PAN POLSKA AKADEMIA NAUK

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

ITP-PIB

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.143727
2022, Special Issue: 119–129

Evaluating the tolerance of chickpea (*Cicer arietinum* L.) genotypes to salinity stress based on a complex of morpho-physiological and yielding traits

Hayat Touchan[1)], Oqba Basal[2)]

[1)] Aleppo University, Faculty of Agriculture, Department of Field Crops, Aleppo, Syria

[2)] University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Department of Applied Plant Biology, Böszörményi Rd, 138/B, 4032, Debrecen, Hungary

RECEIVED 08.06.2022 ACCEPTED 21.07.2022 AVAILABLE ONLINE 31.12.2022

Abstract: Salinity is one of the most significant abiotic stress factors influencing crop production, especially in arid and semi-arid regions. Plants' response to salinity stress depends on the cultivated genotype. A pot experiment was conducted to study the impact of two concentrations of sodium chloride (4 and 6 dS·m^{-1}) on some physiological and production traits of 58 chickpea genotypes. A genetic variation in the response of the investigated chickpea genotypes for NaCl-induced salinity stress was noted. Studied morphophysiological traits and yield components were affected under salt stress in all genotypes tested. Plant height was observed to have the lowest rate of reduction (32%, 48%) at 4 and 6 dS·m^{-1}, respectively. Leaf stomatal conductance decreased as salinity increased. Salinity stress conditions affected all studied yield components, but there was a genetic variation in the response of the studied genotypes. Under no stress conditions and compared to the other genotypes, the number of pods was significantly higher in BG362 genotype. The seed number was significantly higher in ILC9076 genotype. The 100 seed weight was significantly higher in the genotype ILC2664. The mean seed yield was significantly higher in ILC9354 and the harvest index was significantly higher in ILC8617. In general, salinity stress caused the reduction of all parameters. We assume that the assessment of tolerance of chickpea (*Cicer arietinum* L.) genotypes to salinity stress should be based on a complex of morpho-physiological traits and analysis of yield complement.

Keywords: abiotic stress, biomass, chickpea, seed yield

INTRODUCTION

Salinity is among the most important abiotic stresses that influences crop production, especially in semi-arid and arid regions [Isayenkov, Maathuis 2019; Kadioğlu 2021; Wild 2003]. Higher evaporation rates and decreased precipitation during the vegetative period resulted in increasing soil salinity [van der Zee *et al.* 2017]. Overcoming this problem requires selecting the genotypes with salinity tolerance that have high-yielding efficiency under salinity stress conditions [Khataar *et al.* 2018; Qadir, Oster 2004].

Salinity affects various traits on the morphological, physiological and biochemical levels [Bhattarai *et al.* 2020]; it reduces plant height, leaf number and leaf area as a result of decreased water and mineral absorption by the roots, leading to malfunctioning nourishment, misbalancing hormonal levels and protein and nuclear acids and degrading enzyme activity. As a result, many biological actions are negatively affected, especially photosynthesis and respiration.

However, variations in salinity tolerance within different chickpea genotypes are reported [Turner *et al.* 2013; Vadez *et al.* 2007]. Moreover, physiological mechanisms resulting in these different responses to salinity stress are not well documented [Khan *et al.* 2015; Kotula *et al.* 2015].

Chickpea is an important legume in semi-arid areas [FAOSTAT 2016] because its nutritional value is very good,

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

and it is able to fix atmospheric nitrogen, in addition to its position in the crop cycles in alteration with winter cereals (like wheat and barley). However, salinity adversely affects chickpea and its yield [ZAWUDE, SHANKO 2017].

KAFI *et al.* [2011] evaluated the physiological changes of chickpea under salinity stress conditions, where 11 genotypes were grown in hydroponic culture provided with saline water at levels of 8 and 12 dS·m^{-1} and compared with a control treatment. Their results showed that increasing salinity levels was accompanied with decreased chlorophyll content and carotenoids, whereas proline and soluble sugars increased. They also reported that genotypes with higher chlorophyll content, carotenoids and soluble sugars could better tolerate salinity stress. These traits were significantly correlated with Na+ concentrations in the leaves.

KATERJI *et al.* [2012] exposed the seeds of chickpea, soybean, wheat and barley to different levels of salinity (0.1–15 dS·m^{-1}), where two varieties, one tolerant and one susceptible to salinity, of each species were used. The authors concluded that there was no correlation between the germination rate and the plant's yield potential. They reported that the emergence rate, and the not germination rate, is the trait that should be counted on to evaluate the yield potential and the salinity tolerance level.

Salinity stress considerably affects plant height. GREENWAY and MUNNS [1980] reported that low salinity levels in the rhizosphere stimulate root growth but reduce the growth of the aerial parts. AL-MUTAWA [2003] studied the effect of salinity stress on the germination and the growth of 30 chickpea genotypes. The author found out that plant height is the most trait affected by salinity stress. The reduction in plant height under salinity stress was attributed to the decrease in cellular division and cellular elongation [FLOWERS *et al.* 2009; SHANKO *et al.* 2017].

Under salinity stress conditions, chlorophyll content analysis and its parameters are considered important methods in evaluating the integrity during the photosynthetic process; moreover, an association between the high performance of photosynthesis and salinity tolerance was reported [MOHAMED *et al.* 2020]. In addition, chlorophyll content is a very important indicator of the physiological changes in the leaf. SILVA *et al.* [2007] reported that relative chlorophyll content (SPAD) is a reliable indicator when selecting for drought tolerance, whereas MUDGAL *et al.* [2009] have confirmed that salinity stress applied on chickpea resulted in reduced chlorophyll content in the leaves.

High Na^+ concentration and low K^+:Na^+ ratio contribute to chloroplast damage in the mesophyll of chickpea genotype that is susceptible to salinity. Reduced photosynthesis was attributed to inefficient PSII as a result of Na^+ accumulation in chickpea leaflets because of disturbances in the ionic composition of stroma caused by Na^+ and Cl^- and, consequently, it can result in unstacking and distortion of grana and swelling of thylakoids [KHAN *et al.* 2015; KOTULA *et al.* 2019].

Stomatal conductance is one of the most reliable traits that indicate plant response to the salinity applied, as stomatal conductance was reported to decrease with increasing salinity levels. This decrease was attributed to a rapid disturbance in water relations. Salinity decreased transpiration rates, mainly by closing the stomata [MUNNS, TESTER 2008].

VADEZ *et al.* [2012] studied the effect of salinity on some yield traits, using 5 groups of tolerant and susceptible varieties, with the sorts of each group having similar flowering dates. Each group was subjected to salinity levels of 0.97–1.34 dS·m^{-1}. Their results showed that the flower number of the tolerant groups was 75% higher than that of susceptible counterparts. The susceptible groups had 21–24% fewer flowers than the control. The experiments of GOEL and VARSHNEY [1987] on 263 chickpea accessions showed variances in the yield under salinity stress conditions (80 mM of NaCl). 'Desi' genotypes showed better salinity tolerance than 'Kabuli' counterparts. However, there were no significant differences in the ratio of shoot dry matter to seed yield, indicating that it's not possible to differentiate between these genotypes, by means of salinity tolerance, during the vegetative stages.

An experiment was conducted by SAMINENI *et al.* [2011] to study salinity effects on chickpea during vegetative and reproductive periods by applying 3 different levels of NaCl (2, 4 and 6 dS·m^{-1}), in addition to control treatment. The highest salinity concentration resulted in the complete death of the plants after 52 days of salinity application without producing any pods, whereas the plants subjected to 4 dS·m^{-1} salinity level died after 75 days with some pods formed. Dry matter of the 2 dS·m^{-1} treatment decreased by 18–22%, and pod formation by 33% compared to the control. The authors concluded that chickpea was sensitive to salinity during both vegetative and reproductive stages; however, pod formation was the most sensitive stage.

We hypothesised that different genotypes of chickpeas will probably respond differently to salinity stress based on their tolerance potential. In addition, 'Kabuli' and 'Desi' chickpeas and, moreover, the different chickpea genotypes within each group are expected to respond differently to various severities of salinity stress, allowing for selection of the suitable genotypes to be cultivated under certain salinity stress level. The aim of this study was to evaluate the response of different chickpea genotypes to salinity stress, in addition to indicating the morpho-physiological and production traits that are correlated with salinity tolerance.

MATERIALS AND METHODS

The International Center for Agricultural Research in the Dry Areas (ICARDA) provided 58 genotypes of chickpea, 52 'Kabuli' genotypes and 6 'Desi' genotypes. 'Kabuli' and 'Desi' are the 2 distinct chickpea groups into which all domesticated chickpea genotypes were divided based on their seed morphology [VAN DER MAESSEN 1972]. The experiment was carried out in a greenhouse in ICARDA during 2010/2011 growing season. Plastic pots with 14 cm height and 15 cm diameter were filled with soil and sand (1:1) and were put in the greenhouse at 21°C for 16 h and 11°C for 8 h under 55% relative humidity. Five seeds were sown in each pot and irrigated with non-saline water (with an electrical conductivity of 5.0 dS·m^{-1}) until the third leaf was developed (18 days after sowing). Afterwards, the number of plants in each pot was reduced to 3, and each pot received water with electrical conductivity of either 0, 4 or 6 dS·m^{-1} until full maturity (123 days after sowing). Irrigation was applied every fifth day to 60% field capacity.

The experiment was designed using a split-plot design with three replications. The genotypes represented the main plots, and the three salinity treatments represented the sub-plots. The final pot number was 522 pots (58 genotypes×3 salinity treatments×3 replications).

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

Plant height (cm) was measured at full maturity for each plant and for all replications and treatments. Relative chlorophyll content (μg·dm^{-3}) was measured in the fifth leaf of each plant using SPAD-502 (Minolta, Japan). Stomatal conductance was also measured in the fifth leaf of each plant using Promoter SC-1 (Decagon, USA). Statistical analysis was carried out using GenStat (12th version). 2-way ANOVA, followed by Duncan's multiple range test (DMRT), was conducted to indicate the significant differences among genotypes, salinity levels and their interaction at 0.01 probability level ($p \leq 0.01$).

RESULTS AND DISCUSSION

PLANT HEIGHT

This experiment showed that saline irrigation water negatively affected chickpea growth and production. Significant differences ($p \leq 0.01$) among genotypes and salinity levels were recorded (Tab. 1). Under conditions without salinity stress, ILC3279 resulted in the best plant height, followed by ILC10722 and FLIP03-145C. The average plant height decreased by 32 and 48%

Table 1. Stomatal conductance, relative chlorophyll content and plant height of 58 genotypes of chickpea, 52 'Kabuli' genotypes and 6 'Desi' genotypes irrigated by 0, 4 or 6 dS·m^{-1} with saline water

Genotype	Stomatal conductance (mmol·m^{-2}·s^{-1})			Relative chlorophyll content (SPAD)			Plant height (cm)		
	salinity level (dS·m^{-1})								
	0	4	6	0	4	6	0	4	6
CPI060546	138.6	30.7	19.6	53.6	11.0	8.9	26.7	12.7	9.3
ILC1929	150.2	55.9	43.0	59.4	25.6	15.7	28.0	22.5	16.3
ILC2664	132.2	30.5	23.1	61.1	20.1	12.1	34.7	24.0	19.7
ILC8445	138.8	28.6	26.0	62.9	15.7	9.4	34.3	21.8	19.8
ILC8202	134.0	43.1	28.9	56.5	18.8	16.6	33.7	27.0	19.3
ILC9076	103.3	39.8	17.6	50.5	17.7	9.9	36.0	25.3	20.0
ILC9211	137.2	57.6	31.0	56.8	31.1	11.5	25.8	20.5	17.7
ILC9346	109.7	63.5	36.0	54.4	28.4	10.9	31.3	23.0	16.8
ILC9352	123.0	59.0	44.2	53.5	17.6	15.0	32.0	23.2	21.8
ILC9354	111.0	63.5	43.0	61.6	31.1	20.7	30.8	28.2	21.3
ILC9357	136.7	35.9	32.8	48.5	23.0	13.4	38.5	27.7	20.7
ILC9365	130.3	37.4	34.8	56.7	20.0	14.0	25.2	18.3	14.7
ILC9379	142.2	42.1	28.8	53.6	17.2	11.2	31.8	23.7	20.0
ILC9380	145.8	42.2	25.4	50.9	23.0	10.9	34.3	22.3	21.5
ILC9386	110.9	50.0	33.6	59.2	24.0	17.1	34.8	25.8	18.2
ILC9390	132.4	43.3	50.3	59.2	27.2	20.2	29.0	23.7	21.0
ILC9550	139.1	35.5	29.3	55.7	14.8	13.2	28.7	21.5	19.5
ILC9723	111.3	71.6	32.6	55.7	36.7	8.8	31.8	24.5	17.2
ILC9737	110.6	48.9	34.3	54.3	28.9	20.6	34.8	20.8	20.5
ILC588	123.6	65.0	28.3	56.3	35.4	12.1	37.7	25.8	24.2
GHAB4	147.6	51.8	30.6	53.2	21.9	15.3	38.0	21.8	15.7
GHAB5	122.2	47.6	31.2	65.0	23.6	11.5	40.0	27.0	18.0
NERYA	107.6	33.3	26.6	64.0	15.3	12.7	37.5	25.8	17.0
BG1103	134.8	54.9	34.3	47.8	28.5	27.3	35.5	21.3	18.8
BG362	120.4	80.3	80.2	59.2	42.3	41.6	33.0	24.0	18.3
CPI53008	129.7	79.1	33.5	67.8	36.1	12.4	30.7	20.5	10.0
FLIP03-145C	133.5	41.1	28.0	66.1	18.4	10.6	45.8	31.3	19.8
FLIP03-2C	154.0	41.4	21.9	60.6	15.4	7.6	29.0	15.0	8.7
FLIP03-46C	144.6	36.4	18.2	58.8	18.9	7.7	39.7	28.0	13.3
FLIP04-19C	94.1	52.8	15.6	52.3	21.4	7.0	37.7	18.8	11.3
FLIP87-59C	138.4	48.6	60.3	50.5	33.5	20.9	32.7	22.3	20.2

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

cont. Tab. 1

Genotype		Stomatal conductance (mmol·m^{-2}·s^{-1})			Relative chlorophyll content (SPAD)			Plant height (cm)		
		salinity level (dS·m^{-1})								
		0	4	6	0	4	6	0	4	6
FLIP87-8C		122.3	39.8	30.0	59.6	20.0	15.8	41.8	26.0	21.3
FLIP98-1065		117.1	35.6	18.3	60.4	14.3	9.3	37.5	21.8	16.7
ILC01302		145.6	71.9	55.8	56.6	39.7	25.9	31.3	25.2	19.7
ILC263		133.5	65.3	59.8	65.6	33.0	27.2	29.8	24.8	21.8
ILC482		121.2	19.5	21.0	60.6	7.6	8.0	36.8	21.2	12.7
ILC8617		145.2	51.8	17.4	46.3	22.3	7.1	44.8	9.3	6.3
ILC10722		136.1	31.0	27.8	59.9	18.5	7.2	47.2	29.7	24.0
ILC3182		97.1	56.6	21.6	61.0	26.5	15.7	32.3	23.8	15.8
ILC3279		97.0	35.3	25.0	56.1	17.8	10.8	58.3	40.5	14.5
ILC8464		159.7	35.9	25.9	47.6	9.6	9.8	37.0	25.5	19.3
ILC9037		121.7	56.3	52.1	53.6	11.0	8.9	33.5	24.0	21.5
ILC9077		82.4	26.9	16.2	59.4	25.6	15.7	37.2	24.3	14.0
ILC9079		132.4	34.0	28.0	61.1	20.1	12.1	34.7	26.7	21.8
ILC9082		114.8	51.8	62.2	62.9	15.7	9.4	33.2	20.7	20.7
ILC9353		128.0	61.0	43.2	56.5	18.8	16.6	34.7	26.7	20.5
ILC9362		126.5	41.8	37.9	50.5	17.7	9.9	25.8	19.7	14.5
ILC9388		136.6	73.3	91.3	56.8	31.1	11.5	33.2	28.5	27.5
ILC9493		117.2	45.3	53.6	54.4	28.4	10.9	31.3	26.8	19.2
ILC9497		137.9	29.1	24.6	53.5	17.6	15.0	34.0	22.0	21.5
ILC9519		132.7	57.9	29.9	61.6	31.1	20.7	33.5	19.3	17.8
ILC9589		133.9	48.0	31.0	48.5	23.0	13.4	35.8	25.0	18.5
ILC9985		139.2	51.6	24.1	56.7	20.0	14.0	33.7	10.7	2.7
ILwC183		129.4	68.8	36.3	53.6	17.2	11.2	28.7	14.0	8.0
ILwC81		162.7	94.0	56.2	50.9	23.0	10.9	28.2	18.2	15.2
UC27		103.0	75.9	64.8	59.2	24.0	17.1	29.2	18.3	16.2
S050339		134.6	42.7	26.4	68.5	23.8	9.4	27.3	23.7	18.0
ICC9942		144.9	51.8	47.9	64.4	33.8	29.0	31.0	24.8	19.8
Average		128.3	49.4	35.4	57.1	23.0	14.1	34.2	23.1	17.6
LSD (0.01)	genotype	13.3			5.8			3.0		
	salinity level	6.8			2.6			5.1		
	genotype× salinity level	21.2			9.0			5.3		

Explanations: *LSD* = least significant difference.
Source: own study.

when 4 and 6 dS·m^{-1} salinity levels were applied compared to the control, respectively. ILC3279 resulted in the best plant height under 4 dS·m^{-1} level, whereas ILC9388 had the best plant height under 6 dS·m^{-1} level. Our results were in agreement with SINGLA and GARG [2005], and ATIENO *et al.* [2017], who found that high salinity levels reduced water availability and, consequently, reduced plant growth. Under salinity stress conditions, salt-tolerant chickpea genotypes maintained a high shoot biomass [TURNER *et al.* 2013; VADEZ *et al.* 2012].

RELATIVE CHLOROPHYLL CONTENT

Salinity stress negatively influenced the relative chlorophyll content in the studied chickpea genotypes under different concentrations of salt stress, referring to reduced photosynthetic pigments. The analysis of variance showed significant differences ($p \leq 0.01$) among genotypes and salinity levels as well. The decrease of chlorophyll content was more pronounced in ILC8464, whereas BG362 had the highest chlorophyll content

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

under both salinity levels with no significant differences compared to the control treatment. Under control conditions chickpea genotypes varied in relative chlorophyll content as well (Tab. 1). Reductions of 57 and 73% in this trait were recorded in 4 and 6 dS·m^{-1} treatments, respectively. The same conclusion was drawn for ILC9388. According to GARG and SINGLA [2004], the lower reduction of chlorophyll pigments observed in tolerant chickpea genotypes can be responsible for the enhanced accumulation of dry matter. Moreover, the minimal chlorophyll content degradation in chickpea genotypes under salinity stress conditions indicates their potentially better capability of photosynthesis [EPITALAWAGE *et al.* 2003; KAUR *et al.* 2014]. KOTULA *et al.* [2019] found the excessive accumulation of Na in mesophyll cells of chickpea corresponded to structural damage to the chloroplasts, which results in direct toxicity for photosynthesis. Salinity caused leaves to become yellow as a result of damaged chlorophyll [MA *et al.* 2017]. This damage might be caused by inhibiting certain enzymes responsible for chlorophyll synthesis [STROGONOV 1974], or by increased chlorophyllase activity [SUDHAKAR *et al.* 1997], suggesting that chlorophyll content can act as a biochemical marker for salt tolerance in plants [ACOSTA-MOTOS *et al.* 2015; ASHRAF *et al.* 2013].

STOMATAL CONDUCTANCE

Significant differences ($p \leq 0.01$) were recorded among genotypes, salinity treatments, and genotype×salinity treatment (Tab. 1). Under no salinity stress conditions, ILwC81 had the highest stomatal conductance value (mmol·m^{-2}·s^{-1}), followed by ILC8464 and ILC1929. Stomatal conductance decreased by 61 and 82% with increasing salinity levels to 4 and 6 dS·m^{-1}, respectively compared to the control treatment, indicating the strong effect of salinity on this trait. When a plant is subjected to salinity, stomatal closure is the fastest reaction measured on the whole-plant level. This reaction is resulted from the effect of the osmotic pressure outside the roots, resulting in reduced leaf growth and, to a smaller level, reduced root growth, in addition to reduced stomatal conductance and, consequently, photosynthesis [MUNNS 1993; TERMAAT *et al.* 1985]. Salinity alters water relations, as well as abscisic acid synthesis. MOHAMED *et al.* [2020] concluded that salinity causes stomatal closure, decreases transpiration, and increases leaf temperature. FRICKE *et al.* [2004] reported that the most obvious response of the plant to salinity stress is the stomatal conductance reduction, as osmotic stress enhances the accumulation of abscisic acid, which is known for its central role in signal moving from roots to the stem and among the cells, resulting in changes in ion movement and carbohydrate accumulation [ASHRAF 2004; DAVIES *et al.* 2005; ZHU 2002].

POD NUMBER PER PLANT

The number of filled pods is a very important yield component trait. Genotypes, salinity treatments, and genotype×salinity were significantly different ($p \leq 0.01$) – Table 2. Under no stress conditions, BG362 had the highest pod number, followed by ILC482. Increasing salinity level was accompanied by decreased pod number in all genotypes due to a negative effect on shoot biomass as well as yield and yield components. ILC8617 did not yield any pods at 4 dS·m^{-1} salinity level, whereas 12 genotypes did not produce any pods at 6 dS·m^{-1} salinity level, indicating the inability of these genotypes to tolerate the high salinity levels. SOHRABI *et al.* [2008] confirmed that salinity resulted in lower pod numbers as an outcome of the decreased flower number or the inoculation failure [TOUCHAN *et al.* 2005]. According to TURNER *et al.* [2013], the number of filled pods per plant decreased under salinity stress conditions, and this decrease was associated with increased pod abortion in salt-susceptible chickpeas.

Table 2. 100-seed weight, seed number per plant and pod number per plant of 58 genotypes of chickpea; 52 'Kabuli' genotypes and 6 'Desi' genotypes irrigated by 0, 4 or 6 dS·m^{-1} with saline water

Genotype	100-seed weight (g)			Seed number per plant			Pod number per plant		
	salinity level (dS·m^{-1})								
	0	4	6	0	4	6	0	4	6
CPI060546	32.0	0	0	19.0	0	0	26.0	5.7	0
ILC1929	27.7	0	0	16.0	0	0	19.7	15.7	0
ILC2664	40.6	20.6	0	12.7	5.3	0	26.3	8.0	4.7
ILC8445	34.3	13.0	9.3	17.7	5.0	3.3	23.3	8.0	7.7
ILC8202	33.7	5.0	0	19.0	4.3	0	25.0	12.0	4.7
ILC9076	24.7	11.0	0	43.0	8.0	0	15.3	3.7	3.0
ILC9211	36.3	14.5	8.9	22.3	6.7	2.7	16.7	13.3	5.7
ILC9346	26.8	11.8	6.8	19.3	6.0	2.3	23.3	10.3	2.0
ILC9352	30.2	18.1	6.4	13.7	1.0	2.3	15.7	7.0	3.7
ILC9354	40.0	15.8	6.2	13.0	7.0	2.0	24.3	20.0	6.3
ILC9357	30.9	15.9	5.9	16.7	4.0	1.7	26.0	14.0	8.7
ILC9365	25.4	12.1	5.7	25.7	1.0	1.7	17.3	11.0	6.3
ILC9379	18.8	3.6	5.3	13.3	4.3	1.3	16.7	9.3	9.3

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

cont Tab. 2

Genotype	100-seed weight (g)			Seed number per plant			Pod number per plant		
	salinity level (dS·m^{-1})								
	0	4	6	0	4	6	0	4	6
ILC9380	37.0	6.0	5.3	20.0	3.7	1.3	15.3	6.7	4.3
ILC9386	29.3	18.1	0	14.7	8.0	0	33.3	9.0	4.3
ILC9390	35.6	16.1	5.0	19.7	6.0	1.0	22.3	13.7	6.7
ILC9550	31.9	16.9	0	14.0	2.0	0	17.7	13.3	4.7
ILC9723	30.7	11.7	0	22.0	4.7	0	23.7	17.7	9.0
ILC9737	12.8	0	0	29.3	0	0	25.3	11.3	9.3
ILC588	18.2	7.1	0	13.0	2.7	0	20.7	13.0	4.7
GHAB4	27.3	4.0	0	25.0	2.0	0	38.0	12.7	0.7
GHAB5	28.0	3.5	0	15.0	1.7	0	22.0	17.3	3.3
NERYA	28.6	0	0	19.3	0	0	29.7	10.3	0
BG1103	30.6	13.0	2.7	18.0	0.3	0.7	35.3	9.0	9.0
BG362	35.3	6.4	2.3	18.3	5.7	0.3	40.0	19.0	9.3
CPI53008	28.4	0	0	18.3	0	0	33.3	6.3	0
FLIP03-145C	29.7	16.2	0	19.0	4.3	0	22.3	6.0	1.3
FLIP03-2C	22.9	0	0	16.0	0	0	32.7	3.7	0
FLIP03-46C	20.5	8.4	0	22.0	3.7	0	26.3	21.7	1.3
FLIP04-19C	29.3	7.8	0	20.7	3.0	0	23.7	5.3	0
FLIP87-59C	39.1	11.4	1.3	18.3	3.0	0.3	23.7	8.7	3.3
FLIP87-8C	32.7	11.9	1.2	20.7	1.3	0.3	15.3	7.0	2.7
FLIP98-1065	34.6	8.7	0	20.3	0.7	0	29.0	4.3	0.7
ILC01302	33.5	15.8	0	19.0	6.7	0	24.0	19.3	4.7
ILC263	32.3	13.6	0	14.7	6.3	0	23.7	8.0	3.0
ILC482	25.0	0	0	19.3	0	0	39.0	2.0	0
ILC8617	29.7	0	0	16.7	0	0	19.7	0	0
ILC10722	19.3	9.4	0	21.3	4.0	0	31.0	14.7	8.3
ILC3182	26.0	9.0	0	17.7	3.7	0	26.3	22.7	0
ILC3279	32.7	8.8	0	29.0	3.0	0	34.0	17.7	0
ILC8464	18.4	0	0	17.0	0	0	22.0	0	0
ILC9037	31.8	6.9	0	18.7	2.3	0	17.0	12.3	11.3
ILC9077	38.3	6.6	0	14.0	2.3	0	29.0	9.3	0.7
ILC9079	22.3	5.7	0	13.7	1.7	0	21.0	17.3	4.0
ILC9082	17.3	3.2	0	17.0	1.7	0	25.0	18.0	3.0
ILC9353	26.0	3.2	0	23.3	1.3	0	22.0	12.7	5.0
ILC9362	8.1	2.9	0	17.3	1.3	0	22.0	14.3	7.7
ILC9388	26.6	2.7	0	21.0	1.3	0	17.0	9.0	9.3
ILC9493	30.3	2.3	0	18.3	1.0	0	21.0	10.7	4.7
ILC9497	5.5	1.7	0	19.0	0.7	0	17.0	10.7	3.0
ILC9519	34.1	1.4	0	15.3	0.7	0	25.0	22.3	6.7
ILC9589	14.2	0.9	0	20.3	0.3	0	23.7	13.0	3.3
ILC9985	23.1	0.7	0	16.0	0.3	0	22.7	11.7	2.0
ILwC183	22.0	0	0	19.7	0	0	30.0	1.3	0

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

cont Tab. 2

Genotype		100-seed weight (g)			Seed number per plant			Pod number per plant		
		salinity level (dS·m^{-1})								
		0	4	6	0	4	6	0	4	6
ILwC81		13.5	0	0	39.3	0	0	27.7	9.3	0.3
UC27		17.4	0	0	28.3	0	0	15.3	11.3	9.3
S050339		20.7	0	0	7.0	0	0	17.3	9.7	1.0
ICC9942		28.9	0	0	18.7	0	0	23.0	18.3	3.7
Average		27.3	9.0	5.2	19.3	3.3	1.5	24.1	11.4	5.0
LSD (0.01)	genotype	4.4			3.1			4.0		
	salinity level	4.7			2.8			4.2		
	genotype× salinity level	8.1			5.6			6.4		

Explanations: *LSD* = least significant difference.
Source: own study.

SEED NUMBER PER PLANT

Genotypes, salinity treatments, and their interaction were all statistically significant ($p \leq 0.01$) – Table 2. Under no stress conditions, ILC9076 produced the highest seed number, followed by ILwC81 and ILC9737 genotypes. At 4 dS·m^{-1} salinity level, ILC9076 and ILC9386 genotypes had the highest seed number, whereas ILC8445 and ILC9211 had the highest values of this trait at 6 dS·m^{-1} salinity level. The reduction rate was 83 and 95% at 4 and 6 dS·m^{-1} salinity treatments, respectively, compared to the control treatment. Under a high salinity level (6 dS·m^{-1}), 57% of the studied genotypes could not produce any seeds. Dhingra and Varghese [1993] reported that the decrease in chickpea seed number under salinity stress conditions is because of either decreased flower number or the reduced ability of the formed flowers to turn into seeds, as this process is dependent on the pollen viability, and sufficient photosynthesis rate for seed filling. According to Atieno *et al.* [2017], seed number majorly contributes to the final seed yield under salinity stress conditions and, therefore, is an important trait for breeding chickpeas with improved salinity tolerance.

HUNDRED-SEED WEIGHT

The analysis of variance showed significant differences ($p \leq 0.01$) among genotypes, salinity treatments in addition to genotype×salinity interaction (Tab. 2). The highest value of this trait was recorded in the ILC2664 genotype in the absence of salinity stress. Increasing the salinity level to 4 and 6 dS·m^{-1} measurably reduced this trait to 68 and 90%, respectively, compared to the control treatment. ILC2664 had the highest value at 4 dS·m^{-1} salinity level, whereas ILC8445 resulted in the highest 100-seed weight at 6 dS·m^{-1} salinity level, followed by ILC9211 and ILC9346 genotypes. Atieno *et al.* [2017] reported that under salinity stress conditions, genotypic variation in seed yield was associated with better flower and filled pod number and, consequently, better seed number in susceptible genotypes. They also concluded that decreased seed yield under salinity stress conditions is attributed to growth rate and biomass reductions.

BIOMASS

Differences among genotypes, salinity treatments, and the genotype×salinity were all significant ($p \leq 0.01$) – Table 3. Under no stress conditions, the biomass was the highest in the NERYA

Table 3. Harvest index, biomass and seed yield of 58 genotypes of chickpea, 52 'Kabuli' genotypes and 6 'Desi' genotypes irrigated by 0, 4 or 6 dS·m^{-1} with saline water

Genotype	Harvest index			Biomass (g·plant^{-1})			Seed yield (g·plant^{-1})		
	salinity level (dS·m^{-1})								
	0	4	6	0	4	6	0	4	6
CPI060546	0.290	0.003	0	11.6	5.8	4.2	3.4	0	0
ILC1929	0.367	0.003	0	12.2	7.4	5.6	4.5	0	0
ILC2664	0.527	0.013	0	11.7	6.2	5.7	5.7	0.1	0
ILC8445	0.410	0.007	0.017	15.9	5.6	5.3	6.5	0.1	0.1
ILC8202	0.457	0.067	0	13.9	7.5	5.0	6.3	0.6	0
ILC9076	0.407	0.023	0	13.1	6.5	4.6	5.2	0.2	0

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

cont Tab. 3

Genotype	Harvest index			Biomass (g·plant^{-1})			Seed yield (g·plant^{-1})		
	salinity level (dS·m^{-1})								
	0	4	6	0	4	6	0	4	6
ILC9211	0.363	0.087	0	14.3	7.6	5.1	5.2	0.7	0
ILC9346	0.390	0.100	0.013	14.4	6.7	4.5	5.6	0.7	0.1
ILC9352	0.343	0.027	0.030	13.7	6.6	6.5	4.7	0.2	0.2
ILC9354	0.487	0.143	0.030	14.7	7.9	6.4	7.2	1.2	0.2
ILC9357	0.390	0.113	0.023	14.3	6.8	5.7	5.5	0.8	0.1
ILC9365	0.437	0.023	0.023	12.7	6.8	3.8	5.4	0.2	0.1
ILC9379	0.423	0.117	0.037	12.0	7.3	6.4	5.1	0.9	0.2
ILC9380	0.347	0.027	0.007	13.9	7.0	5.8	4.8	0.2	0.1
ILC9386	0.367	0.020	0	14.1	6.1	4.8	5.1	0.1	0
ILC9390	0.387	0.090	0.027	13.5	8.1	5.3	5.2	0.7	0.2
ILC9550	0.410	0.087	0	14.5	6.5	5.1	6.0	0.6	0
ILC9723	0.467	0.143	0	12.3	6.4	4.5	5.8	0.9	0
ILC9737	0.433	0.007	0	11.3	5.6	5.3	4.8	0	0
ILC588	0.413	0.010	0	13.3	6.4	5.3	5.5	0.1	0
GHAB4	0.387	0.040	0	14.5	6.6	4.6	5.4	0.3	0
GHAB5	0.380	0.057	0	14.1	7.4	4.9	5.2	0.4	0
NERYA	0.243	0	0	18.9	5.4	4.9	4.2	0	0
BG1103	0.367	0.013	0.023	13.4	6.1	4.7	4.8	0.1	0.1
BG362	0.393	0.087	0.030	14.9	7.1	5.7	5.5	0.6	0.1
CPI53008	0.407	0	0	12.8	5.4	4.1	5.3	0	0
FLIP03-145C	0.320	0.017	0	13.3	6.4	4.7	4.2	0.1	0
FLIP03-2C	0.267	0	0	17.4	5.4	4.3	4.6	0	0
FLIP03-46C	0.370	0.070	0	14.9	6.3	4.5	5.5	0.6	0
FLIP04-19C	0.277	0.010	0	14.6	6.2	4.1	4.0	0.1	0
FLIP87-59C	0.423	0.057	0.013	11.2	6.8	5.0	4.6	0.4	0.1
FLIP87-8C	0.340	0.070	0.010	13.6	6.3	5.3	4.6	0.4	0.1
FLIP98-1065	0.313	0.017	0	10.7	5.6	4.2	3.2	0.1	0
ILC01302	0.410	0.077	0	15.1	7.9	5.9	6.2	0.6	0
ILC263	0.590	0.013	0	11.2	6.6	4.8	6.3	0.1	0
ILC482	0.343	0	0	14.6	5.3	4.4	4.9	0	0
ILC8617	0.710	0	0	6.5	5.7	4.3	1.4	0	0
ILC10722	0.400	0.033	0	13.2	6.3	4.7	5.3	0.2	0
ILC3182	0.360	0.070	0	13.3	8.0	5.2	4.7	0.6	0
ILC3279	0.240	0.040	0	14.9	6.7	4.4	3.5	0.3	0
ILC8464	0.393	0	0	13.5	6.3	5.8	5.4	0	0
ILC9037	0.657	0.303	0.103	10.4	6.2	6.0	5.7	2.0	0.6
ILC9077	0.403	0.027	0	15.0	6.7	4.7	6.1	0.2	0
ILC9079	0.407	0.090	0.010	14.9	7.6	4.9	6.0	0.7	0.1
ILC9082	0.520	0.080	0	14.0	7.7	6.2	6.5	0.6	0
ILC9353	0.400	0.053	0.033	11.5	7.4	6.6	4.1	0.4	0.2
ILC9362	0.357	0.073	0.017	16.7	7.8	5.7	5.9	0.5	0.1
ILC9388	0.453	0.197	0.120	11.5	6.4	6.7	5.2	1.2	0.8

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

cont Tab. 3

Genotype		Harvest index			Biomass (g·plant^{-1})			Seed yield (g·plant^{-1})		
		salinity level (dS·m^{-1})								
		0	4	6	0	4	6	0	4	6
ILC9493		0.420	0.093	0.060	13.4	7.1	5.7	5.6	0.8	0.3
ILC9497		0.380	0.057	0	12.0	7.0	5.4	4.7	0.5	0
ILC9519		0.420	0.120	0	15.2	8.1	5.4	6.3	0.9	0
ILC9589		0.350	0.097	0	13.8	7.7	5.1	4.9	0.8	0
ILC9985		0.380	0.040	0	13.6	7.2	4.7	5.1	0.3	0
ILwC183		0.077	0	0	11.4	0	0	0.9	0	0
ILwC81		0.160	0	0	8.9	0	0	1.4	0	0
UC27		0.383	0	0	12.4	0	0	4.8	0	0
S050339		0.297	0	0	15.1	0	0	4.5	0	0
ICC9942		0.333	0	0	11.0	0	0	3.6	0	0
Average		0.387	0.064	0.033	13.4	6.7	5.1	5.0	0.5	0.2
LSD (0.01)	genotype	0.086			1.1			0.7		
	salinity level	0.046			0.5			0.3		
	genotype× salinity level	0.150			2.1			1.3		

Explanations: *LSD* = least significant difference.
Source: own study.

genotype, followed by FLIP03-2C. Decreased biomass was recorded in all genotypes when salinity levels increased. ILC9390 and ILC9519 had the highest biomass under 4 dS·m^{-1} salinity level, whereas ILC9388 could produce the highest biomass under the higher salinity level (6 dS·m^{-1}). According to ZAWUDE and SHANKO [2017], biomass decrease is a result of prohibited kinase activity that affects cell division and vegetative development, causing a decrease in shoot dry weight, whereas KAASHYAP *et al.* [2017] justified the reduced biomass under salinity stress conditions by increased energy levels needed by plant cells under salinity conditions due to stomatal closure, where the internal reduction of carbon dioxide reduces the activity of many enzymes, including rubisco [CHAVES *et al.* 2009], which leads to limited carboxylation and decreased net photosynthesis. GEISSLER *et al.* [2015] noted that intercellular CO_2 concentration can be considered a good parameter in estimating salinity influence on photosynthesis.

SEED YIELD

The influence of salinity stress on seed yield (g·plant^{-1}) was more measurable than its influence on biomass. Analysis of variance revealed significant differences ($p \leq 0.01$) among genotypes, salinity treatments, and their interaction (Tab. 3). The highest seed yield was achieved from the ILC9354 genotype. Under 4 and 6 dS·m^{-1} salinity levels, 91 and 99% less yield was recorded, respectively, in comparison with the control treatment. Under the higher salinity level, ILC9388 had the highest seed yield, followed by ILC9037. Significant variations in seed yield under salinity stress conditions were previously reported [FLOWERS *et al.* 2010]. DHINGRA and VARGHESE [1993] attributed yield reduction under salinity stress conditions of certain 'Desi' and 'Kabuli' chickpeas genotypes to the reductions in photosynthesis rate, nitrogen and carbon metabolism. ATIENO *et al.* [2017] concluded that seed yield reduction under salinity stress conditions was due to the decreases in relative growth rate and in total plant biomass, in addition to the damage of reproductive tissues, which lead to the depletion of filled pod number, seed number, and 100-seed weight. SOUSSI *et al.* [1998] indicated that malfunctions in plant nutrition result in various element reductions and sodium concentration increase in the plant cells, causing reductions in flower, pod, and seed numbers and, consequently, the final seed yield. SAMINENI *et al.* [2011] and HIRICH *et al.* [2014] reported that yield decrease under salinity conditions is caused by many factors acting simultaneously: leaf area decline, photosynthesis and stomatal conductance reductions, resulting in decreased biomass. They also attributed the better seed yield of tolerant chickpea genotypes under salinity stress conditions to higher flower numbers under salinity conditions and to their ability to produce pods with fully developed seeds. However, MUDGAL *et al.* [2009] concluded that yield components of 'Desi' chickpeas CPI060546, BG1103, BG362, CPI53008, ILwC183, and ILwC81 were affected by salinity stress more negatively than 'Kabuli' chickpeas.

HARVEST INDEX

The harvest index (*HI*) varied greatly with increasing irrigation water salinity via genotypes, salinity levels and genotype×salinity were all significantly different ($p \leq 0.01$) – Table 3. Reductions in the *HI* of 86 and 97% were associated with increasing salinity levels to 4 and 6 dS·m^{-1}, respectively, compared to the control. ILC9037 genotype had the highest *HI* under 4 dS·m^{-1} salinity level, followed by the ILC9388 genotype. On the other hand, ILC9379 genotype was the best in this trait at the 6 dS·m^{-1} salinity level. It's worth noting that the genotypes which produced the

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

highest yield were the same genotypes that had the highest *HI*, indicating a close connection between these two traits, where a high ratio of the dry weight is devoted to seed growth and development [GONZÁLEZ *et al.* 2007]. Our results were in agreement with SINGLA and GARG [2005] who concluded that the negative influence of salinity stress on the *HI* is correlated with decreased dry mass and, consequently, with unfavourable supplements of photosynthates to developing seeds.

CONCLUSIONS

It could be concluded that salinity directly and negatively affected both vegetative and productive stages of all studied chickpea genotypes. The seed yield of both 'Kabuli' and 'Desi' chickpeas was similar; however, 'Desi' chickpeas tolerated salinity stress better. Under salinity stress conditions, ILC9388, ILC9379, ILC9037, BG362, ILC9390 and ILC9519 genotypes were significantly better than other genotypes in terms of most of the yield component traits, indicating that these genotypes could be identified as salt-tolerant genotypes that can be used in breeding programs in the future. However, extended field experiments should be carried out to support this conclusion under field conditions. Moreover, different genotypes differently express their ability to tolerate salinity stress during each growing stage. That said, selection should be made during different stages of chickpea life cycle in order to provide the ability to collect all resistance or tolerance resources of salinity stress throughout the plant life cycle.

ACKNOWLEDGEMENT

We would like to thank the International Center for Agriculture Research in the Dry Areas (ICARDA) for providing all the research requirements.

REFERENCES

ACOSTA-MOTOS J.R., DIAZ-VIVANCOS P., ÁLVAREZ S., FERNÁNDEZ-GARCÍA N., SANCHEZ-BLANCO M.J., HERNÁNDEZ J.A. 2015. Physiological and biochemical mechanisms of the ornamental *Eugenia myrtifolia* L. plants for coping with NaCl stress and recovery. Planta. Vol. 242 (4) p. 829–846. DOI 10.1007/s00425-015-2315-3.

AL-MUTAWA M. 2003. The effect of salinity on germination and seedling growth of chickpea (*Cicer arietinum* L.) genotypes. International Journal of Agriculture and Biology. Vol. 5(3) p. 226–229.

ASHRAF M. 2004. Some important physiological selection criteria for salt tolerance in plants. Flora-Morphology, Distribution, Functional Ecology of Plants. Vol. 199(5) p. 361–376. DOI 10.1078/0367-2530-00165.

ASHRAF M.H.P.J.C., HARRS P.J. 2013. Photosynthesis under stressful environments: An overview. Photosynthetica. Vol. 51(2) p. 163–190. DOI 10.1007/s11099-013-0021-6.

ATIENO J., LI Y., LANGRIDGE P., DOWLING K., BRIEN C., BERGER B., SUTTON T. 2017. Exploring genetic variation for salinity tolerance in chickpea using image-based phenotyping. Scientific Reports. Vol. 7(1) p. 1–11. DOI 10.1038/s41598-017-01211-7.

BHATTARAI S., BISWAS D., FU Y.B., BILIGETU B. 2020. Morphological, physiological, and genetic responses to salt stress in alfalfa: A review. Agronomy. Vol. 10(4), 577. DOI 10.3390/agronomy10040577.

CHAVES M., FLEXAS J., PINHEIRO C. 2009. Photosynthesis under drought and salt stress: Regulation mechanisms from whole plant to cell. Annals of Botany. Vol. 103 p. 551–560. DOI 10.1093/aob/mcn125.

DAVIES W.J., KUDOYAROVA G., HARTUNG W. 2005. Long-distance ABA signaling and its relation to other signaling pathways in the detection of soil drying and the mediation of the plant's response to drought. Journal of Plant Growth Regulation. Vol. 24(4) p. 285–295. DOI 10.1007/s00344-005-0103-1.

DHINGRA H.R., VARGHESE T.M. 1993. Flowering and male reproductive functions of chickpea (*Cicer arietinum* L.) genotypes as affected by salinity. Biologia plantarum. Vol. 35(3) p. 447–452. DOI 10.1007/BF02928525.

EPITALAWAGE N., EGGENBERG P., STRASSER R.J. 2003. Use of fast chlorophyll a fluorescence technique in detecting drought and salinity tolerant chickpea (*Ci1cer arietinum* L.) varieties. Archives Des Sciences. Vol. 56(2) p. 79–93.

FAOSTAT 2016. FAOSTAT statistics database [online]. Rome. FAO. [Access 08.06.2022]. Available at: https://www.fao.org/faostat/en/#data/QCL

FLOWERS T.J., GAUR P.M., GOWDA C.L., KRISHNAMURTHY L., SAMINENI S., SIDDIQUE K.H., COLMER T.D. 2010. Salt sensitivity in chickpea. Plant, Cell & Environment. Vol. 33(4) p. 490–509. DOI 10.1111/j.1365-3040.2009.02051.x.

FRICKE W., AKHIYAROVA G., VESELOV D., KUDOYAROVA G. 2004. Rapid and tissue specific changes in ABA and in growth rate in response to salinity in barley leaves. Journal of Experimental Botany. Vol. 55 (399) p. 1115–1123. DOI 10.1093/jxb/erh117.

GARG N., SINGLA N. 2004. Growth, photosynthesis, nodule nitrogen and carbon fixation in the chickpea cultivars under salt stress. Brazilian Journal of Plant Physiology. Vol. 16(3) p. 137–146. DOI 10.1590/S1677-04202004000300003.

GEISSLER N., HUSSIN S., EL-FAR M.M., KOYRO H.W. 2015. Elevated atmospheric CO_2 concentration leads to different salt resistance mechanisms in a C3 (*Chenopodium quinoa*) and a C4 (*Atriplex nummularia*) halophyte. Environmental and Experimental Botany. Vol. 118 p. 67–77. DOI 10.1016/j.envexpbot.2015.06.003.

GOEL N., VARSHNEY K.A. 1987. Seed germination and early seedling growth to two chickpea varieties under saline conditions. Note. Legume Research. Vol. 10(6) p. 34–36.

GONZÁLEZ A., MARTÍN I., AYERBE L. 2007. Response of barley genotypes to terminal soil moisture stress: phenology, growth, and yield. Australian Journal of Agricultural Research. Vol. 58(1) p. 29–37. DOI 10.1071/AR06026.

GREENWAY H., MUNNS R. 1980. Mechanism of salt tolerance in nonhalophytes. Annual Review of Plant Physiology. Vol. 31 p. 149–190. DOI 10.1146/annurev.pp.31.060180.001053.

HIRICH A., EL OMARI H., JACOBSEN S.E., LAMADDALENA N., HAMDY A., RAGAB R., CHOUKR-ALLAH R. 2014. Chickpea ('*Cicer arietinum*' L.) physiological, chemical and growth responses to irrigation with saline water. Australian Journal of Crop Science. Vol. 8(5) p. 646–654.

ISAYENKOV S.V., MAATHUIS F.J. 2019. Plant salinity stress: many unanswered questions remain. Frontiers in Plant Science. Vol. 10, 80 p. 1–11. DOI 10.3389/fpls.2019.00080.

KAASHYAP M., FORD R., BOHRA A., KUVALEKAR A., MANTRI N. 2017. Improving salt tolerance of chickpea using modern genomics tools and molecular breeding. Current Genomics. Vol. 18(6) p. 557–567. DOI 10.2174/1389202918666170705155252.

KADIOĞLU B. 2021. Determination of germination biology of some sage (*Salvia* ssp.) species under salinity stress. Journal of Tekirdag Agricultural Faculty. Vol. 18(2) p. 359–367. DOI 10.33462/jotaf.802681.

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)

Kafi M., Bagheri A., Nabati J., Mehrjerdi M.Z., Masomi A. 2011. Effect of salinity on some physiological variables of 11 chickpea genotypes under hydroponic conditions. Journal of Science and Technology of Greenhouse Culture. Vol. 1(4) p. 55–70.

Katerji N., Mastrorilli M., Lahmer F.Z., Oweis T. 2012. Emergence rate as a potential indicator of crop salt-tolerance. European Journal of Agronomy. Vol. 38 p. 1–9. DOI 10.1016/j.eja.2011.11.006.

Kaur G., Sharma A., Guruprasad K., Patii P.K. 2014. Versatile roles of plant NADPH oxidases and emerging concepts. Biotechnology Advances. Vol. 32 p. 551–563. DOI 10.1016/j.biotechadv.2014.02.002.

Khan H.A., Siddique K.H., Munir R., Colmer T.D. 2015. Salt sensitivity in chickpea: Growth, photosynthesis, seed yield components and tissue ion regulation in contrasting genotypes. Journal of Plant Physiology. Vol. 182 p. 1–12. DOI 10.1016/j.jplph.2015.05.002.

Khataar M., Mohammadi M.H., Shabani F. 2018. Soil salinity and matric potential interaction on water use, water use efficiency and yield response factor of bean and wheat. Scientific Reports. Vol. 8(1) p. 1–13. DOI 10.1038/s41598-018-20968-z.

Kotula L., Clode P.L., Jimenez J.D.L.C., Colmer T.D. 2019. Salinity tolerance in chickpea is associated with the ability to 'exclude' Na from leaf mesophyll cells. Journal of Experimental Botany. Vol. 70(18) p. 4991–5002. DOI 10.1093/jxb/erz241.

Kotula L., Khan H.A., Quealy J., Turner N.C., Vadez V., Siddique K.H., Colmer T.D. 2015. Salt sensitivity in chickpea (*Cicer arietinum* L.): Ions in reproductive tissues and yield components in contrasting genotypes. Plant, Cell & Environment. Vol. 38(8) p. 1565–1577. DOI 10.1111/pce.12506.

Ma N., Hu C., Wan L., Hu Q., Xiong J., Zhang C. 2017. Strigolactones improve plant growth, photosynthesis, and alleviate oxidative stress under salinity in rapeseed (*Brassica napus* L.) by regulating gene expression. Frontiers in Plant Science. Vol. 8, 1671 p. 1–15. DOI 10.3389/fpls.2017.01671.

Mohamed I.A., Shalby N., Bai C., Qin M., Agami R.A., Jie K., Zhou G. 2020. Stomatal and photosynthetic traits are associated with investigating sodium chloride tolerance of *Brassica napus* L. cultivars. Plants. Vol. 9(1), 62. DOI 10.3390/plants9010062.

Mudgal V., Madaan N., Mudgal A., Mishra S., Singh A., Singh P.K. 2009. Changes in growth and metabolic profile of chickpea under salt stress. Journal of Applied Biosciences. Vol. 23 p. 1436–1446.

Munns R. 1993. Physiological processes limiting plant growth in saline soils: Some dogmas and hypotheses. Plant Cell and Environment. Vol. 16 p. 15–24. DOI 10.1111/j.1365-3040.1993.tb00840.x.

Munns R., Tester M. 2008. Mechanisms of salinity tolerance. Annual Review of Plant Biology. Vol. 59 p. 651–681. DOI 10.1146/annurev.arplant.59.032607.092911.

Qadir M., Oster J.D. 2004. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. Science of the Total Environment. Vol. 323(1–3) p. 1–19. DOI 10.1016/j.scitotenv.2003.10.012.

Samineni S., Siddique K.H., Gaur P.M., Colmer T.D. 2011. Salt sensitivity of the vegetative and reproductive stages in chickpea (*Cicer arietinum* L.): Podding is a particularly sensitive stage. Environmental and Experimental Botany. Vol. 71(2) p. 260–268. DOI 10.1016/j.envexpbot.2010.12.014.

Shanko D., Jateni G., Debela A. 2017. Effects of salinity on chickpea (*Cicer arietinum* L.) landraces during germination stage. Biochemistry & Molecular Biology Journal. Vol. 3 p. 214–219. DOI 10.21767/2471-8084.100037.

Silva M.D.A., Jifon J.L., Da Silva J.A., Sharma V. 2007. Use of physiological parameters as fast tools to screen for drought tolerance in sugarcane. Brazilian Journal of Plant Physiology. Vol. 19(3) p. 193–201. DOI 10.1590/S1677-04202007000300003.

Singla R., Garg N. 2005. Influence of salinity on growth and yield attributes in chickpea cultivars. Turkish Journal of Agriculture and Forestry. Vol. 29(4) p. 231–235.

Sohrabi Y., Heidari G., Esmailpoor B. 2008. Effect of salinity on growth and yield of Desi and Kabuli chickpea cultivars. Pakistan Journal of Biological Sciences. Vol. 11(4) p. 664–667. DOI 10.3923/pjbs.2008.664.667.

Soussi M., Ocaña A., Lluch C. 1998. Effects of salt stress on growth, photosynthesis and nitrogen fixation in chick-pea (*Cicer arietinum* L.). Journal of Experimental Botany. Vol. 49(325) p. 1329–1337. DOI 10.1093/jxb/49.325.1329.

Strogonov B.P. 1974. Structure and function of plant cells in saline habitats. New York, London. Israel Program for Scientific Translation pp. 284.

Sudhakar C., Ramanjulu S., Reddy P.S., Veeranjaneyulu K. 1997. Response of some Calvin cycle enzymes subjected to salinity shock in vitro. Indian Journal of Experimental Botany. Vol. 35 p. 665–667.

Termaat A., Passioura J.B., Munns R. 1985. Shoot turgor does not limit shoot growth of NaCl-affected wheat and barley. Plant Physiology. Vol. 77(4) p. 869–872. DOI 10.1104/pp.77.4.869.

Touchan H., Al-Dermouch K., Ghandour G. 2005. Effect of salinity stress on chickpea growth and productivity. In: Sustainable development and management of drylands in twenty-first century. Eds. A. El-Beltagy, M.C. Saxena. Proceedings of the Ninth International Conference on Dryland Development. 14–17.09.2003, Tehran, Iran. Aleppo, Syria. ICARDA p. 379–382.

Turner N.C., Colmer T.D., Quealy J., Pushpavalli R., Krishnamurthy L., Kaur J., Vadez V. 2013. Salinity tolerance and ion accumulation in chickpea (*Cicer arietinum* L.) subjected to salt stress. Plant and Soil. Vol. 365(1) p. 347–361. DOI 10.1007/s11104-012-1387-0.

Vadez V., Krishnamurthy L., Serraj R., Gaur P.M., Upadhyaya H.D., Hoisington D.A., Siddique K.H.M. 2007. Large variation in salinity tolerance in chickpea is explained by differences in sensitivity at the reproductive stage. Field Crops Research. Vol. 104(1–3) p. 123–129. DOI 10.1016/j.fcr.2007.05.014.

Vadez V., Rashmi M., Sindhu K., Muralidharan M., Pushpavalli R., Turner N.C., Colmer T.D. 2012. Large number of flowers and tertiary branches, and higher reproductive success increase yields under salt stress in chickpea. European Journal of Agronomy. Vol. 41 p. 42–51. DOI 10.1016/j.eja.2012.03.008.

Van der Maessen L.J. 1972. *Cicer* L., a monograph of the genus, with special reference to the chickpea (*Cicer arietinum* L.), its ecology and cultivation. Wageningen University and Research pp. 355.

Van der Zee S.E.A.T.M., Stofberg S.F., Yang X., Liu Y., Islam M.N., Hu Y.F. 2017. Irrigation and drainage in agriculture: A salinity and environmental perspective. In: Current perspective on irrigation and drainage. Eds. S. Kulshreshtha, A. Elshorbagy. IntechOpen p. 1–21. DOI 10.5772/66046.

Wild A. 2003. Soils, land and food: Managing the land during the twenty-first century. Cambridge. Cambridge University Press. ISBN 9780511815577 pp. 246. DOI 10.1017/CBO9780511815577.

Zawude S., Shanko D. 2017. Effects of salinity stress on chickpea (*Cicer arietinum* L.) landraces during early growth stage. International Journal of Scientific Reports. Vol. 3(7) p. 214–219. DOI 10.18203/issn.2454-2156.IntJSciRep20173093.

Zhu J.K. 2002. Salt and drought stress signal transduction in plants. Annual Review of Plant Biology. Vol. 53(1) p. 247–273. DOI 10.1146/annurev.arplant.53.091401.143329.

© 2022. The Authors. Published by Polish Academy of Sciences (PAN) and Institute of Technology and Life Sciences – National Research Institute (ITP – PIB).
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/3.0/)