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Seed germination and seedling growth parameters in nine tall fescue varieties under salinity stress

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ABSTRACT

To assess seed germination parameters and identifying tolerant varieties, seeds of nine tall fescue varieties (*Festuca arundinacea* Schreb.) were germinated under various salinity levels for 14 days. Tall fescue is considered 'moderately tolerant' to salinity stress, but our study revealed a remarkable diversity among the tested varieties. Armani, Essential, Fatcat, and Starlett were found to reach the same final germination (>90%), irrespective of NaCl concentration up to 15 ds m^{-1} NaCl; Asterix and Meandre expressed lower germination under the highest salinity level (>75%); and final germination decreased in Eyecandy, Rhizing star, and Thomahawk gradually with increasing salinity (>55%). The main effect of increasing salinity was a delay in germination, and our study suggests that the recording of final germination, which is performed on day-14 in a standard germination test, should be postponed in order to understand the full effect of salinity on germination potential. Nonetheless, a delay in germination will affect turf quality negatively and hence there is good reason to test for salinity tolerance when choosing a variety for sowing on saline soil. Further, our findings indicate a future perspective for breeding for improved salinity tolerance in tall fescue by the identification of salinity-tolerant breeding lines or varieties.

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Cumulative germination percentage; germination rate; salinity tolerance; salt stress; vigour index

Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is a cool-season grass broadly used for home lawns, golf courses and other sports grounds (Hatamzadeh et al. 2014). It has an extensive adaptation to different abiotic stresses such as heat, drought, and high soil pH, and therefore it can be used in salt-affected soils (Carrow 1996a, 1996b; Gao and Li 2012, 2014); in other words, it is assumed that the main contributor of its high persistence could be the possibility of summer dormancy and expansion of a considerable root system, as well (Pirnajmedin et al. 2016). Manuchehri and Salehi (2015) found that tall fescue has a salinity tolerance threshold value of 3.9 ds m^{-1}, and several studies have shown that among cool-season turfgrass species, tall fescue has an intermediate to high salinity tolerance (Lunt et al. 1961; Alshammary et al. 2004; Friell et al. 2012).

Salinity stress is becoming a more serious problem in turfgrass management, particularly in arid and semi-arid regions. Due to declining freshwater availability, the use of non-potable water with high levels of salts, for example, recycled, effluent or reclaimed water, is becoming a considerable source of irrigation for turfgrass (Alshammary et al. 2004; Huang et al. 2017). High soil salinity can also be caused by other conditions, such as low precipitation, water percolation from high water tables, salts from fertilisers and road de-icers (Zhang et al. 2013), and higher temperatures combined with increased evaporation caused by changing climate (Carlos et al. 2018).

Salinity is one of the most detrimental environmental factors restricting plant growth and development worldwide (Reddy et al. 2017). The harmful effects of high salinity can be detected during the whole life cycle from inhibition or delay in germination to the death of plants (Parida and Das 2005). Salt stress can affect plants in several ways including disordered ion homeostasis due to decreased plant water uptake ability (Zanetti et al. 2019), accumulation of Na^+ and Cl^- causing hyperosmotic stress (Foti et al. 2018), toxicity (Zanetti et al. 2019), and high quantity of dissolved ions in the soil environment, in addition to Na^+, Cl^- including SO_4^{2-}, HCO_3^-, and rarely K^+, Ca^{2+}, Mg^{2+}, NO^{3-} (Kujawska et al. 2020). A high concentration of absorbed Na^+ may restrict K^+ uptake and disrupt regulation of stomatal conductance resulting in significant water loss and dehydration (Dai et al. 2014).

Furthermore, a high uptake of Cl^- may lead to chlorophyll damage (Tavakkoli et al. 2010). It also is able to

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critically decrease grass quality and ornamental appearance (Chen et al. 2014).

Seed germination and seedling growth are important phases in the successful establishment of the plant (Ibrahim 2016). Germination takes place when the environmental conditions (for example temperature, moisture, light and oxygen) are suitable (Arias et al. 2018). Salt stress induces toxic effects in the germinating seeds, and under high salinity stress, seed germination, seedling growth and establishment, and root and shoot length are significantly reduced (Murillo-Amador et al. 2002; Liang et al. 2018).

In a newly seeded turf, rapid germination and plant establishment are important to increase the competition against weeds. Similarly, in established turf, gaps in plant cover will allow weeds to establish which reduces turf quality. Restoring turf is performed by reseeding which is costly and time-consuming and, in salt-influenced areas, requires access to varieties with tolerance to salinity stress (Ouji et al. 2015). Warm season grasses are generally considered more salt tolerant than cool season grasses but they have a relatively long period of dormancy caused by low temperatures. To prolong the playing period when turf is used for golf courses and other sports grounds, cool season grasses are overseeded in autumn and tall fescue has been shown a good candidate for overseeding into zoysia grass (*Zoysia japonica* Steud.) (Yin et al. 2014). Hence, identification and development of salinity-tolerant varieties is useful for long-term sustainable management of turfgrass. There are contrasting reports concerning the effect of salinity on germination in tall fescue. A reduction in final germination was found by Horst and Beadle (1984), and Zhang et al. (2011) by exposing seeds to salinity levels up to 23.4 and 26.1 ds m^{-1}, respectively. In contrast, screened tall fescue at salinity levels up to 22.5 ds m^{-1} and found no effect on final germination.

The objective of this study was to investigate and compare seed germination and growth parameters of tall fescue subjected to different levels of salinity stress. There are contrasting findings in this field, but most reports are based on the characterisation of one or two varieties per species. The further aim was therefore to elucidate the range of variation in salinity tolerance among nine tall fescue turf varieties.

Material and methods

Plant material

Nine commercial varieties of tall fescue ('Armani', 'Asterix', 'Essential', 'Eyecandy', 'Fatcat', 'Meandre', 'Rhizing star', 'Starlett' and 'Tomahawk') were provided by the seed companies DLF and DSV Frø Danmark A/S. During the experiment, the seeds were kept in paper bags at room temperature (22 ± 2°C). From each variety, 4 × 25 seeds were characterised for physical parameters (area, seed length and diameter) using a VideometerLab instrument (Videometer A/S, Hørsholm, Denmark). Information from multispectral images captured at 19 different wavelengths from visible light to the near-infrared region (375–970 nm) were used to determine length, diameter and area of each individual seed. Thousand seed weight (TSW) was calculated based on the weight of four subsamples of 100 seeds. Further, each variety was characterised by a standard germination test (ISTA 2018) using 4 × 100 seeds.

Salinity stress treatments and experimental design

Seeds were surface-sterilised for 2 min in a 13.5% hypochlorite/H_2O solution, with gentle mixing, then rinsed three times with distilled water. Salinity stress treatments were created using NaCl at five concentrations (3, 6, 9, 12 and 15 ds m^{-1}, equivalent to 30, 60, 90, 120 and 150 mmol l^{-1}). Distilled water was used as the non-saline control (0 ds m^{-1}). Germination tests were carried out in Petri dishes (90 mm-diameter) with one layer of filter paper. Five millilitres of the desired saline solution or distilled water were applied to each Petri dish and after the placement of seeds (four replicates of 40 seeds each, for each salinity concentration), they were sealed with Parafilm to avoid evaporation. The Petri dishes were placed randomly in a germinator with alternating 30°C 8 h, 20°C 16 h. The germination test was performed following the International Seed Testing Association's rules for tall fescue (ISTA 2018), but in this experiment the number of germinated seeds was recorded on a daily basis from 2 to 14 days from sowing. Seeds were considered germinated when the radicle was at least 2 mm long.

Measurements

Salinity tolerance was measured based on final germination (%), germination rate (GR), length (mm) of roots and shoots on day-7 and day-14 expressed as the mean of five randomly selected seeds per replicate, root to shoot ratio (R:S), and seedling vigour index (SVI) on day-7 and day-14. GR was calculated as:

$$\mathrm{GR} = \sum G_i / T_i$$

where *G* is the number of seeds germinated and *t* is the number of days from start of germination and *i* = day of scoring. Seedling vigour index (SVI) was calculated following the modified formula (Abdul-Baki and Anderson 1973).

$$\text{SVI} = \text{shoot lengh (mm)} \times \text{germination percentage}$$

Statistical analysis

Data were analysed by ANOVA. For all data, normality of the residuals were analysed by the Shapiro–Wilk test. Data sets where the residuals did not follow a normal distribution were arcsine-transformed. Differences between means were compared using the least significant difference (LSD) values from Duncan's multiple range test. All statistical analyses were performed using SAS statistical software version 9.3 (SAS 2011).

Results

There was some variation in the size and 1000-seed weight of the nine varieties of tall fescue (Table 1). Seeds of 'Starlett' appeared to have the highest area and length, and were relatively wide, but were not the heaviest. Conversely, seeds of 'Eyecandy' were relatively small with respect to area and length, but had the highest 1000-seed weight. In the initial germination test, final germination ranged between 92% and 99% with the exception of seeds of 'Rhizing star' and 'Asterix', with 85% and 86% germination, respectively.

The seeds of the different tall fescue varieties responded differently to salinity (Figure 1). Final germination was not affected by salinity for 'Armani', 'Essential', 'Fatcat' and 'Starlett'. In 'Asterix' and 'Meandre' only the highest salinity level decreased final germination, whereas it was gradually decreased in 'Eyecandy', 'Rhizing star' and 'Tomahawk' with increasing salinity. A standard germination test contains evaluation on both day-7 and day-14 (final germination) and for all varieties, germination on day-7 was affected by salinity. The results shown in Table 2 confirm these findings as the overall germination rate decreased as the salinity level increased from 6 to 15 ds m^{-1}. Even the four varieties unaffected by salinity at day-14 expressed a lower germination rate at higher salinity levels.

The nine varieties showed variability in germination rate in the control treatment, with seeds of 'Armani' showing the fastest germination rate (GR = 11.09; Table 2) with 94% germination on day 3 (Figure 1) and seeds of 'Rhizing star' the slowest (GR = 6.40; Table 2) with 1% germination on day 3 (Figure 1). The GR was not significantly reduced at 3 ds m^{-1}, except for seeds of 'Armani' and 'Meandre', although seeds of 'Rhizing star' still showed the lowest GR (Table 2). Further increases in salinity resulted in decreases in GR for all varieties, with the greatest percentage reduction seen in 'Eyecandy' (declining from 7.96 at 3 ds m^{-1} to 1.90 at 15 ds m^{-1}).

Seed vigour index (SVI) calculated for day-7 and day-14 decreased with increasing salinity level (Table 3). Among the varieties, 'Rhizing star' had the lowest SVI at any salinity level and 'Armani', 'Essential', 'Eyecandy', 'Fatcat' and 'Starlett' had the highest SVI in the control and the 3 ds m^{-1} NaCl treatment on day-14. In the high salinity treatments (12 and 15 ds m^{-1}), SVI was highest in 'Armani', 'Essential' and 'Fatcat'.

Root length of all varieties decreased with increasing salinity level (Figure 2). The longest roots were recorded in 'Starlett' in the control and the 3 ds m^{-1} NaCl treatment, but at higher salinity levels, it exhibited the highest reduction rates (68%, 80%, 80% and 98% at 6, 9, 12 and 15 ds m^{-1}, respectively). At 15 ds m^{-1}, 'Starlett' had the shortest roots. Salinity also affected the root length in 'Armani', 'Essential', 'Eyecandy', 'Rhizing star' and 'Tomahawk' with decreasing root length with increasing salinity level, but in these varieties the decline in root length was less than for 'Starlett'. The longest roots at the highest salinity levels were found in 'Armani', 'Asterix', 'Essential' and 'Fatcat'.

The shoot length of all varieties showed a similar trend as root length (Figure 3). In the control treatment, 'Essential' exhibited the longest shoots, whereas 'Asterix'

Table 1. Seed characteristics of nine tall fescue varieties (area, length, diameter, 1000-seed weight and germination) and their standard error (SE).

Variety	Area (mm^2)	SE	Seed length (mm)	SE	Seed diameter (mm)	SE	1000-seed weight* (g)	Germination* (%)
Asterix	5.8	1.0	6.1	0.7	1.4	0.1	0.1	93
Armani	5.7	0.9	6.1	0.7	1.3	0.1	0.2	95
Essential	5.4	0.8	5.9	0.6	1.2	0.1	0.2	93
Eyecandy	5.1	0.8	5.5	0.5	1.3	0.1	0.2	95
Fatcat	5.5	0.8	5.9	0.6	1.4	0.1	0.2	93
Meandre	5.5	0.9	5.7	0.7	1.4	0.1	0.2	94
Rhizing star	5.6	0.7	6.0	0.5	1.3	0.1	0.1	86
Starlett	6.0	0.9	6.4	0.7	1.4	0.1	0.2	97
Tomahawk	5.7	1.0	5.9	0.7	1.4	0.1	0.2	94

*Information on 1000-seed weight and germination is provided by the seed companies based on ISTA analysis.

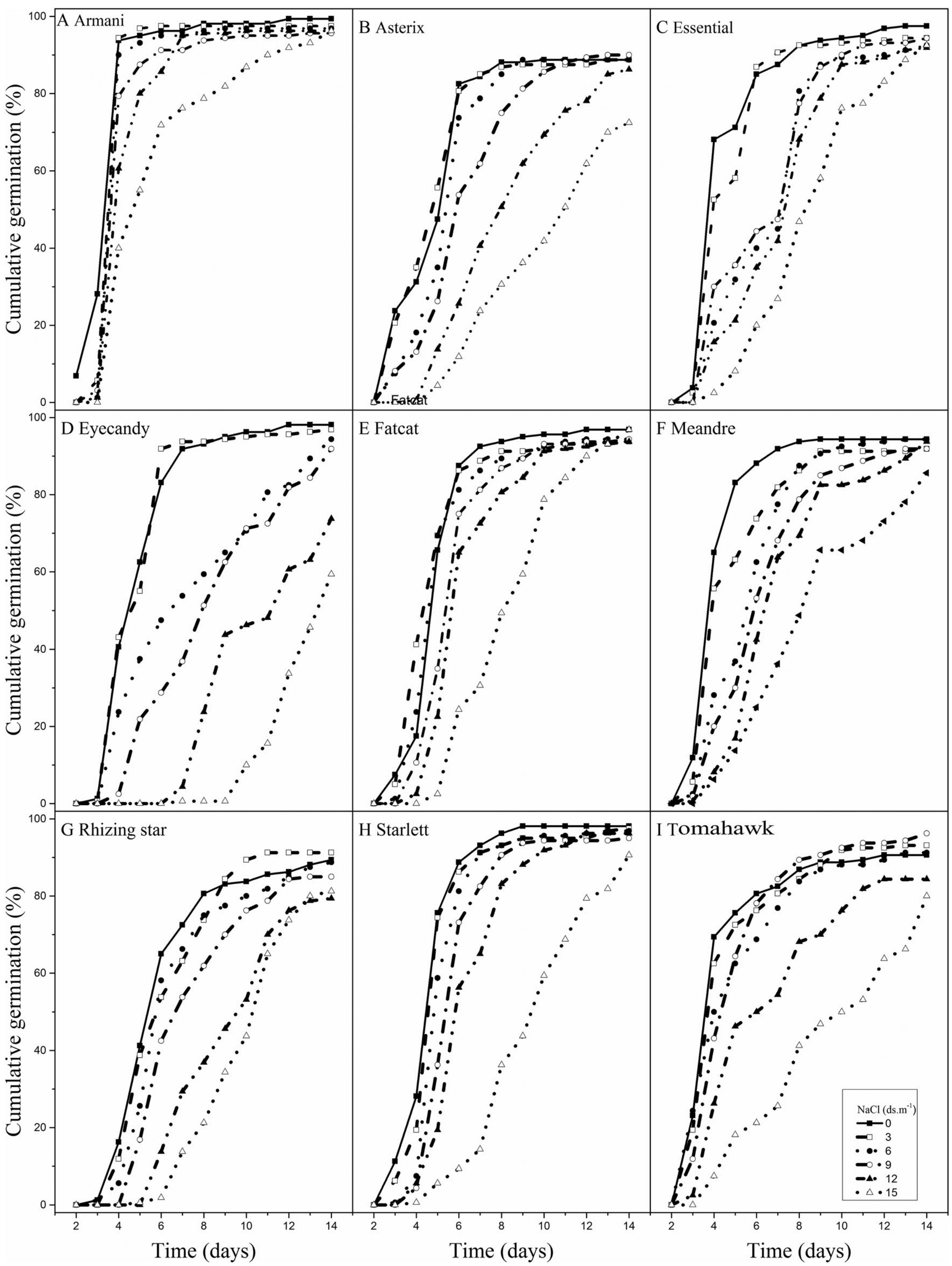

Figure 1. Seed germination (%) in tall fescue as affected by salinity stress. The varieties (a) 'Arman', (b) 'Asterix', (c) 'Essential', (d) 'Eyecandy', (e) 'Fatcat', (f) 'Meandre', (g) 'Rhizing star', (h) 'Starlett' and (j) 'Tomahawk' were subjected to six NaCl concentrations (0, 3, 6, 9, 12 and 15 ds m^{-1}) over a 14-day germination period. Within each variety, final germination values with different letters show significant difference at $p < 0.05$.

was the variety with the shortest shoots at 15 ds m^{-1} NaCl. At low stress levels (control, 3 and 6 ds m^{-1}), most varieties did not show statistical differences. In contrast, at higher stress levels (9, 12 and 15 ds m^{-1}), the shoot length was reduced in all varieties. 'Eyecandy' showed the highest reduction rate and at the two

Table 2. Effect of salinity stress on germination rate of seeds of nine tall fescue varieties subjected to six NaCl concentrations over a 14-day germination period and standard error (SE).

	NaCl concentration ($ds\ m^{-1}$)											
Variety	0	SE	3	SE	6	SE	9	SE	12	SE	15	SE
Armani	11.0 aA	0.3	9.8 bB	0.3	9.5 bA	0.3	9.1 bcA	0.6	8.6 cA	0.4	7.3 dA	0.7
Asterix	7.8 aC	0.3	7.9 aB	1.3	6.7 bCD	0.5	6.1 bC	0.5	4.6 cC	0.5	3.3 dD	0.4
Essential	8.6 aB	0.6	8.0 aB	0.7	6.0 bED	0.4	6.4 bC	0.6	5.5 bB	0.2	4.6 cBC	0.3
Eyecandy	7.9 aC	0.4	7.9 aB	0.3	6.0 bED	0.0	4.9 cD	0.3	3.0 dE	0.7	1.9 eE	0.4
Fatcat	7.7 aC	0.2	8.0 aB	0.7	7.4 abBC	0.3	6.6 bC	0.2	6.0 bB	0.3	4.7 cB	0.1
Meandre	9.0 aB	0.3	7.9 bB	0.1	6.9 cC	0.2	6.3 cdC	0.1	5.6 dB	0.2	4.6 eBC	0.1
Rhizing star	6.4 aD	0.4	6.1 aC	0.6	5.7 abE	0.6	5.0 bD	0.7	3.7 dcD	0.5	3.4 cD	0.1
Starlett	8.3 aBC	0.4	7.8 aB	0.4	7.1 bC	0.4	6.5 cC	0.1	6.0 cB	0.3	4.0 dC	0.1
Tomahawk	9.0 aB	0.2	8.7 abB	0.4	8.3 abB	0.6	8.1 abB	0.6	6.1 cB	0.55	4.1 dC	0.4

Notes: Data are the mean of four replicates (± standard error). Values with different letters show significant difference at $p < 0.05$ as determined by Duncan's multiple range test; lower-case letters in rows relate to differences between salinity levels within each variety and capital letters in columns relate to differences between varieties within each NaCl concentration.

Table 3. The effect of salinity on the seedling vigour index (SVI) of nine tall fescue varieties subjected to six NaCl concentrations. The SVI was calculated on day 7 and day 14 of germination.

Time	Variety	NaCl concentration ($ds\ m^{-1}$)											
(day)		0	SE	3	SE	6	SE	9	SE	12	SE	15	SE
7	Armani	2390.0aA	114.5	1537.5bA	157.7	1464.9bA	156.1	623.1dcA	67.5	944.4bcA	429.8	0.0dA	0.0
	Asterix	1016.8aC	71.7	451.4bC	40.2	118.6bcBC	56.8	110.8bcBC	21.8	0.0cB	0.0	0.0cA	0.0
	Essential	1159.3aC	69.2	1124.1abB	78.7	214.1bcBC	159.9	308.1dcB	82.5	42.0deB	31.4	0.0eA	9.8
	Eyecandy	375.4aD	160.7	238.5aD	89.2	0.0bC	0.0	0.0bC	0.0	0.0bB	0.0	0.0bA	0.0
	Fatcat	959.3aC	56.9	944.8 aB	75.8	471.1bB	22.4	69.4cBC	40.2	14.6 cB	0.0	0.0cA	0.0
	Meandre	1064.4abC	150.5	1028.8abB	127.6	1252.0aA	370.5	607.0bcA	183.4	92.5 dcB	92.5	0.0dA	0.0
	Rhizing star	271.6aD	71.7	69.8bD	40.1	119.9bBC	56.7	21.8bC	21.7	0.0bB	0.0	0.0bA	0.0
	Starlett	411.5aD	90.4	380.3aD	56.0	207.1bC	70.6	109.4bcBC	16.4	39.0cB	39.0	9.8cA	0.0
	Tomahawk	1706.3aB	400.8	1533.1aA	216.6	1480.0aA	132.1	582.5bA	142.9	403.1bB	100.6	0.0bA	0.0
14	Armani	4365.0aAB	76.08	3999.4aABC	225.2	3775.0aB	123.7	3827.5aA	64.7	2963.1bA	43.4	747.5cB	443.4
	Asterix	3658.8aC	128.9	3482.2aDC	294.2	3400.0baBC	260.0	1873.1bD	637.1	542.1 cCD	254.7	76.9cCD	41.3
	Essential	4827.5aA	106.9	4016.3aABC	309.5	3392.5bcBC	437.0	2868.1bABCD	303.2	2177.5cAB	438.0	1238.1cA	258.4
	Eyecandy	4393.8aAB	208.0	3728.1aBCD	151.0	2538.1bC	561.1	603.8cE	125.7	0.0cD	0.0	0.0cD	0.0
	Fatcat	4261.3abB	345.3	4587.5abA	278.6	4808.8aA	196.9	3645.0bcAB	609.1	3047.5cA	213.7	764.6dB	105.2
	Meandre	4012.5aC	129.3	3262.5bD	242.9	3164.2bBC	153.5	3063.5bABC	151.2	665.0cCD	134.4	361.3cC	35.3
	Rhizing star	3010.6aD	128.9	3271.3aD	249.2	2985.6aC	260.0	2606.3aBCD	637.0	369.0bD	254.7	41.3bCD	41.2
	Asterix	3658.8aC	128.9	3482.2aDC	294.2	3400.0baBC	260.0	1873.1bD	637.1	542.1 cCD	254.7	76.9cCD	41.3
	Tomahawk	3603.8abC	135.1	3840. aBCD	87.9	3053.1bcBC	136.4	2388.8cCD	453.3	1306.3dBC	221.1	260.0eD	163.9

Notes: Data are the mean of four replicates (±standard error). Values with different letters show significant difference at $p < 0.05$ as determined by Duncan's multiple range test; lower-case letters in rows relate to differences between salinity levels within each variety and capital letters in columns relate to differences between varieties within each NaCl concentration.

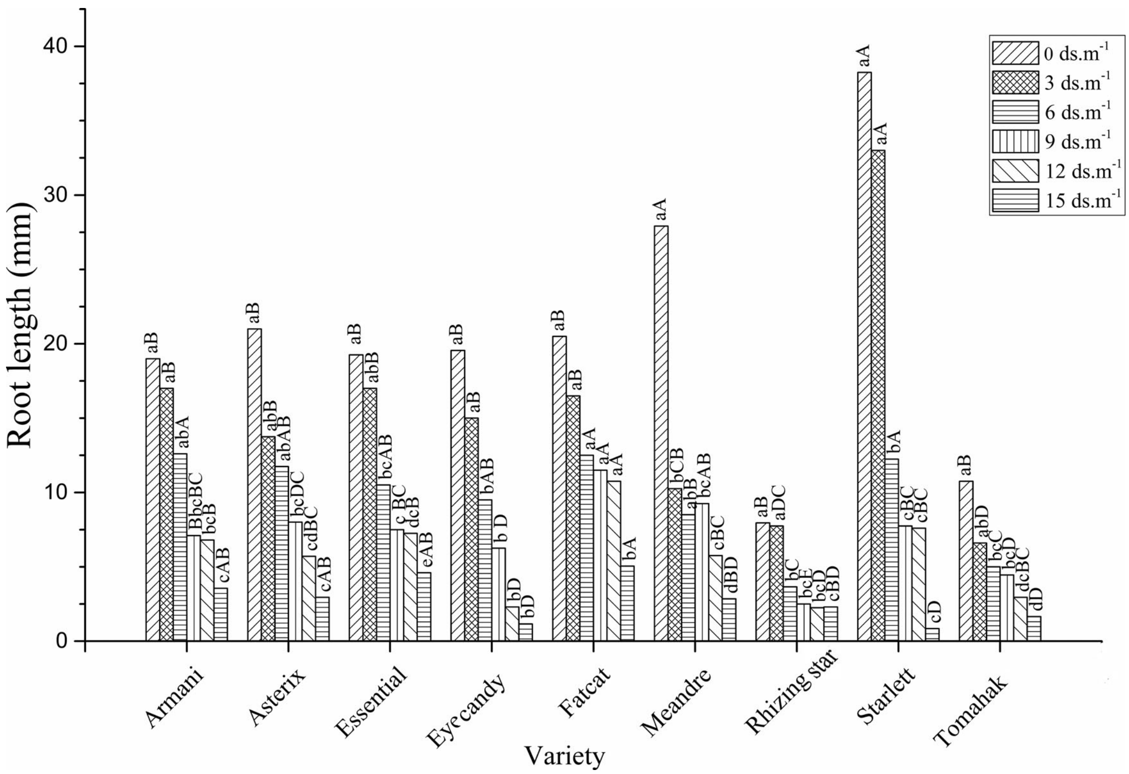

Figure 2. Effect of salinity stress on the root length (mm) of 14-day-old seedlings of nine tall fescue varieties subjected to six NaCl concentrations (ds m^{-1}). Data are the mean of four replicates. Values with different letters show significant difference at $p < 0.05$; lower-case letters relate to difference between salinity levels within each variety and capital letters relate to differences between varieties within each NaCl concentration.

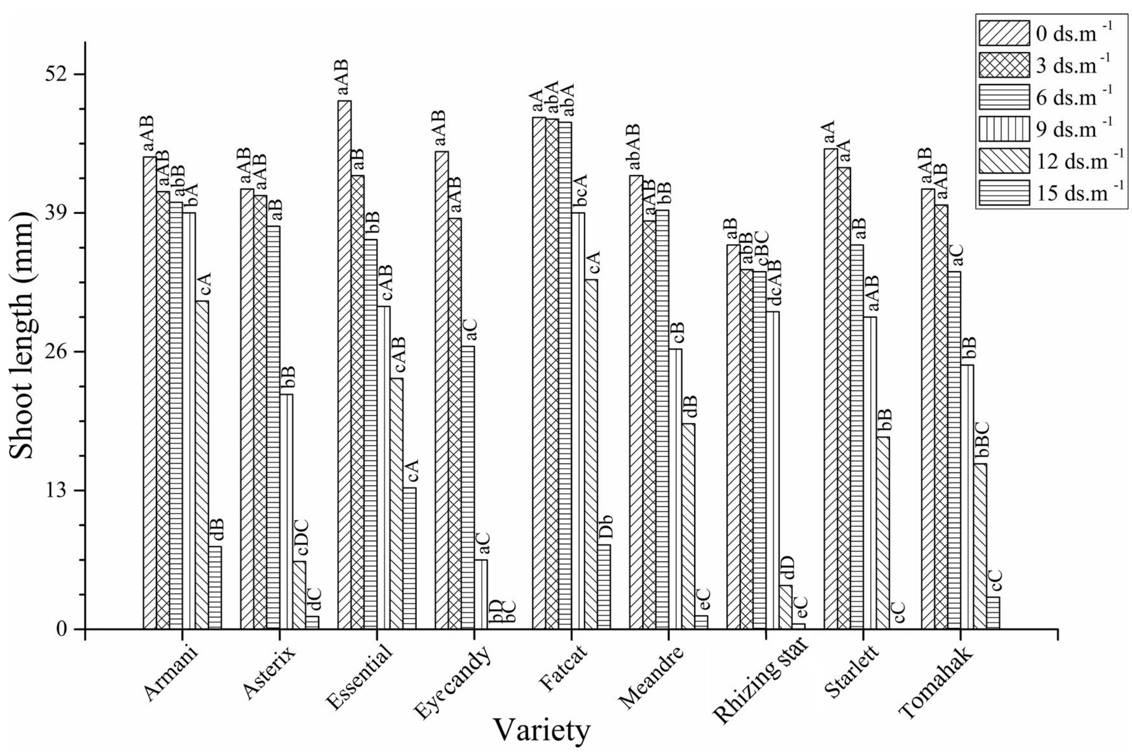

Figure 3. Effect of salinity stress on the shoot length (mm) of 14-day-old seedlings of nine tall fescue varieties subjected to six NaCl concentrations (ds m^{-1}). Data are the mean of four replicates. Values with different letters show significant difference at $p < 0.05$; lower-case letters relate to differences between salinity levels within each variety and capital letters relate to differences between varieties within each NaCl concentration.

highest salinity levels shoot growth was inhibited. Similarly, 'Starlett' had no shoots at 15 ds m^{-1}. In general, shoot length was more negatively affected by increasing salinity than root length.

Root to shoot ratio (R:S) was calculated (data not shown). There was a tendency to a decreasing R:S with increasing salinity up to 6 ds m^{-1}, but a further increase in salinity level increased R:S. 'Rhizing star', 'Asterix' and 'Meandre' showed a higher R:S (4.6, 2.46 and 2.28, respectively) compared with other varieties.

Discussion

The current study identified a variation in salinity tolerance during germination and early seedling growth in tall fescue. Four ('Fatcat', 'Starlett', 'Essential' and 'Armani') of the nine varieties included in the study reached the same final germination irrespective of NaCl concentration in the interval 0–15 ds m^{-1}, two varieties ('Asterix' and 'Meandre') had lower germination under the highest salinity level and in the remaining three varieties ('Rhizing star', 'Eyecandy' and 'Thomahawk'), final germination decreased gradually with increasing salinity (Figure 1). Our results showed that salinity stress delayed germination, which is in agreement with studies by Rubio-Casal et al. (2003), Ouji et al. (2015), Foti et al. (2018) and, Melendo and Giménez (2018). When final germination was recorded (day-14), some seed lots tested under high salinity levels were still in the process of germination. Therefore, it may be necessary to allow for a longer germination period by postponing the scoring of final germination beyond day-14 in order to record the full potential under salinity stress.

There is limited information concerning differences in salinity tolerance among turfgrass species, and the available reports date back to when there was limited focus on breeding for turfgrass quality and stress tolerance. Ali Harivandi et al. (1992) rated tall fescue 'moderately tolerant' to salt stress, which they categorised as being tolerant to salinity levels of 6–10 ds m^{-1}. Wheatgrass (*Agropyron cristatum* L.), perennial ryegrass (*Lolium perenne* L.), red fescue (*Festuca rubra* L.), and switchgrass (*Panicum virgatum L.*) were also classified 'moderately tolerant' together with tall fescue. Among the cool-season turfgrasses, the authors only rated alkali grass (*Puccinellia* spp.) as 'tolerant': able to grow at salt levels equivalent to >10 ds m^{-1}. In our study, this salinity level did not affect final germination in 'Armani', 'Asterix', 'Essential', 'Fatcat', 'Meandre' and 'Starlett', but it reduced the germination rate in all varieties except 'Armani'. Marcum (2006) also classified alkali grass as more tolerant to salt stress than tall fescue with a 50% decrease in growth for three alkali grass species and one tall fescue variety ('Alta') grown in 12–18 and 7 ds m^{-1}, respectively, in soil saturated paste extract (ECe). Alshammary et al. (2004) distinguished between salt stress levels for 50% reduction in root and shoot lengths in four grass species. In general, the reported salt stress levels were a bit higher than reported by Marcum (2006), but the ranking of species according to salt tolerance level was the same. In tall fescue, R:S increased with increasing salt level (Alshammary et al. 2004), which was also found in the current study for salinity levels >6 ds m^{-1}.

Most studies of salt tolerance in turfgrasses evaluate growth and plant cover/plant density. However, fast establishment, which comprises germination and seedling growth, is important to avoid the growth of weeds and to improve turf quality. A reduction in seedling number and germination rate with increasing salt concentration was found in tall fescue by Horst and Beadle (1984), and Zhang et al. (2011). In the experiment performed by Horst and Beadle (1984) a variation in response to increasing salinity was found among varieties but no information about the germination in a non-stressed control was included. In the study by Zhang et al. (2011), two varieties were included. In contrast, Serena et al. (2012) saw no decline in germination in response to increasing salinity levels for the one variety used in their experiment. The recent study supports both of these contrasting findings depending on which variety is evaluated. This implies that to characterise salinity tolerance at the species level, several varieties should be screened.

While increasing salinity generally delayed germination with the consequence that seeds were still actively germinating under the high salinity levels at the time of recording final germination, the varieties 'Rhizing star' and 'Asterix' seemed to have reached the highest achievable germination for all salinity levels on day-14. The standard test showed a low final germination for these two varieties (Table 1). Thus, the current seed lots representing these two varieties might be of a poorer quality, perhaps older seed lots and hence they may also react differently to salinity stress. For a better characterisation of salt tolerance at variety level it would have been preferred to test a range of seed lots in each variety. 'Eyecandy' is the variety showing the strongest effect in response to the tested salinity levels with an interval from 98% to 59% final germination with increasing salinity levels.

There was limited variation in physical parameters among the seeds of all nine tall fescue varieties and all had a standard germination of 85% or above (Table 1), as required for certification according to the OECD standards. However, germination of 'Rhizing star' and 'Asterix' was very close to the threshold level, showing 85% and 86%, respectively.

Seedling growth parameters gradually decreased with increasing NaCl concentration, this is a common occurrence for plants under salt stress (Arias et al. 2018), as expressed by decreased root and shoot lengths (Tables 2 and 3) and this could reflect toxic effects along with insufficient water and nutrient uptake (Foti et al. 2018). As roots absorb water from soil, root length can be one of the most important traits for assessing salt stress. Salinity is found to increase the osmotic potential and results in ion toxicity by inducing cellular dehydration and rising solute concentration in plants (Yang et al. 2018). High concentrations of NaCl may also inhibit the elongation of roots and shoots by lowering the water uptake by the plant for osmotic adjustments (Munns 2002). Reduction of shoot length might be caused by a higher accumulation of salts in the cell walls, which results in a more rigid cell wall that would diminish the turgor pressure efficiency and, consequently, cell enlargement and shoot elongation will be slower and shorter (Ouji et al. 2015). Another reason for the growth limitation at high salinity may be due to depletion of resources for growth (Alshammary et al. 2004). In other words, rapid accumulation of salt in plant organs might have obliged it to close its stomata to preserve water; this protective process may lead to alteration in photosynthate allocation (Zanetti et al. 2019).

The highest germination rate of tall fescue seeds was obtained in the distilled water control. Fast germination under non-saline conditions was also revealed for *Haloxylon recurvum* and *H. salicornicum*, halophytes of the Indian desert (Sharma and Sen 1989). It was suggested that this phenomenon is a mechanism to use the short availability of water after a rainfall event. Rapid germination ensures fast seedling establishment and thus reduced competition with other plant species in salt-affected areas. The seed vigour index decreased at increasing salinity levels for all varieties; similar results were obtained by Foti et al. (2018).

Tall fescue varieties were found to possess a wide range of variation in salinity tolerance, which is in agreement with findings in *Poa annua* as reported by Dai et al. (2009). This might be the explanation for contrasting findings of the effects of salinity in tall fescue as identified in reports from Horst and Beadle (1984), Leinauer et al. (2012) and Zhang et al. (2011). These findings are based on a limited number of varieties tested and our data highlight the importance of evaluating a range of varieties to characterise the range of diversity in this trait. The review by Huang et al. (2014) addresses the reported variation in ranking of salinity tolerance and points to the importance of the parameters used for the evaluation, variable growing conditions or the method for imposing salinity. Our study revealed, that tall fescue varieties possess a wide range of variation in salinity tolerance and we identified varieties with a tolerance to salinity levels higher than previously reported for this species. With the increased frequency of saline soils, in particular on golf courses and other sports grounds, where the availability of fresh water resources for irrigation is limited, there is an increasing demand for turfgrasses with demonstrated salinity tolerance.

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Disclosure statement

The authors assert that there is no conflict of interest.

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References

Abdul-Baki AA, Anderson JD. 1973. Relationship between decarboxylation of glutamic acid and vigor in soybean seed. Crop Sci. 13(2):227. https://doi.org/10.2135/cropsci1973.0011183X001300020023x.

Ali Harivandi M, Butler JD, Wu L. 1992. Salinity and turfgrass culture. turfgrass, (turfgrass), 207–229.

Alshammary SF, Qian YL, Wallner SJ. 2004. Growth response of four turfgrass species to salinity. Agric Water Manag. 66 (2):97–111. https://doi.org/10.1016/j.agwat.2003.11.002.

Arias C, Serrat X, Moysset L, Perissé P, Nogués S. 2018. Morpho-physiological responses of alamo switchgrass during germination and early seedling stage under salinity or water stress conditions. Bioenergy Res. 11(3):677–688. https://doi.org/10.1007/s12155-018-9930-3.

Carlos FS, Schaffer N, Andreazza R, Morris LA, Tedesco MJ, Boechat CL, Camargo FADO. 2018. Treated industrial wastewater effects on chemical constitution maize biomass, physicochemical soil properties, and economic balance. Commun Soil Sci Plant Anal. 49(3):319–333. https://doi.org/10.1080/00103624.2018.1427257.

Carrow RN. 1996. Drought avoidance characteristics of diverse tall fescue cultivars. Crop Sci. 36(2):371–377.

Carrow RN. 1996. Drought resistance aspects of turfgrasses in the southeast: root-shoot responses. Crop Sci. 36(3):687–694. https://doi.org/10.2135/cropsci1996.0011183X003600030028x.

Chen J, Zong J, Gao Y, Chen Y, Jiang Q, Zheng Y, Liu J. 2014. Genetic variation of salinity tolerance in Chinese natural bermudagrass (*Cynodon dactylon* L.) Pers.) germplasm resources. Acta Agric Scand B Soil Plant Sci. 64(5):416–424.

Dai J, Huff DR, Schlossberg MJ. 2009. Salinity effects on seed germination and vegetative growth of greens-type *Poa annua* relative to other cool-season turfgrass species. Crop Sci. 49(2):696–703. https://doi.org/10.2135/cropsci2008.04.0221.

Dai LY, Zhang LJ, Jiang SJ, Yin KD. 2014. Saline and alkaline stress genotypic tolerance in sweet sorghum is linked to sodium distribution. Acta Agric Scand B Soil Plant Sci. 64 (6):471–481. https://doi.org/10.1080/09064710.2014.925574.

Foti C, Khah EM, Pavli OI. 2018. Germination profiling of lentil genotypes subjected to salinity stress. Plant Biol. https://doi.org/10.1111/plb.12714.

Friell J, Watkins E, Horgan B. 2012. Salt tolerance of 75 cool-season turfgrasses for roadsides. Acta Agric Scand B Soil Plant Sci. 62(sup1):44–52. https://doi.org/10.1080/09064710.2012.678381.

Gao Y, Li D. 2012. Detecting salinity stress in tall fescue based on single leaf spectrum. Sci Hortic. 138:159–164. https://doi.org/10.1016/j.scienta.2012.02.018.

Gao Y, Li D. 2014. Growth responses of tall fescue (*Festuca arundinacea* schreb.) to salinity stress. Eur J Hortic Sci. 79(3):123–128.

Hatamzadeh A, Nalousi AM, Ghasemnezhad M, Biglouei MH. 2014. The potential of nitric oxide for reducing oxidative damage induced by drought stress in two turfgrass species, creeping bentgrass and tall fescue. Grass Forage Sci. 70(30):538–548. https://doi.org/10.1111/gfs.12135.

Horst GL, Beadle NB. 1984. Salinity affects germination and growth of tall fescue cultivars [salt tolerance]. J Am Soc Hortic Sci. 109(3):419–422.

Huang B, DaCosta M, Jiang Y. 2014. Research advances in mechanisms of turfgrass tolerance to abiotic stresses; from physiology to molecular biology. *Crit Rev Plant Sci*. 33(2-3): 141–189. https://doi.org/10.1080/07352689.2014.870411.

Huang Q, Zhang H, Xue D. 2017. Enhancement of antioxidant activity of Radix Puerariae and red yeast rice by mixed fermentation with *Monascus purpureus*. Food Chem. 226:89–94. https://doi.org/10.1016/j.foodchem.2017.01.021.

Ibrahim EA. 2016. Seed priming to alleviate salinity stress in germinating seeds. J Plant Physiol. 192:38–46. https://doi.org/10.1016/j.jplph.2015.12.011.

ISTA. 2018. International rules for seed testing. Bassersdorf: International Seed Testing Association.

Kujawska J, Wasąg H, Gawryluk A. 2020. Assessment of drilling waste addition on the salinity of soils and growth of selected grass species. J Ecol Eng. 21(1):63–71.

Leinauer B, Maier B, Serena M, Schiavon M, Sallenave R. 2012. Media selection and seed coating influence germination of turfgrasses under salinity. HortScience. 47 (1):116–120.

Liang W, Ma X, Wan P, Liu L. 2018. Plant salt-tolerance mechanism: a review. Biochem Biophys Res Commun. 495(1):286–291. https://doi.org/10.1016/j.bbrc.2017.11.043.

Lunt OR, Youngner VB, Oertli JJ. 1961. Salinity tolerance of five turfgrass varieties. Agron J. 53(4):247. https://doi.org/10.2134/agronj1961.00021962005300040012x.

Manuchehri R, Salehi H. 2015. Morphophysiological and biochemical changes in tall fescue (*Festuca arundinacea* Schreb.) under combined salinity and deficit irrigation stresses. Desert. 20(1):29–38.

Marcum KB. 2006. Use of saline and non-potable water in the turfgrass industry: constraints and developments. Agric Water Manag. 80(1–3):132–146. https://doi.org/10.1016/j.agwat.2005.07.009.

Melendo M, Giménez E. 2018. All aspects of plant biology seed germination responses to salinity and temperature in *Limonium supinum* (Plumbaginaceae), an endemic halophyte from Iberian Peninsula. Plant Biosyst. 31:1–7. https://doi.org/10.1080/11263504.2018.1473303.

Munns R. 2002. Comparative physiology of salt and water stress. Plant Cell Environ. 25(2):239–250. https://doi.org/10.1046/j.0016-8025.2001.00808.x.

Murillo-Amador B, López-Aguilar R, Kaya C, Larrinaga-Mayoral J, Flores-Hernández A. 2002. Comparative effects of NaCl and polyethylene glycol on germination, emergence and seedling growth of cowpea. J Agron Crop Sci. 188(4):235–247. https://doi.org/10.1046/j.1439-037X.2002.00563.x.

Ouji A, El-bok S, Mouelhi M, Younes MB. 2015. Effect of salinity stress on germination of five Tunisian lentil. Eur Sci J. 11 (21):63–75.

Parida AK, Das AB. 2005. Salt tolerance and salinity effects on plants: a review. Ecotoxicol Environ Saf. 60(3):324–349. https://doi.org/10.1016/j.ecoenv.2004.06.010.

Pirnajmedin F, Majidi MM, Gheysari M. 2016. Survival and recovery of tall fescue genotypes: association with root characteristics and drought tolerance. Grass Forage Sci. *71*(4):632–640. https://doi.org/10.1111/gfs.12231.

Reddy INBL, Kim BK, Yoon IS, Kim KH, Kwon TR. 2017. Salt tolerance in rice: focus on mechanisms and approaches. Rice Sci. 24(3):123–144. https://doi.org/10.1016/j.rsci.2016.09.004.

Rubio-Casal AE, Castillo JM, Luque CJ, Figueroa ME. 2003. Influence of salinity on germination and seeds viability of two primary colonizers of Mediterranean salt pans. J Arid Environ. 53 (2):145–154. https://doi.org/10.1006/jare.2002.1042.

SAS. 2011. SAS/STAT 9.3 user's guide. Cary, NC: SAS Institute. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Sas/stat+9.3#1.

Sharma TP, Sen DN. 1989. A new report on abnormally fast germinating seeds of Haloxylon spp. An ecological adaptation to saline habitat. Curr Sci. 58(7):382–385.

Tavakkoli E, Rengasamy P, McDonald GK. 2010. High concentrations of Na^+ and Cl^- ions in soil solution have simultaneous detrimental effects on growth of faba bean under salinity stress. J Exp Bot. 61(15):4449–4459. https://doi.org/10.1093/jxb/erq251.

Yang A, Akhtar SS, Iqbal S, Qi Z, Alandia G, Saddiq MS, Jacobsen SE. 2018. Saponin seed priming improves salt tolerance in quinoa. J Agron Crop Sci. 204(1):31–39. https://doi.org/10.1111/jac.12229.

Yin S, Li Q, Liu W, Li D. 2014. Managing tall fescue and zoysiagrass mixtures as turfgrass in the transition zone. Agron J. 106(1):1–6. https://doi.org/10.2134/agronj2013.0148.

Zanetti F, Zegada-lizarazu W, Lambertini C, Monti A. 2019. Biomass and bioenergy salinity e ff ects on germination, seedlings and full-grown plants of upland and lowland switchgrass cultivars. Biomass Bioenergy. 120(November 2018):273–280. https://doi.org/10.1016/j.biombioe.2018.11.031.

Zhang Q, Wang S, Rue K. 2011. Salinity tolerance of 12 turfgrasses in three germination media. HortScience. 46 (4):651–654.

Zhang Q, Zuk A, Rue K. 2013. Salinity tolerance of nine fine fescue cultivars compared to other cool-season turfgrasses. Sci Hortic. 159:67–71. https://doi.org/10.1016/j.scienta.2013.04.033.