Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 21, Issue 3, 2021
PRINT ISSN 2284-7995, E-ISSN 2285-3952

REACTION OF SUDAN GRASS AND SORGHUM-SUDAN HYBRIDS TO SALINITY

Sergey Ivanovich KAPUSTIN[1,3], Alexander Borisovich VOLODIN[1], Andrey Sergeevich KAPUSTIN[2], Olga Ivanovna VLASOVA[3], Inna Anatolievna DONETS[3]

[1]North Caucasus Federal Agrarian Research Center, 49 Nikonov street, Mikhailovsk, Stavropol region, 356241, Russia, Phone: +79624512303; E-mail: sniish@mail.ru
[2]North Caucasus Federal University, 1 Pushkin street, Stavropol, 355017, Russia, Phone: +78652330291; E-mail: hpplus@bk.ru
[3]Stavropol State Agrarian University, 12 Zootekhnicheskiy Lane, Stavropol 355017, Russia, Phone: +78652352282; E-mail: inf@stgau.ru

Corresponding author: hpplus@bk.ru

Abstract

According to the data obtained in 2019-2020, a noticeable decrease in seed germination to 84-94% in sterile female parent lines of Sorghum was found when the concentration of NaCl in the solution was 1.0%, and at 1.5% it decreased to 23-80%. The lowest performance (23%) was obtained in A-63 line. Paternal varieties of Sudan grass reduce germination to 68-87% with 1.0 NaCl and to 45-74% with 1.5% of salinity. The most significant seed germination of Sudan grass with 1.0% of salinity (82-87%) was found in Zemlyachka, Sputnitsa and Zlata varieties with a solution concentration of 1.5% in Zemlyachka (74%). Among the other varieties of Sudan grass, the most salt-tolerant were Alexandrina and Violeta varieties. In the Bulgarian variety SVE, when NaCl concentration in the soil solution was 1.0%, the seed germination rate was 82%, and when its concentration increased to 1.5%, it was 32%. In the obtained Sorghum-Sudan hybrids with 0.6% salt concentration, seed germination decreased to 67-96%, but most of all (96%) it was obtained in the combinations of Zersta 90C x Sputnitsa and A-63 x Nika. The highest seed germination with 1.0% – 1.5% saturation of NaCl solution was obtained in the recognized hybrids Zersta 90C x Zemlyachka, Zersta 90C x Sputnitsa, and the combination of Knyazhna x Sputnitsa. The increase in concentration of the soil solution significantly reduces the length of the shoots and roots of the seedlings to 1.6 – 3.4 cm with 1.0% NaCl con-centration and 0.7 – 2.4 cm in the variant with 1.5% of salt presence. In the Navi-gator and Gvardeets hybrids, the length of seedlings with high salt concentration (0.6-1.5%) was the highest.

Key words**:** *sterile lines, varieties of Sudan grass, Sorghum-Sudan hybrids, germination, length of seedlings*

INTRODUCTION

The area of solonetz in the Stavropol Territory is 1.5 million hectares. The main features of these soils are high density and cloddy structure [12]. pH of chernozem and chestnut soils in the region on an area of 38-43% is 6.9-8.0. The soil salinity is one of the main negative factors that reduces the productivity of agricultural production [7]. The amount of exchangeable sodium in solonetzic soils reaches 15-20%, and in solonetz soils more than 20% of the base exchange capacity. At the same time, solonetz soils are relatively rich in nutrient elements. The cultiva-tion of salt-tolerant crops is effective on such soils [5].

Russian and foreign varieties, hybrids and sterile lines of Sweet sorghum, Sudan grass, and Sorghum-Sudan hybrids have a relatively high drought resistance (transpiration coefficient 230-300), but their cultivation in the North Caucasus is often combined with a high concentration of NaCl in the soil [4, 13]. To create salt-tolerant hybrids and varieties, special breeding programs for sorghum crops are carried out [8, 12]. The species composition, variety assortment and salinity tolerance largely determine the time of sowing and the density of Sudan grass and Sorghum-Sudan hybrids [6].

Literature sources show that the use of NH_4^+ increases the salt tolerance of plants by limiting the accumulation of Na^+ [15]. In Sweet sorghum, the concentration of Na^+ in the roots decreases, which ensures their low concentration in the shoots by protecting the photosynthesis structures [18, 19]. Under

conditions of salinity stress, Arabidopsis improves the ability of photosynthesis [9]. Wheat increases salt tolerance when its seeds are treated with sorghum extracts [3]. Jasmonic and humic acids improve the salt tolerance of plants due to an increase in antioxidant enzymes [2, 14]. The increased activity of such enzymes points to better compartmentalization of Na^+ under salinity stress condition [1]. Transgenic hybrids in conditions of significant salinity of the soil show higher concentration of chlorophyll and provide better yields [11]. The locuses of quantitative traits of salinity stress adaptibility serve as target sites for selection using marker assisted selection (MAS) to improve salt tolerance [17].

The aim of the research is to clarify the methods of laboratory evaluation of salt tolerance and to determine its level under exogenous exposure to sodium chloride (NaCl) in new varieties of Sudan grass, sterile female parent lines of Sorghum, and the degree of inheritance of this trait in Sorghum-Sudan hybrids obtained on their basis.

MATERIALS AND METHODS

In the arid conditions of the North Caucasus, information about the degree of salt tolerance of sorghum plants during the first growing season contributes to their profitable cultivation on saline soils. Clarification of the conditions of seed cultivation, NaCl concentrations, and the study of the results of their growth under saline conditions was the aim of the research. Seeds of the same size without visible infection and damage were selected for trial establishment. They were sprouted in sterile Petri dishes. The sample size was 100 seeds in four-fold replication for each variant. The seeds were germinated on filter paper moistened with distilled water (control) or salt solutions (experimental versions). The concentration of NaCl in the solution was 0.15%, 0.3, 0.6, 1.0, and 1.5%. All variants were kept for 8 days in an aeration bath with the temperature of 24-25^{o}C. We took into account the energy and laboratory germination, the length of the shoot and root. The basis for the evaluation of salt tolerance was the methods of Ivanov Yu.M., Udovenko G.V. [10], Semushkina L.A. [16] and our own research [12].

In the experiment, we studied the seeds of 4 sterile female parent lines of Sorghum (Zersta 90C, Zersta 38A, A-63, Knyazhna), 5 varieties of Sudan grass (Zemlyachka, Sputnitsa, Nika, Zlata, Sofia) – fertility restorers (Table 1) and 11 new Sorghum-Sudan hybrids obtained on their basis (Table 2). The Navigator (Zersta 90S x Zemlyachka) and Gvardeets (Zersta 90S x Sputnitsa) hybrids have been in the register of selective breeding results of the Russian Federation from 2007 to 2020, respectively. Salt tolerance of 11 varieties of Sudan grass selected by other Russian and foreign breeding centers was determined (Table 3).

RESULTS AND DISCUSSIONS

Minimal growth inhibition and accumulation of biological mass of seedlings of the studied plants in a solution of NaCl in comparison with the control version indicates the stability of the sample. In the results of salt tolerance studies presented in tables 1 – 3, a high seed germination rate was established on the control variant without NaCl, the minimum experiment rate of which was 92%.

0.15% solution concentration in some cases increases the seed germination in comparison with the control. A noticeable decrease in germination to 84-94% in sterile female parent lines was found at 1.0% NaCl, and at 1.5% it decreased to 23-80%. The lowest rate (23%) was obtained at the A-63 line.

Paternal varieties of Sudan grass reduced germination to 68-87% at 1.0% NaCl concentration and to 45-74% at 1.5% salinity. The most significant seed germination at 1.0% salinity (82-87%) was obtained in the varieties Zemlyachka, Sputnitsa and Zlata, at 1.5% solution concentration – in Zemlyachka (74%) and Nika (62%).

Table 1. Seed germination and the length of seedlings of the seed parents, depending on the degree of salinity of the aqueous solution

Name of the variety, line	Control, without NaCl			NaCl concentration											
				0.3%			0.6%			1.0%			1.5%		
	seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm	
		shoot	root		shoot	root		shoot	root		shoot	root		shoot	root
Sterile female parent lines of Sorghum															
Zersta 90C	98	6.6	6.8	94	7.6	5.5	92	7.0	5.9	90	5.1	2.2	44	2.4	0.7
Zersta 38A	99	7.1	7.5	96	6.2	6.1	97	4.0	6.2	94	3.0	5.5	76	1.3	2.2
A-63	99	7.0	6.7	91	6.7	4.5	89	3.8	5.9	84	3.0	3.4	23	1.4	1.2
Knyazhna	99	7.7	8.9	98	6.2	6.7	90	6.4	5.3	90	5.8	5.3	80	2.7	2.1
Paternal varieties of Sudan grass – fertility restorers															
Zemlyachka	98	9.2	9.6	90	7.1	4.7	89	6.5	4.6	87	2.3	2.3	74	1.4	0.9
Sputnitsa	98	9.8	9.6	94	9.1	7.8	93	6.2	7.6	82	2.0	1.6	45	0.9	1.0
Nika	98	8.9	10.5	98	8.5	9.7	97	5.9	3.8	68	5.3	2.1	62	1.4	1.1
Zlata	99	9.0	12.5	9.8	9.1	6.3	97	5.7	5.8	82	5.0	5.9	52	0.3	0.5
Sofia	97	7.8	11.7	93	6.7	9.0	89	5.5	6.0	76	4.3	5.0	49	2.6	2.0

Source: developed by the authors based on [10].

Table 2. Influence of soil salinity of NaCl on germination rates and seedling length of the new obtained Sorghum-Sudan hybrids

Name of the hybrid	Control, without NaCl			NaCl concentration											
				0.3%			0.6%			1.0%			1.5%		
	seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm	
		shoot	root		shoot	root		shoot	root		shoot	root		shoot	root
Zersta 90C x Zemlyachka	99	8.9	10.3	95	7.3	8.9	91	6.8	6.9	68	2.3	3.4	22	0.9	1.8
Zersta 90C x Sputnitsa	99	7.6	11.3	97	7.3	10.2	96	5.7	7.4	63	2.3	3.3	19	1.0	1.7
A-63 x Sputnitsa	96	6.8	9.6	89	6.7	6.9	73	4.6	6.5	42	1.8	2.0	8	0.5	1.1
Zersta 90C x Nika	94	9.0	9.5	94	7.0	7.9	89	4.4	6.3	34	1.1	2.9	17	0.9	1.2
A-63 x Nika	99	7.9	10.5	97	5.3	8.0	96	5.2	7.2	73	2.3	3.8	9	0.8	1.2
Zersta 38A x Nika	97	7.3	8.8	95	7.0	7.7	78	3.4	6.1	51	2.8	4.2	4	0.9	1.7
Knyazhna x Nika	97	7.4	8.7	81	5.0	5.2	67	4.1	3.5	44	3.3	2.5	10	1.0	0.8
Zersta 38A x Sputnitsa	99	7.1	11.9	96	5.2	9.7	82	4.1	5.9	39	2.7	4.1	8	0.6	1.6
Knyazhna x Sputnitsa	99	6.3	6.0	96	6.7	5.2	88	4.2	5.0	62	1.8	0.6	39	0.5	0.5
Zersta 90C x Sofia	98	8.4	9.9	95	5.1	6.8	78	3.8	6.5	59	3.2	3.1	10	1.0	2.2
Zersta 90C x Zlata	99	7.3	9.0	94	5.8	7.6	89	2.8	5.4	50	2.0	2.5	12	0.8	1.4

Source: developed by the authors based on [10].

Table 3. Seed germination rates depending on the degree of soil salinity in varieties of Sudan grass

Name of the variety	Control, without NaCl			NaCl concentration											
				0.3%			0.6%			1.0%			1.5%		
	seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm		seed germination, %	length, cm	
		shoot	root		shoot	root		shoot	root		shoot	root		shoot	root
Alexandrina	97	7.0	7.5	92	5.9	6.9	92	6.1	5.1	82	3.1	3.1	57	1.8	1.9
Anastasia	97	7.3	6.8	94	6.7	6.0	91	6.2	5.9	81	4.5	5.0	43	1.3	1.2
Fioleta	92	10.2	11.7	86	8.5	6.6	80	6.2	7.0	72	6.9	4.6	51	1.6	0.7
Zernogradskaya 576	93	9.4	6.4	78	8.2	5.7	75	7.2	4.2	69	4.0	2.9	14	2.0	0.5
SVE Bulgaria	99	6.8	10.7	95	4.6	6.7	93	4.0	6.3	82	2.7	3.7	32	0.3	2.0
Udacha	96	5.1	8.3	98	5.0	6.4	90	4.4	8.7	78	3.1	5.1	17	0.6	0.7
Mechta Povolzhya	98	10.3	14.3	98	8.3	12.1	94	6.1	6.7	65	1.5	1.9	54	0.4	1.0
Spartanka	98	7.1	8.6	93	6.2	6.9	88	3.5	4.7	63	2.8	3.5	23	2.3	1.8
Evgenia	94	8.5	11.6	90	8.0	12.9	80	6.9	12.7	74	4.7	7.1	53	1.3	0.5
Yubilejnaya 20	92	10.2	9.6	89	8.7	9.2	77	7.0	6.3	65	1.7	2.5	28	1.3	1.0
Zonalnaya 6	97	8.9	8.1	95	6.5	6.9	87	2.3	3.6	81	3.2	1.9	27	0.6	0.5

Source: developed by the authors based on [10].

In the obtained Sorghum-Sudan hybrids, the seed germination in the control variant and at 0.15% solution concentration had the same rate and varied within 93-99%. Increasing the degree of salinity to 0.3% reduced seed germination by 2-8%. At a solution concentration of 0.6%, the germination rate decreased to 67-96%. The lowest (67%) rate was in the new hybrid Knyazhna x Nika, and the highest (96%) in the combinations of Zersta 90C x Sputnitsa (Gvardeets) and A-63 x Nika. Increasing the NaCl content to 1.0% and 1.5% reduced the germination rate to 34-73% and 4-39%, respectively. The highest seed germination at 1.0% and 1.5% NaCl concentration was obtained in recognized Navigator hybrids, Gvardeets and Knyazhna x Sputnitsa combinations.

In A-63 x Nika, 1.0% concentration of the solution provided seed germination of 73%, and 1.5% – 9%. Thus, taking into account high doses of NaCl (1.0%), the maximum germination rates were obtained in Sorghum-Sudan hybrids Navigator, Gvardeets, A-63 x Nika, Knyazhna x Sputnitsa. In the presence of salt in the solution of 0.6% or less in the above combinations, the seed germination had standard rates. The solution concentration of

1.5% reduces the germination rate in these variants to 9-39%. At the same time, at this concentration, the germination rate of the female parent of Zersta 38A was 76%, the male parent of Zemlyachka – 74%, Nika – 62%.

Seed germination rates are important but in most cases they are approximate and do not always correlate with the true salt tolerance of varieties and hybrids of sorghum crops. A more significant correlation with productivity in the field was established when evaluating salt tolerance according to the length of the shoots and roots of the sprouts [10, 12].

When a minimum dose of NaCl (0.15%) was added to the solution, in addition to a slight change in germination, the sizes of the root and shoot also fluctuated. In comparison with the control, the concentration of 0.15% in sterile lines increased the length of the shoot by an average of 0.3-0.4 cm, and the root by 1.5 cm. The paternal varieties of Sudan grass showed a decrease in the length of the shoot by 1.9 cm, and the root by 2.9 cm.

In Sorghum-Sudan hybrids, the averaged data also show a decrease in the size of the shoot to 3.3 cm and the root by 0.9 cm when sowing in a solution with a minimum salt concentration.

The increase in NaCl concentration to 0.3% also did not cause a significant reduction in the length of the shoot and root of seedlings in comparison with the control data. In most variants, the rates were similar to the data, as at 0.15% salt concentration. The increase in NaCl to 0.6% provided a slight decrease in the length of the shoot in comparison with the control by 1.8-2.9 cm and 2.0-5.4 cm of the root, but in general these rates had high values – 4.8-6.0 cm.

A significant reduction in the length of seedlings was found with an increase in NaCl concentration to 1.0% -2.2-4.4 cm in the shoots and 2.4-3.9 cm in the roots. 1.5% salt concentration reduced these values to 0.8-2.0 cm and 1.3-1.5 cm, respectively. At a salt solution concentration of 1.0-1.5 %, there is a decrease in the length of Sorghum-Sudan hybrid seedlings in comparison with their seed parents by 1.2-1.5 cm. At a salinity of 0.15-0.6%, such variations were not established.

In the sterile line of Zersta 90C, fertility restorers of the varieties of Sudan grass Zemlyachka, Sputnitsa, as well as obtained on their base recognized Sorghum-Sudan hybrids Navigator (Zersta 90C x Zemlyachka) and the new combination of Gvardeets (Zersta 90C x Sputnitsa), the length of the shoot and root of the seedlings with NaCl concentration of 0.15 and 0.3% were identical to the values of the standard variants. The solution concentration of 0.6% tended to slightly reduce the length of the shoot of the seedlings by 0.6-2.9 cm and the root by 0.1-2.8 cm. At the same time, the length of the shoot and the Navigator hybrid had a value of 6.8 cm, and the root of 6.9 cm. The average data of their parents were 5.3 cm and 6.7 cm, respectively.

The new hybrid Gvardeets had similar measurements in the shoot – 5.7 cm, the root – 7.4 cm, and their seed parents had 6.6 cm and 6.8 cm. This indicates a better toleration of the roots of the seedlings of both hybrids and the shoot of the seedlings of the Navigator hybrid to salinization with 0.6% solution.

The further increase in the concentration of the soil solution significantly reduced the length of the seedlings to 1.6-3.4 cm with 1.0% NaCl concentration and 0.7-2.4 cm in the 1.5% variant. As with 0.6% salt concentration in Sorghum-Sudan hybrids in comparison with the shoot, longer measurements were obtained in the roots – 0.95 cm and 1.75 cm, respectively, with 1.5% NaCl concentration and 2.3 cm and 3.4 cm in 1.0% solution. As for their seed parents, a certain pattern in the size of the roots and shoots was not established. In the Navigator and Gvardeets hybrids, the size measures of the shoots and roots at a salt concentration of 0.6-1.5% were among the highest. The significant measurements of the shoot length were obtained in the combinations of Zersta 90C x Sofia and Knyazhna x Nika, the root length – Zersta 90C x Sofia, Zersta 38A x Sputnitsa and Zersta 38A x Nika. Among the other varieties of Sudan grass, the most salt-tolerant were the varieties of Alexandrina and Fioleta. In the Bulgarian variety SVE, with 1.0% NaCl concentration in the solution, the seed germination rate was 82%, but with its increase to 1.5% – 32%.

The increase in the level of salt tolerance among the obtained Sorghum-Sudan hybrids in comparison with their seed parents was not established.

CONCLUSIONS

The most significant seed germination of the Sudan grass at 1.0% salinity (82-87%) was obtained from the Zemlyachka, Sputnitsa and Zlata. At 1.5% solution concentration – in Zemlyachka (74%) and Nika (62%).

In Sorghum-Sudan hybrids with 1.0% NaCl salinity, the maximum germination rate was obtained in Navigator (68%), Gvardeets (63%), A-63 x Nika (73%) and Knyazhna x Sputnitsa (62%). With 0.6% salt concentration or less, the germination rate was standard.

At 0.6-1.5% salt solution concentration, the most significant size measurements of the shoots and roots were found in the Navigator and Gvardeets hybrids.

The increase in the level of salt tolerance among the obtained Sorghum-Sudan hybrids in comparison with their seed parents was not established.

REFERENCES

[1]Ahire, M.L., Kumar, S.A., Punita, D.L., Mundada, P.S., Kishor, P.B.K., Nikam, T.D., 2018, The vacuolar proton pyrophosphatase gene (SbVPPase) from the Sorghum bicolor confers salt tolerance in transgenic Brahmi [Bacopamonnieri (L.) Pennell]. Physiology and molecular biology of plants, 24(5):809-819. DOI: 10.1007/s12298-018-0586-4

[2]Ali, A.Y.A., Ibrahim, M.E.H., Zhou, G.S., Nimir, N.E.A., Jiao, X.R., Zhu, G.L., Elsiddig, A.M.I., Zhi, W.F., Chen, X.B., Lu, H.T., 2019, Ameliorative Effects of Jasmonic Acid and Humic Acid on Antioxidant Enzymes and Salt Tolerance of Forage Sorghum under Salinity Conditions. Agronomy journal, 111(6):3099-3108. DOI: 10.2134/agronj2019.05.0347

[3]Bajwa, A.A., Farooq, M., Nawaz, A., 2018, Seed priming with sorghum extracts and benzyl aminopurine improves the tolerance against salt stress in wheat (Triticum aestivum L.). Physiology and molecular biology of plants, 24(2):239-249. DOI: 10.1007/s12298-018-0512-9

[4]Baranovsky, A.V., Kapustin, S.I., Kapustin, A.S., 2019, The study of modern hybrids of grain sorghum in the conditions of the Steppe zone. International journal of ecosystems and ecology science-IJEES, 9(4):717-722. DOI: 10.31407/ijees9417

[5]Baranovsky, A.V., Kosogova, T.M., Kapustin, S.I., Kapustin, A.S., 2020, The effect of nitrogen fertilizers on the productivity of grain sorghum. Bioscience research, 17(1): 228-234.

[6]Baranovsky, A.V., Sadovoy, A.S., Kapustin, S. I., Kapustin, A.S., 2020, Optimization of sowing time for grain sorghum and millet. Bioscience research,17(2):1121-1128.

[7]Ding, T., Yang, Z., Wei, X., Yuan, F., Yin, S., Wang, B., 2018, Evaluation of salt-tolerant germplasm and screening of the salt-tolerance traits of sweet sorghum in the germination stage. Functional plant biology, 45(10): 1073-1081.DOI: 10.1071/FP18009

[8]Gull, M., Kausar, A., 2019, Screening the Variability in Salt Tolerance of Sorghum bicolor L. by Nutrients Uptake and Growth Analysis of Four Genotypes. Pharmacophore, 10 (2):43-50.

[9]Guo, Y.Y., Song, Y.S., Zheng, H.X., Zhang, Y., Guo, J.R., Sui, N., 2018, NADP-Malate Dehydrogenase of Sweet Sorghum Improves Salt Tolerance of Arabidopsis thaliana. Journal of agricultural and food chemistry, 66(24):5992-6002. DOI: 10.1021/acs.jafc.8b02159

[10]Ivanov, Y.M., Udovenko, G.V., 1970, Technological modification of the method of seedlings and analysis of its suitability for assessing the salt tolerance of plants. Transactions in Applied Botanical Genetics and Breeding, 43(1): 160-166.

[11]Kandula, V., Pudutha, A., Kumari, P.H., Kumar, S.A., Kishor, P.B.K., Anupalli, R.R., 2019, Overexpression of Sorghum plasma membrane-bound Na^+/H^+ antiporter-like protein (SbNHXLP) enhances salt tolerance in transgenic groundnut (Arachis hypogaea L.). Plant cell tissue and organ culture, 138(2):325-337. DOI: 10.1007/s11240-019-01628-0

[12]Kapustin, S.I., Volodin, A.B., Kapustin, A.S., 2020, Assessment of salt tolerance of a collection of sorghum genotypes. Bioscience research, 17(3): 1676-1681.

[13]Kapustin, S. I., Volodin, A. B., Kapustin, A. S., 2020, Process of the selection of sorghum-sudank hybrids in arid conditions Steppe zone. International journal of ecosystems and ecology science-IJEES, 10(2): 331-336. DOI: 10.31407/ijees10.212

[14]Merwad, A.R.M.A., 2017, Effect of humic and fulvic substances and Moringa leaf extract on Sudan grass plants grown under saline conditions. Canadian journal of soil science, 97(4):703-716. DOI: 10.1139/cjss-2017-0050

[15]Miranda, R.S., Mesquita, R.O., Costa, J.H., Alvarez-Pizarro, J.C., Prisco, J.T., Gomes, E., 2017, Integrative Control Between Proton Pumps and SOS1 Antiporters in Roots is Crucial for Maintaining Low Na^+ Accumulation and Salt Tolerance in Ammonium-Supplied Sorghum bicolor. Plant and cell physiology, 58 (3):522-536. DOI:10.1093/pcp/pcw231

[16]Semushina, L.A., 1973, Methods for assessing the salt tolerance of corn by germinating seeds in saline solutions. Corn, 12: 26-27.

[17]Wang, H.L., Wang, R.F., Liu, B., Yang, Y.B., Qin, L., Chen, E.Y., Zhang, H.W., Guan, Y.N., 2020, QTL analysis of salt tolerance in Sorghum bicolor during

whole-plant growth stages. Plant breeding, 139(3): 455-465. DOI: 10.1111/pbr.12805
[18]Yang, Z., Li, J.L., Liu, L.N., Xie, Q., Sui, N., 2020, Photosynthetic Regulation Under Salt Stress and Salt-Tolerance Mechanism of Sweet Sorghum. Frontiers in plant science, 10: 1722.DOI: 10.3389/fpls.2019.01722
[19]Yang, Z., Zheng, H.X., Wei, X.C., Song, J., Wang, B.S., Sui, N., 2018, Transcriptome analysis of sweet Sorghum inbred lines differing in salt tolerance provides novel insights into salt exclusion by roots. Plant and soil, 430 (1-2):423-439. DOI: 10.1007/s11104-018-3736-0