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Effects of cycocel on growth, some physiological traits and yield of wheat (*Triticum aestivum* L.) under salt stress

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Abstract

In order to investigate changes in sodium ion (Na^+), potassium ion (K^+), dry matter mobilization and grain filling period of wheat (*Triticum aestivum* L.) under salinity stress, a factorial experiment was conducted based on randomized complete block design with three replications. Factors were salinity at four levels [no-salt (S_0) and salinity of 25 (S_1), 50 (S_2) and 75 (S_3) mM NaCl, equivalent of 2.3, 4.61 and 6.92 dS m^{-1}, respectively] and four cycocel levels [without cycocel (C_0) and application of 400 (C_1), 800 (C_2) and 1200 (C_3) mg L^{-1} cycocel)]. Results showed that salinity stress decreased grain yield, chlorophyll index, grain filling period, stomata conductance and relative water content in plant shoots. But grain filling rate and dry matter remobilization from shoots increased. Application of cycocel at C_3 level led to the reduction of 36.36% and 5.75% in dry matter remobilization from shoot and stem, respectively. In the case of mineral content, Na^+/K^+ ratio was increased with increasing salinity level. At all salinity levels, cycocel application resulted in lower Na^+ content and Na^+/K^+ ratio. Higher K^+ accumulation in the cycocel treated plants, resulted in a low Na^+/K^+ ratio leading to their efficiency in salinity tolerance. It was concluded that cycocel can be a proper tool for increasing wheat yield under salinity condition.

Keywords: Cycocel; Grain filling duration; Na^+/K^+ ratio; Stomatal resistance

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Introduction

Soil salinity is one of the major abiotic environmental constraints to plant growth and crop production (Yamaguchi and Blumwald 2005). Salinity is a serious threat to crop productivity especially in semiarid and saline regions (Parvaiz and Satyawati 2008). Reductions in growth resulting from high salt levels are the subsequences of both osmotic stress and Na^+ and Cl^- ions toxicity (Munns and Tester 2008). Leaf growth and carbon metabolism of plants could be affected by water shortage, osmotic pressure, nutritional deficiency and oxidative metabolism as the result of high salinity level (Bashan and de-Bashan 2010). Development of salt stress within a plant results in the lack of water, early senescence and higher translocation of pre-anthesis assimilates to grains in cereals (Yang *et al.* 2003). In general plants that are able to sustain photosynthesis in the flag leaf for a longer time tend to have higher yield (Karimi *et al.* 2005). The harmful effects of salinity are photosynthetic inhibition, destruction of pigments and plasma membrane damage by increasing stomatal resistance and other metabolic disturbances (Sairam *et al.* 2005).

Crop water uptake ability before anthesis can have major impact on crop growth because grain number and grain weight are set during this phase. Furthermore, final grain weight is related to rate and duration of grain filling and their interactions (Sadras and Egli 2008). Photosynthesis of flag leaf and spike (Tambussi *et al.* 2007) and redistribution of assimilates stored in the stem (Ehdaie *et al.* 2008) contribute to grain filling in wheat and barley. Most of the assimilates used for grain growth are constructed by the upper part of plants such as spike, flag leaf blade and its sheath (Loss and Siddique 1994). Lack of assimilate supply during the grain filling period could result in a dramatic decline in grain weight (Borrás *et al.* 2004). Stem reserves are powerful sources for grain filling under any type of stress which inhibits current assimilation (Wang *et al.* 2009). Ehdaie *et al.* (2008) suggested that in water deficit condition the wheat plant may depend more on stem reserves for grain filling than current photosynthesis two weeks after anthesis at the beginning of rapid seed filling period, because stress condition decreases photosynthetic rate (Lawlor 2002) and promotes leaf senescence (Martinez *et al.* 2003). When photosynthetic activity is depressed by drought or salinity after anthesis, grain filling becomes more dependent on mobilized stem reserves, which may then represent 22 to 80% of dry matter accumulation in the grain (Xue *et al*. 2006).

Resistance to salt stress is correlated negatively with Na^+ concentration and positively with K^+ concentration (Meloni *et al.* 2008). Furthermore, high K^+ /Na^+ in plant tissues and the selective uptake of K^+ as opposed to Na^+ are considered as the main physiological responses contributing to salt tolerance in many plant species (Meloni *et al.* 2008; Song *et al.* 2009). Hamdia *et al.* (2004) reported that application of *Azospirillum brasilense* altered the Na^+ and K^+ selectivity of salt stressed plants, decreased the Na^+/K^+ ratio and enhanced plant growth and yield. Adjustment of mineral absorption may be the key mechanism involved in alleviation of salt stress.

It is well known that cycocel could make changes in the physiological properties of plants under stress condition. Cycocel is an essential growth regulator for plants that decrease the concentration of gibberellins and mediate with the concentration of other plant hormones such as cytokinins, ethylene, and abscisic acid (Rademacher 2000). Generally, growth retardants reduce transpiration rate by retarding leaf growth (Luoranen *et al.* 2002). Application of cycocel in plants may increase the concentration of chlorophyll and carotenoids, accelerate the process of photophosphorylation, elevate the number of chloroplasts, stimulate the photosynthetic rate and photo-assimilates partitioning in plants (Wang and Xiao 2009). Researches have shown that chlorophyll derivatives act as antioxidants to exclude oxidative DNA degradation and lipid peroxidation both by scavenging free radicals and chelating reactive ions (Hsu *et al.* 2013). Therefore, treatment of cycocel might be a promising practice for improving plant yield under stress conditions. However, the underlying physiological mechanisms of cycocel treatment for enhancing the ability of crops to resist the stressful growing conditions are not fully understood. The aim of this research was to investigate physiological and biochemical responses of wheat to cycocel application under salinity stress.

Materials and Methods

A factorial experiment based on randomized complete block design with three replications was conducted under greenhouse condition in 2014**.** Factors included salinity at four levels [no-salt (S_0), and salinity of 25 (S_1), 50 (S_2) and 75 (S_3) mM NaCl equivalent of 2.3, 4.61 and 6.92 dS m^{-1}, respectively] and four cycocel (2-chloro ethyl trimethyl ammonium chloride, Sigma Aldrich Co. U.S.A) levels (without cycocel (C_0) and application of 400 (C_1), 800 (C_2), 1200 (C_3) mg L^{-1} cycocel). The soil was silty loam with the EC of about 2.68 dS/m and pH of about 6.9. Air temperature was about 22 to 27 °C during the day and 18 to 21°C during the night. Humidity ranged from 60 to 65%. The wheat cultivar used in this research was "Attila 4", a spring variety with the growth period of 90 days. The optimal plant density of this cultivar is 400 seeds m^{-2}. Pots were filled with 20 kg of soil. Then, 40 seeds were sown in each pot at the depth of 4 cm. Pots had the diameter of 25 cm at the base with the depth of 40 cm. Salinity treatments were applied two weeks after planting (at 3-4 leaf stage). Foliar application of cycocel was done at two growth stages (4-6 leaf stage and before booting stage).

Assay of rate and period of grain filling

For measuring the grain filling attributes, three plants were taken from each pot in each sampling time. The first sampling was taken on the 12th day after heading and other samples were taken at 4-day intervals for determining the grain weight accumulation. At each sampling, grains were removed and dried at 80 °C for 48 hours. Grain dry weight and number were used to calculate the average grain weight for each sample. Total duration of grain filling was determined for each treatment combination by fitting a bilinear model (Borrás and Otegui 2001):

$$GW = \begin{cases} a + gfr(daa), \ldots\ldots if \ldots daa < p_m \\ a + gfr(p_m), \ldots\ldots. if \ldots daa \geq p_m \end{cases}$$

where GW is the grain dry weight, a the GW-intercept, gfr the slope of grain weight indicating grain filling rate, daa the days after anthesis and p_m physiological maturity. Borrás *et al.* (2004) illustrated grain filling by a bilinear model. Effective grain filling duration (EGFD) was calculated from the following equation:

EGFD = the highest grain weight (g)/rate of grain filling (g day^{-1})

SAS software was utilized to fit the above bilinear model using Proc NLIN DUD.

Assay of dry matter and stem reserves mobilization to grain

Dry matter and stem reserves mobilization to grains were evaluated as follows (Inoue *et al.* 2004):

Dry matter remobilization to grain (g per plant) = maximum shoot dry matter after anthesis (g per plant) – shoot dry matter (except grains) at maturity (g per plant)

Dry matter contribution of assimilates to grains (%) = [remobilization/grain yield] ×100

Stem reserves remobilization to grains (g per plant) = maximum stem dry matter after anthesis – stem dry matter at maturity

Stem reserve contribution to grain yield (%) = [stem dry matter remobilization/grain yield] × 100.

Assay of root and shoot Na^+/ K^+ ratio

Root and shoot Na^+/K^+ ratio was estimated according to the method of Izadi *et al.* (2014). In this method leaf samples were collected and washed in distilled water to remove any external salt and then oven dried at 60 °C for 48 hours. The dried samples were ground into a fine powder using a mortar and pestle. Ashing of the samples (1 g) were done by putting them into crucibles and placing in 600 °C electric furnace, for 4 h. Then 5 mL of 2 N hydrochloric acid (HCl) was added to cool the ash. Then samples were dissolved in boiling deionized water and after filtering they were brought up to the final volume of 50 mL. Na^+ and K^+ were measured using standard flame photometer procedure and reported as mg g^{-1} dry weight.

Chlorophyll content, relative water content (RWC) and electrolyte leakage

The fully developed flag leaf of main tillers was selected from five random plants of each pot for determination of stomata conductance using a leaf prometer (Model SC-J Eijkelkamp, Netherlands). The chlorophyll content of leaves was determined with a SPAD-502 (Konica Minolta Sensing, Osaka, Japan) (Jifon *et al.* 2005). RWC was estimated gravimetrically according to the method of Tambussi *et al.* (2005).

Measuring grain yield

In order to measure grain yield per plant, 10 random plants from each pot were harvested. Analysis of variance and mean comparisons were performed using SAS software. Means were compared by the least significant difference test at 0.05 probability level.

Results and Discussion

Analysis of variance showed the significant effect of soil salinity on grain filling rate and duration, dry matter remobilization from shoots, stem reserve contribution to grain yield, chlorophyll index, RWC, stomata conductance, K^+ content in the shoot and root, Na^+ content in shoot and root and Na^+/K^+ ratio in shoot and root (Table 1). Grain filling rate and duration, dry matter remobilization from shoots and stem, chlorophyll index, RWC, K^+ content in root and shoot, Na^+ content in shoot and Na^+/K^+ ratio in shoot and root were affected by the cycocel application. Interaction of cycocel and salinity was significant for grain filling rate and duration, Na^+ content in shoot and Na^+/K^+ ratio in shoot (Table 1).

Under stress condition, grain yield depends on the rate of grain filling and transfer of stored assimilates to grain (Santiveri *et al.* 2002). The results showed that maximum grain filling rate (1.48 g day^{-1}) was obtained at the highest salinity level and no application of cycocel (S_4C_0) (Table 2). As shown in Tables 2, at the highest salinity level, application of cycocel as C_3 increased grain filling rate about 7.43% in comparison with S_1C_0. The grain-filling period was shortened by increasing salinity levels, but a faster grain filling rate (Table 2) and enhanced remobilization of dry matter from shoot were achieved (Table 3). Santiveri *et al.* (2002) found that grain filling duration seems to be more affected by environmental factors than grain filling rate. The highest grain filling duration (42.21 days) was obtained at no salinity condition and application of cycocel at C_3 level (Table 2). But the minimum of grain filling duration (29.40 days) observed in S_4C_0 (Table 2). Chlorophyll index and RWC decreased significantly at 75 mM salinity as compared to no salinity (Table 3) and it seems that it can be the major reason for the low grain filling rate and high grain filling period. Treated plants with cycocel under salinity stress showed a significantly lower grain filling rate. One reason for this may be the improvement of chlorophyll index and RWC due to cycocel application (Table 4), which in turn causes a decrease in grain filling rate and increase grain filling period (Table 2) and grain yield (Table 4).

Table 1. Summary of the analysis of variance for all measured characters.

SOV	df	Mean squares									
		Grain filling rate	Grain filling duration	Dry matter remobilization from shoots	Dry matter remobilization from stem	Contribution of remobilization from shoots to grain	Stem reserve contribution in grain yield	Chlorophyll index	RWC	Stomata conductance	Grain yield
Replication	2	0.345**	125.121**	0.326**	0.138**	1935**	1127**	11.74**	629.57*	10.123**	0.0006**
Soil salinity (S)	3	0.0058**	8.15**	0.028**	0.012^{ns}	3089^{ns}	5501^{ns}	6.91**	233.90**	11.25**	0.043**
Cycocel (C)	3	0.0063**	26.89**	0.054**	0.025*	3091^{ns}	1640^{ns}	1.027**	189.66*	0.086^{ns}	0.003**
S × C	9	0.0012**	7.346**	0.0002^{ns}	0.0005^{ns}	8227^{ns}	8044^{ns}	0.151^{ns}	130.85ns	0.745^{ns}	0.0001^{ns}
Error	30	0.00002	0.033	0.0014	0.0046	9623	1183	0.142	139.64	0.486	0.0002
C.V.	-	5.31	5.34	10.35	20.34	26.77	16.28	8.04	27.48	1.26	7.31

ns,* and ** not significant and significant at 0.05 and 0.01 probability levels, respectively.

Table 1 continued

SOV	df	Mean squares					
		Na^+ concentration		K^+ concentration		Na^+ /K^+ ratio	
		Shoot	Root	Shoot	Root	Shoot	Root
Replication	2	0.002*	0.002^{ns}	0.349**	3.765**	0.10**	3.20**
Soil salinity (S)	3	0.012**	0.163**	0.539**	0.048*	0.007**	0.18*
Cycocel (C)	3	0.002*	0.010^{ns}	0.543**	0.070**	0.018**	0.19*
S × C	9	0.003**	0.008^{ns}	0.038ns	0.004^{ns}	0.004**	0.01^{ns}
Error	30	0.0006	0.005	0.023	0.013	0.001	0.06
C.V.		5.12	13.50	10.62	14.51	10.69	27.56

ns, * and ** not significant and significant at 0.05 and 0.01 probability levels, respectively.

High grain filling duration for cycocel application could have been resulted from adequate assimilate supply and large partitioning capacity. Deficiency of assimilate supply during the grain filling duration may result in a decrease in grain filling duration and grain yield (Borrás *et al.* 2004). Michihiro *et al.* (1994) suggested that the increase in grain weight under application of cycocel is mainly attributed to the higher number of endosperm cells that led to reduced sink strength.

In our study, salinity reduced the chlorophyll content and RWC that led to higher mobilization of dry matter reserves assimilates to grain. In contrast, cycocel foliar application slowed senescence and retarded such mobilization. The highest (0.422 g per plant) and lowest (0.305 g per plant) dry matter remobilization from shoots was obtained at the highest (S_4) and lowest (S_1) salinity levels, respectively (Table 3). By increasing salinity levels, chlorophyll index (Table 3) and RWC (Table 3) reduced but dry matter reserves remobilization to grain (Table 3) significantly increased. It seems that high chlorophyll index in the cycocel treated plants due to current photosynthesis, reduced mobilization of dry matter reserves to grain yield. On the other hand, application of cycocel as C_3 led to the reduction of 36.36% and 5.75% in dry matter reserves remobilization from shoot and stem to grains, respectively (Table 4). Yang *et al.* (2003) reported that the enhanced remobilization and increased grain filling duration are mainly attributed to elevated abscisic acid levels in the stems and grains when subjected to stress condition. Wang *et al*. (2009) has also shown a decrease in partitioning of the stem dry matter to the potato plants treated with cycocel. Thus, there is a possibility that a lower remobilization of dry matter in cycocel-treated plants was attributed to the slow plant development. Wang and Xiao (2009) reported that cycocel compounds are able to decrease the partitioning of assimilates to grain yield through hampering the gibberellin biosynthesis.

Our results showed that the highest chlorophyll index (45.35) was observed under no-salinity stress (Table 3) and cycocel application as C_3 (44.81) (Table 4). The lowest value of this trait was obtained at 75 mM salinity (Table 3) and under no cycocel application (Table 4). A decrease in chlorophyll index of wheat under salinity stress (Table 3) would be a typical symptom of oxidative stress (Reddy *et al*. 2004). Salinity stress increased the formation of reactive oxygen species and consequently damaged plants through oxidizing photosynthetic pigments (Seyed Sharifi *et al.* 2016). Bernstein *et al*. (2010) also indicated that the total chlorophyll content of leaves reduced under salinity. Low chlorophyll content under salt stress may be due to the result of higher chlorophyll degradation, lower chlorophyll biosynthesis, inconsistency of the ion flux inside plants, reduction of photosynthesis by increasing stomata resistance and degradation of biosynthesis of photosynthetic pigments (Sairam *et al.* 2005). On the other hand, the increase in chlorophyll content by cycocel application may be the result of increased relative water content in plants as compared with non-treated plants (Table 4), where RWC was reduced by salinity stress. Foliar application of 1200 mg L^{-1} cycocel led to a 28% increase in RWC and an increase in chlorophyll index (Table 4). Wang *et al.* (2010) stated that cycocel can stimulate root growth, reduce transpiration, increase water use efficiency and prevent chlorophyll destruction. The increased chlorophyll index in the cycocel treated plants might also be due to the influence of cycocel on improving the synthesis of enzymes and soluble proteins, chlorophyll synthesis by higher enzymes activity, retardation of leaf senescence and avoiding chlorophyll degradation (Osman 2014).

Table 2. Means of some physiological traits of wheat affected by combination of salinity and cycocel.

Treatment		Grain filling rate (g.day^{-1})	Grain filling duration (day)	Na^+ concentration (mg g^{-1} DW)	Na^+/K^+ ratio
Salinity Stress	Cycocel			Shoot	Shoot
S_1	C_0	1.28g	33.58hg	0.49c-f	0.34bc
	C_1	1.24h	34.50d	0.47fg	0.31c
	C_2	1.201i	39.25b	0.46fg	0.25d
	C_3	1.20i	42.21a	0.40f	0.21d
S_2	C_0	1.38d	32.47i	0.53b	0.40ab
	C_1	1.36f	33.51efg	0.47efg	0.37bc
	C_2	1.33f	34.53c	0.46fg	0.35bc
	C_3	1.34ef	35.50def	0.44gh	0.32c
S_3	C_0	1.37bc	31.44j	0.50b-f	0.40ab
	C_1	1.35e	32.46fg	0.53cd	0.34bc
	C_2	1.34ef	33.47dc	0.51b-d	0.31c
	C_3	1.33f	35.53ef	0.47f-g	0.32c
S_4	C_0	1.48a	29.40k	0.58a	0.40ab
	C_1	1.39b	31.46h	0.50b-d	0.36bc
	C_2	1.36d	32.47def	0.51bcd	0.35bc
	C_3	1.37dc	33.49hg	0.51bc	0.32bc

S_1, S_2, S_3 and S_4 indicate no salinity and 25, 50 and 75 mM salinity, respectively.
C_0, C_1, C_2 and C_3 indicate no application and application of 400, 800 and 1200 mg L^{-1} cycocel, respectively.
Means with similar letters in each column are not significantly different at 0.05 probability level.

Salinity stress at 25, 50 or 75 mM NaCl reduced stomatal conductance by about 0.84%, 0.88% and 2.99%, respectively (Table 3). Véry *et al.* (1998) found that high salinity levels affect growth through closure of stomata, limiting transpiration and thus the transport of salts.

RWC in leaves gradually decreased by increasing salt stress as compared to the no-salt treatment (Table 3). The highest RWC (48.93%) was obtained at no-salinity condition (S_0). Whereas, the lowest RWC (38.91 %) was observed at the salinity level of 90 mM (S_4) (Table 3). Tuna *et al*. (2008) also reported that RWC was significantly decreased with increasing salinity level. RWC is considered as an important parameter for balancing water statues. Plant water status depends on several physiological attributes such as stomatal conductance, transpiration, photosynthesis, respiration and leaf turgor. High salinity level might damage the plant cellular membrane and increase the ionic flux which affects water states of the plant's cell (Hussain *et al*. 2008). Hence, the reduction in water content under salinity stress was reflected on the growth parameters in this study. The reduction in RWC may occur as the result of lower water status in roots, not being able to compensate for water loss through transpiration (Gadallah 2000). Katerji *et al.* (1997) indicated that the decrease in RWC displayed a loss of turgor due to the limited water availability for the cell extension process. In the present study, the inhibitory and deleterious effects of water deficit can be reduced by the application of cycocel. The highest (46.07%) and lowest (37.55%) RWC were obtained at the highest cycocel level (C_3) and control (C_0), respectively (Table 4).

Table 3. Means of some physiological traits of wheat affected by salinity.

Treatment	Dry matter remobilization from shoots (g per plant)	Chlorophyll index	RWC (%)	Stomata conductance (mmol/m^2/s)	Grain yield (g per plant)	Na$^+$ concentration (mg/g)	K$^+$ concentration (mg/g)		Na$^+$ /K$^+$ ratio
Salinity Stress						Root	Shoot	Root	Root
S_1	0.305c	45.35a	48.93a	66.51a	1.21a	0.45d	1.74a	0.86a	0.78a
S_2	0.366b	44.82b	43.56ab	65.95b	0.98b	0.50c	1.40b	0.78b	0.83b
S_3	0.370b	43.88c	40.54ab	65.92b	0.83c	0.58b	1.38b	0.66	0.97ab
S_4	0.422a	42.77c	38.91b	64.52c	0.74c	0.68a	1.25c	0.58b	1.05a

S_1, S_2, S_3 and S_4 indicate no salinity and 25, 50 and 75 mM salinity, respectively.
Means with similar letters in each column are not significantly different at 0.05 probability level.

The highest Na$^+$ concentration and Na$^+$/ K$^+$ ratios in plant roots (0.68 and 1.05 mg g^{-1} DW, respectively) were obtained at the highest salinity level (Table 3) and the lowest values (0.45 and 0.78 mg g^{-1} DW, respectively) were observed at the S_1 level (Table 3). Higher Na$^+$ accumulation in plant roots resulted in high Na$^+$/K$^+$ under salinity treatment (Table 3). The Na$^+$/K$^+$ ratio may be used as an indicator of crop tolerance to stress as the increase of K$^+$ in the cycocel treated plants is generally related to a decline in its Na$^+$ content (Upadhyay *et al.* 2012). However, cycocel application significantly increased K^+ content and decreased Na^+/K^+ ratio in plant roots (Table 4). Furthermore, the highest Na^+ concentration and Na^+/K^+ ratio in plant shoots (0.58 and 0.40 mg g^{-1} DW, respectively) were obtained at the highest salinity level combined with zero cycocel (S_4C_0) and the lowest values (0.40 and 0.21 mg g^{-1} DW respectively) were observed in S_1C_0 (Table 2). At the highest cycocel level (C_3), there was a reduction of 16.98%, 6% and 12.06% Na^+ content of shoots at 25, 50 and 75 mM NaCl, respectively. When plants were exposed to salinity stress, the Na^+ accumulation was significantly lower in the cycocel-treated plants as compared to control plants, suggesting resistance to negative effects of sodium (Na^+) ions. Exclusion of Na^+ is a costly mechanism, energetically, since energy is diverted from plant growth. However, cycocel-treated plants were able to exclude higher Na^+ from photosyntetically active leaves and showed higher growth than non-treated plants. Hamdia *et al.* (2004) also found that growth regulation markedly altered the Na^+ and K^+ selectivity of salt stressed maize (*Zea mays* L.) and decreased the Na^+/K^+ ratio.

Highest K^+ concentration in shoots and roots of wheat plants (1.74 and 0.86 mg g^{-1} DW, respectively) was observed at the zero salinity level (S_0), whereas, the lowest values (1.25 and 0.58 mg g^{-1} DW) were obtained at the salinity of 90 mM (S_3) (Table 3). The highest Na^+/K^+ ratio in plant roots (1.09 mg g^{-1} DW) was observed at zero cycocel level (C_0), whereas, the lowest value (0.80 mg g^{-1} DW) was obtained at the C3 cycocel concentration (Table 4). The reduction of K^+ under high external salinity concentration could be explained by the competition between Na^+ and K^+ in the wheat plant (Botella *et al.* 1997). This can explain why Na^+/K^+ ratio increased in our study and consequently reduced the plant growth. On the other hand, higher K^+ accumulation in the cycocel treated plants, resulted in a low Na^+/K^+ ratio leading to the effectiveness of this compound in salinity tolerance. Gurmani *et al.* (2011) reported that cycocel was an effective plant growth regulator in reducing Na^+ and Cl^- concentrations and also Na^+/K^+ ratio, and increasing K^+ and Ca^{2+} concentrations. Higher protoplasmic change due to faster penetration of K^+ into the plant cell increase water retaining capacity and resistance to water stress (Tammam *et al.* 2008).

Table 4. Means of some physiological traits of wheat affected by cycocel.

Treatment	Dry matter remobilization from shoots (g per plant)	Dry matter remobilization from stem (g per plant)	Chlorophyll index	RWC (%)	Grain yield (g per plant)	K^+ concentration (mg/g)		Na^+/K^+ ratio
Cycocel						Shoot	Root	Root
C_0	0.44a	0.139a	44.10c	37.55c	0.79c	1.16c	0.67b	1.09a
C_1	0.39b	0.135ab	44.45b	42.48b	0.86b	1.40b	0.79a	0.86b
C_2	0.34c	0.133bc	44.46b	45.84ab	0.98ab	1.59a	0.81a	0.88ab
C_3	0.28d	0.131c	44.81a	46.07a	1.12a	1.65a	0.85a	0.80b

C_0, C_1, C_2 and C_3 indicate no application and application of 400, 800 and 1200 mg L^{-1} cycocel, respectively.
Means with similar letters in each column are not significantly different at 0.05 probability level.

The highest grain yield (1.21 g per plant) was obtained under no salinity (S_0) (Table 3) and the lowest yield (0.74 g per plant) was obtained at the highest salinity level (S_4) (Table 3). Also, the highest (1.12 g per plant) and lowest (0.79 g per plant) grain yield was observed in the plants treated by C_3 and C_0, respectively (Table 3). Application of cycocel at C_3 reduced salinity effect and caused an increase of about 42% in grain yield in comparison with the control treatment (Table 4). Pakar *et al.* (2015) showed that high salinity level affected growth, yield and ions accumulation in barley plant, negatively. They further stated that some of these adverse effects might be compensated by foliar application of cycocel. Exogenous cycocel have resulted in the increased grain yield in wheat (Fathi and Jiriaie 2014), sunflower (Kumar and Haripriya, 2010) and pea (Bora and Sarma 2006).

Conclusions

The results showed that salinity stress reduced grain yield of wheat, chlorophyll index, grain filling period, stomata conductance, RWC and K^+ concentration in plant shoots and roots. But grain filling rate, Na^+ concentration in plant roots, Na^+/K^+ ratio in plant roots and dry matter remobilization from shoots increased. However, application of cycocel improved grain filling period and decreased Na^+ concentration and Na^+/K^+ ratio under salinity condition. It seems that application of cycocel can be suggested to improve mobilization of the reserved compounds for increasing grain filling and grain yield under salinity condition.

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تاثیر سایکوسل بر برخی صفات فیزیولوژیکی و عملکرد گندم تحت تنش شوری

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چکیده

به‌منظور ارزیابی تغییر در یون‌های سدیم (Na^+) و پتاسیم (K^+)، انتقال مجدد ماده خشک و دوره پر شدن دانه گندم تحت تنش شوری، یک آزمایش فاکتوریل بر پایه طرح بلوک‌های کامل تصادفی با سه تکرار اجرا شد. تیمارها شوری خاک در چهار سطح [بدون اعمال شوری به عنوان شاهد و شوری ۲۵، ۵۰ و ۷۵ میلی مولار با نمک NaCl به ترتیب معادل۲/۳، ۴/۶۱ و ۶/۹۲ دسی‌زیمنس بر متر]، و چهار سطح سایکوسل [بدون سایکوسل به عنوان شاهد و کاربرد ۴۰۰، ۸۰۰ و ۱۲۰۰ میلی‌گرم در لیتر سایکوسل] را شامل شدند. تنش شوری عملکرد دانه ، شاخص کلروفیل، دوره پر شدن دانه، هدایت الکتریکی و محتوای نسبی آب در اندام‌های هوایی گندم را کاهش داد. ولی سرعت پر شدن دانه و انتقال ماده خشک از اندام‌های هوایی افزایش یافت. کاربرد ۱۲۰۰ میلی‌گرم در لیتر سایکوسل سهم فرایند انتقال مجدد ماده خشک در اندام هوایی و ساقه را به ترتیب ۳۶/۳۶ و ۵/۷۵ درصد کاهش داد. در عوض نسبت سدیم به پتاسیم با افزایش سطح شوری، افزایش یافت. در تمامی سطوح شوری کاربرد سایکوسل محتوای سدیم و نسبت سدیم به پتاسیم را کاهش داد. زیادی انباشتگی پتاسیم در گیاهان تیمار شده با سایکوسل منجر به کاهش نسبت سدیم به پتاسیم و در نتیجه افزایش کارآیی مقاومت این گیاهان به شوری شد. به طور کلی، نتیجه گرفته شد که کاربرد سایکوسل می‌تواند به عنوان یک ابزار مناسب برای افزایش عملکرد گندم در شرایط شوری مورد استفاده قرار گیرد.

واژه‌های کلیدی: دوره پر شدن دانه؛ سایکوسل؛ گندم؛ نسبت سدیم به پتاسیم؛ هدایت روزنه‌ای