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Evaluation of NaCl salt tolerance of selected spring durum wheat (*Triticum durum* Desf.) genotypes

Ocena tolerancji wybranych genotypów jarej pszenicy twardej (*Triticum durum* Desf.) na stres solny

Summary. The influence of NaCl on the germination of kernels and the growth of seedlings of twenty spring varieties of durum wheat (*Triticum durum* Desf.) coming from different countries was investigated. The kernels were germinated on blotting paper, in Petri dishes supplemented with distilled water or NaCl solution at the concentration of 0 (control), 100, 150, 200 mM x dm^{-3}. After 2 days, germination energy, and after 5 days, germination capacity, maximum length of roots and leaves of seedlings were determined. The NaCl tolerance index (I_T) was determined based on leaf length measurements. High concentrations of NaCl had a negative effect on germination of kernels and significantly limited the growth of roots and leaves of durum wheat seedlings. Among the 20 durum wheat genotypes, the highest values of the tolerance index of salinity were found in the Mexican varieties Gavza and Totanus, Moroccan line Marokko 216, French variety Aramon, Austrian variety Floradur and German variety Weihenstephan.

Key words: germination, growth of seedlings, salt stress, *Triticum durum* Desf.

INTRODUCTION

Soil salinity is one of the main problems that limits the productivity of crops. Progressive soil degradation due to the intensive use of artificial fertilizers, plant protection agents and more often occurring droughts favor this phenomenon. Remarkable number of publications on salinity allows to know and understand the mechanisms of the excessive salt impact on plants as well as the response of plants to unfavorable conditions and possibility of their adaptation [Bilski 1988, Munns 2002, Flowers 2004, Chinnusamy et al. 2005, Kłosowska 2010, Mohammadi et al. 2012].

Plants sensitivity to salinity can vary greatly depending on the type and concentration of salt, duration, and above all, on the species, variety and developmental stage of a plant. As a result of salt stress, there is a reduction in plant's growth and development rate as well as disturbances in its life processes [Starck et al. 1995, Shannon and Grieve 1999, Kacperska 2002, Munns 2002, Fricke et al. 2006, Starck 2006, Munns and Tester 2008].

Plant's resistance to unfavorable environmental conditions, such as excessive salt concentration, consists in creating barriers preventing from penetration of stress factor into the plant or tolerating the toxic effects of increased Na^+ and Cl^- ions concentration, which according to Tester and Davenport [2003], are the main cause of plant damage. The tolerance of plants from *Triticeae* genus to salt stress is probably related to the preferential uptake of K^+ ions at the expense of Na^+ ions, even if sodium ions are found in excess in the external environment of roots. Research on Chinese Spring substitution lines with *Lophopyrum elongatum* chromosomes showed that the feature of preferential potassium cation uptake at the expense of sodium is highly correlated with tolerance to salinity [Dvořák and Gorham 1992]. According to Gorham [1990], the preferential potassium uptake is determined by genes located on the 4D chromosome in hexaploid wheat and on the chromosome 4A in diploid wheat, whereas in tetraploid wheat, the genes are not expressed. In the studies of Prażak [2001], hexaploid and diploid wheat proved to be more tolerant to salt stress than tetraploid wheat.

The salinity problem cannot be completely eliminated. A certain solution with the use of genetic engineering and possibility of interfering with the activity of genes related to the plant's reaction to salt stress, is the search for varieties tolerant to salinity [Sadat Noori and McNeilly 2000, Zhang and Blumwald 2001, Dec et al. 2003].

Table 1. Origin of spring durum wheat genotypes

No.	Genotype	Country of origin
1.	Agridur	FRA
2.	Akmolinska 2	RUS
3.	Alkantara	ITA
4.	Antas	ITA
5.	Aramon	FRA
6.	Capelli	ITA
7.	Floradur	AUT
8.	Gavza	MEX
9.	Griechischer von Atlantis	GRC
10.	Krasnokutskaja	RUS
11.	Marokko 216	MAR
12.	Marokko 239	MAR
13.	Marokko 609	MAR
14.	Psatmas	GRC
15.	Rascon	MEX
16.	Ship	MEX
17.	Sora	MEX
18.	Totanus	MEX
19.	Valbelice	ITA
20.	Weihenstephan	DEU

Many authors suggest a salinity tolerance assessment based on physiological markers and points to the presence of a high correlation between results of testing the seedlings in aquatic cultures and growth and development under field conditions. Evaluation of seedling germination and growth may be the first indicator of tolerance to salt stress [Sadat Noori and McNeilly 2000, Kubicka and Dec 2001, Nader 2012].

The aim of the present study was to assess the effect of NaCl on germination of kernels and growth of seedlings of selected spring durum wheat varieties and lines (Tab. 1).

MATERIAL AND METHODS

Material for study consisted of kernels of 20 spring durum wheat genotypes (*Triticum durum* Desf.) from the collection of the Institute of Genetics, Plant Breeding and Biotechnology, University of Life Sciences in Lublin (Tab. 1).

Decontaminated kernels were germinated on Whatman No. 10 filter paper, in Petri dishes (10 kernels per dish) supplemented with distilled water with NaCl addition at concentrations 0 (control), 100, 150, 200 mM dm^{-3}. From the time of seeding to 5 days seedlings, cultures were carried out in a thermostat, in the dark, at 25°C. In each combination, three replicates were made. After 2 days, germination energy was determined, and after 5 days – germination capacity, maximum length of roots and leaves of seedlings. Based on the length measurements of 5-day seedling leaves, the NaCl tolerance index was determined: I_T = (average length of leaves treated with NaCl / average length of control leaves) × 100%. The order of the analyzed forms in Figure 1 and in Tables 1–3 is the same. The obtained results were statistically processed applying variance analysis, and the significance of differences was verified by Tukey test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The tests showed significant effect of high NaCl concentrations (150 and 200 mM dm^{-3}) on germination energy and capacity of six spring durum wheat genotypes: Alkantara, Ship, Valbelice, Antas, Psatmas and Marokko 239; the latter three ones treated with 200 mM dm^{-3} concentration did not germinate at all (Tab. 2). The average germination energy of studied forms in the control combination ranged from 82.3% to 98.5%, whereas average germination capacity from 83.4% to 98.9%. Varieties Floradur, Gavza, Akmolinska 2, Aramon, Totanus and line Marokko 216 germinated best in combinations with high salt concentration. The average germination energy at a dose of 150 mM dm^{-3} NaCl ranged from 24.6% to 85.4%, and germination capacity from 32.5% to 86.4%, while at NaCl concentration 200 mM dm^{-3}, respectively from 0% to 76.1% and from 0% to 79.3%. Previous studies by Prażak [2001, 2003] did not reveal any significant differences in germination of four varieties of *T. aestivum*, *T. durum* cv. Grandur and *T. monococcum* under conditions of salinity (100 and 200 mM dm^{-3} NaCl) relative to the control. Significantly lower germination energy and capacity at the above-mentioned NaCl concentrations occurred in the case of *Triticum dicoccum*. Dec et al. [2003] reported a decrease in germination capacity of eight inbred lines of winter rye under the influence of

150 and 200 mM dm^{-3} NaCl. Matuszak and Brzóstowicz [2001], assessing the influence of salinity on germination of wheat cv. Roma, recorded a decrease in germination capacity as the concentration of NaCl increased. Delayed or reduced seed germination in most species, referred to as halophytes or glycophytes, was observed by Khan et al. 2002, Khan and Gulzar 2003, Kaydan and Yagmur 2008.

Table 2. Effect of NaCl on germination of spring durum wheat

No.	Genotype	Germination energy (%)				Germination capacity (%)			
		NaCl (mM dm^{-3})							
		0	100	150	200	0	100	150	200
1.	Agridur	85.7	73.7	71.6	62.0	87.5	75.3	74.0	62.0
2.	Akmolinska 2	92.0	84.0	75.3	69.3	93.3	85.0	76.0	71.7
3.	Alkantara	82.3	63.3	46.0*	41.7*	83.4	63.7	46.0*	44.0*
4.	Antas	94.0	67.5	24.6*	0.0	95.0	70.0	32.5*	0.0
5.	Aramon	96.7	86.2	74.1	69.3	96.7	87.5	76.0	70.6
6.	Capelli	93.3	76.0	71.7	63.6	95.0	79.4	73.6	65.4
7.	Floradur	98.4	90.0	85.4	76.1	96.6	90.0	86.4	79.3
8.	Gavza	96.7	84.0	76.0	68.6	96.7	85.0	77.5	70.0
9.	Griechischer von Atlantis	84.0	67.5	60.0	59.4	90.0	67.5	66.0	62.5
10.	Krasnokutskaja	82.5	66.4	62.0	60.0	86.4	68.0	62.5	60.0
11.	Marokko 216	90.0	76.0	73.3	69.3	90.0	77.5	73.3	69.3
12.	Marokko 239	89.3	67.5	40.0*	0.0	90.0	70.6	41.7*	0.0
13.	Marokko 609	98.5	78.6	70.7	65.3	98.9	82.0	76.0	67.3
14.	Psatmas	94.0	70.0	38.3*	0.0	96.6	71.0	38.3*	0.0
15.	Rascon	92.0	76.0	64.0	41.7*	94.0	78.3	66.0	43.2*
16.	Ship	84.0	67.5	44.0*	36.4*	85.7	69.5	46.0*	38.3*
17.	Sora	85.7	66.0	62.5	60.0	87.5	67.5	63.7	60.0
18.	Totanus	96.7	82.0	73.6	66.0	96.7	82.5	75.3	66.0
19.	Valbelice	85.3	73.6	47.5*	40.0*	89.3	78.3	47.5*	42.0*
20.	Weihenstephan	92.0	78.3	70.6	68.6	93.3	76.7	70.6	69.3

* result significantly different from the control (at $\alpha = 0.05$)

According to Noble [1985], wheat, sorghum, rice and some grasses are less susceptible to salinity during the germination than at the third leaf stage. This is consistent with results of other tests confirming significant reduction in the length of second and third barley leaves at increased salinity [Atabayeva et al. 2013, Wasilewski et al. 2015].

Negative, statistically significant effect of all NaCl concentrations was observed in the case of root and leaf length measurements (Tab. 3). The longest roots in the combination without salt were developed by Akmolinska 2 cv. (109.5 mm), while the longest leaves were produced by Marokko 609 line (79.8 mm) and Akmolinska cv. (79.4 mm). Long roots and leaves also grown at Weihenstephan cv. – 90.2 mm and 75.6 mm, respectively. The applied NaCl doses led to a significant reduction in the length of both roots and leaves. The dose of 100 mM dm^{-3} caused a reduction in root length from 50% to 78%, and leaves from 49% to 74%. The shortest roots and leaves at a concentration of 200 mM dm^{-3} NaCl appeared at Alkantara cv. (10.5 mm and 4.8 mm, respectively). In research of Matuszak et al. [2004] and Matuszak-Slamani and Brzóstowicz [2015], high concentrations of NaCl (100, 150 mM dm^{-3}) significantly affected the root and leaf length reduction as well as fresh and dry matter of the underground and above-ground parts of Almari cv. wheat, Tornado cv. triticale and Amilo cv. rye. Prażak [2003] reported significant shortening of roots and aboveground part of common wheat, durum wheat and *Aegilops* × *Triticum* hybrid seedlings under the influence of high sodium chloride concentrations (100 and 200 mM dm^{-3}). In the research of Dec et al. [2003], there was significant inhibition of the above-ground parts and roots of eight inbred rye lines under the influence of 150 and 200 mM dm^{-3} NaCl. Similar results were obtained for barley by Matuszak and Brzóstowicz [2006] as well as Wasilewski et al. [2015].

Table 3. Effect of NaCl concentrations on growth of spring durum wheat seedlings

No.	Genotype	Root length (mm)				Leaf length (mm)			
		NaCl (mM dm^{-3})							
		0	100	150	200	0	100	150	200
1.	Agridur	77.2	29.5*	20.4*	15.1*	73.4	26.1*	18.7*	10.8*
2.	Akmolinska 2	109.5	27.5*	16.8*	12.2*	79.4	23.5*	16.1*	6.4*
3.	Alkantara	71.5	22.2*	18.8*	10.5*	61.6	21.3*	11.7*	4.8*
4.	Antas	75.2	16.7*	9.6*	–	57.1	16.2*	4.8*	–
5.	Aramon	67.5	29.8*	22.4*	16.6*	56.5	27.6*	20.3*	12.4*
6.	Capelli	80.8	23.6*	13.3*	11.7*	65.4	21.5*	17.2*	9.8*
7.	Floradur	75.5	30.8*	21.8*	11.3*	56.7	25.2*	16.4*	10.4*
8.	Gavza	67.7	29.3*	21.3*	13.5*	58.6	26.3*	17.8*	12.2*
9.	Griechischer von Atlantis	71.8	24.3*	14.8*	12.3*	67.9	22.7*	17.9*	9.3*
10.	Krasnokutskaja	76.4	36.3*	30.3*	19.2*	75.3	24.8*	19.8*	7.3*
11.	Marokko 216	74.9	30.1*	27.3*	14.8*	54.3	26.2*	18.3*	11.2*
12.	Marokko 239	81.2	24.1*	14.2*	–	62.7	18.8*	8.3*	–
13.	Marokko 609	70.1	18.8*	16.5*	11.1*	79.8	23.5*	14.4*	9.1*
14.	Psatmas	66.6	16.1*	10.7*	–	57.6	14.8*	10.3*	–
15.	Rascon	78.6	26.5*	18.8*	11.7*	66.4	23.5*	17.2*	8.2*
16.	Ship	63.9	26.6*	19.3*	11.9*	60.2	23.7*	15.4*	8.7*
17.	Sora	67.6	33.8*	16.5*	13.3*	57.4	24.6*	11.1*	7.8*
18.	Totanus	60.5	37.5*	23.7*	16.4*	55.3	28.3*	20.4*	14.5*
19.	Valbelice	73.6	26.9*	13.4*	12.2*	60.5	21.6*	9.8*	6.2*
20.	Weihenstephan	90.2	34.3*	32.7*	13.8*	75.6	27.4*	21.3*	11.3*

* result significantly different from the control (at $\alpha = 0.05$)

The measurements show that growth of above-ground parts of spring durum wheat seedlings was more strongly inhibited than root growth. According to Kuiper et al. [1990], plant roots in saline environments are easier to cope with negative effects of increased salt concentration than leaves. Reduction in fresh and dry matter, especially of the above-ground parts of barley cultivars at a dose of sodium chloride above

100 mM dm^{-3}, was observed by Mahmood [2011]. This was also confirmed by results of Gawlik et al. [2014] reporting significant reduction in fresh and dry matter of above-ground parts of soybean plants with increasing concentrations of NaCl.

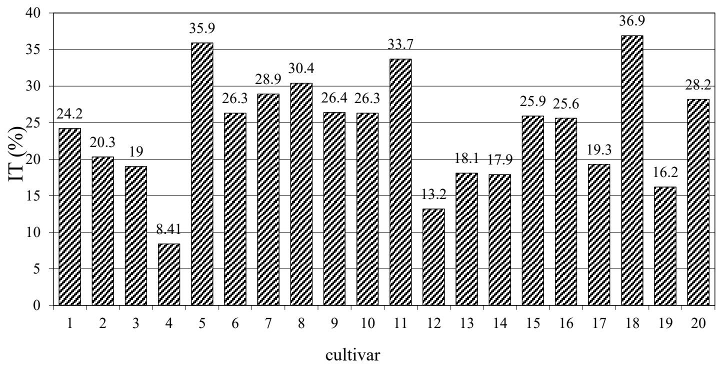

Fig. 1. Tolerance index of 150 mM dm^{-3} NaCl for the 5-days old spring durum wheat seedlings

Value of the tolerance index was calculated for the concentration of 150 mM dm^{-3} NaCl, because it was the concentration, at which all forms formed seedlings (Fig. 1). The largest value of the tolerance index characterized the Mexican Totanus cv. (36.9%), French Aramon cv. (35.9%), and Moroccan Marokko 216 line (33.7%). Slightly lower index was recorded for the following varieties: Gavza (30.4%), Floradur (28.9%) and German Weihenstephan cv. (28.2%). The lowest value of this coefficient was obtained by Italian Antas cv. (8.41%) and Moroccan Marokko 239 line (13.2%).

Genotypes with higher tolerance can be used in breeding programs, the aim of which is to obtain starting materials that are more resistant to salinity.

CONCLUSIONS

1. High NaCl concentrations did not significantly affect the germination of majority of tested spring durum wheat varieties.

2. Presence of NaCl at concentrations of 100, 150 and 200 mM dm^{-3} caused significant reduction in the determined biometric parameters of durum wheat seedlings.

3. High NaCl concentrations inhibited the growth of above-ground parts of seedlings more strongly than roots.

4. Among the studied 20 spring durum wheat genotypes, there was a large variation in terms of the tolerance to environmental salinity, with the largest value of salinity tolerance index showed by genotypes from Mexico (Gavza and Totanus), Morocco (Marokko 216) and France (Aramon).

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Streszczenie. Badano wpływ NaCl na kiełkowanie ziarniaków i wzrost siewek 20 genotypów jarej pszenicy twardej (*Triticum durum* Desf.) pochodzących z różnych krajów. Ziarniaki kiełkowano na bibule, w szalkach Petriego uzupełnionych wodą destylowaną lub roztworem NaCl w stężeniu 0 (kontrola), 100, 150, 200 mM dm^{-3}. Po 2 dniach określono energię kiełkowania, a po 5 dniach zdolność kiełkowania, maksymalną długość korzeni i liści siewek. Na podstawie pomiarów długości liści wyznaczono indeks tolerancji NaCl (I_T). Wysokie stężenia NaCl wpływały negatywnie na kiełkowanie ziarniaków oraz istotnie ograniczały wzrost korzeni i liści siewek badanych genotypów jarej pszenicy twardej. Wśród 20 form pszenicy twardej największą wartością indeksu tolerancji zasolenia charakteryzowały się odmiany meksykańskie Gavza i Totanus, marokańska linia Marokko 216 oraz francuska odmiana Aramon, austriacka Floradur i niemiecka Weihenstephan.

Słowa kluczowe: kiełkowanie, stres solny, *Triticum durum* Desf.

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