae) and *Eryngium paniculatum* (Apiaceae), perennial herbs from Patagonia Argentina. *Revista Peruana de Biología*. 26(3), 311–316.
- [25] Gheidary, S., Akhzari, D. and Pessarakli, M. (2017) Effects of salinity, drought, and priming treatments on seed germination and growth parameters of *Lathyrus sativus* L. *Journal of Plant Nutrition*. 40(10), 1507–1514.
- [26] Pantola, S., Bargali, K.V. and Bargali, S.S. (2017) Screening of three leguminous crops for drought stress tolerance at germination and seedling growth stage. *Indian Journal of Agricultural Sciences*. 87(4), 467–472.
- [27] Moghanibashi, M., Karimmojeni, H., Nikneshan, P. and Behrozi, D. (2012) Effect of hydropriming on seed germination indices of sunflower (*Helianthus annuus* L.) under salt and drought conditions. *Plant Knowledge Journal*. 1(1), 10.
- [28] Davies, W.J. and Bacon, M.A. (2003) Adaptation of root to drought. In: *Root Ecology*. (De Kroon, H. and Visser, E.J.W. Eds.). Springer-Verlag, Berlin, Germany. 173–192.
- [29] Franco, J.A., Bañón, S., Vicente, M.J., Miralles, J. and Martínez-Sánchez, J.J. (2011) Root development in horticultural plants grown under abiotic stress conditions – a review. *The Journal of Horticultural Science and Biotechnology*. 86(6), 543–556.
- [30] Okcu, G., Kaya, M.D. and Atak, M. (2005) Effects of salt and drought stresses on germination and seedling growth of pea (*Pisum sativum* L.). *Turkish Journal of Agriculture and Forestry*. 29(4), 237–242.

- [31] Kaya, M.D., Okcu, G., Atak, M., Cikili, Y. and Kolsarici, O. (2006) Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). European Journal of Agronomy. 24(4), 291-295.
- [32] Avci, S., Ileri, O. and Demirkaya, M. (2017) Determination of Genotypic Variation among Sorghum Cultivars for Seed Vigor, Salt and Drought Stresse. Journal of Agricultural Sciences. 23(3), 335-343.
- [33] Jovović, M., Tunguz, V., Miroslavljević, M. and Pržulj, N. (2018) Effect of salinity and drought stress on germination and early seedlings growth of bread wheat (*Triticum aestivum* L.). Genetika. 50(1), 285-298.
- [34] Krishnamurthy, L., Serraj, R., Hash, C.T., Dakheel, A.J. and Reddy, B.V.S. (2007) Screening sorghum genotypes for salinity tolerant biomass production. Euphytica. 156, 15-24.
- [35] Hamid, M., Ashraf, M.Y., Rehman, K.U. and Arshad, M. (2008) Influence of salicylic acid seed priming on growth and some biochemical attributes on wheat growth under saline conditions. Pak. J. Botany. 40(1), 361-367.
- [36] Patade, V.Y., Bhargava, S. and Suprasanna, P. (2009) Halopriming imparts tolerance to salt and PEG induced drought stress in sugarcane. Agriculture, Ecosystems & Environment. 134(1-2), 24-28.
- [37] Marcos Filho, J. (2015) Seed vigor testing: an overview of the past, present and future perspective. Scientia Agricola. 72(4), 363-374.
- [38] Ahmadi, M. and Yadegari, M. (2014) The effect of salinity and drought stress on seed germination, seedling growth and biochemical changes in Borago. Advances in Environmental Biology. 8(17), 1082-1087.

Received: 14.06.2021

Accepted: 08.08.2021

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