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Act of phosphorus on cell hydraulic state, K$^+$ use efficiency and induction of positive correlations between yield and vegetative traits in chickpea

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ABSTRACT

Salinity is one of the most severe factors that can affect agricultural productivity worldwide particularly in the arid and semi-arid agro-ecological zones. Chickpea seedlings were grown in the field and subjected to different NaCl concentrations (0, 50 and 150 mM) and P application (90 kg ha^{-1}). The experimental design was based on a completely randomised design with three replications. Salinity has disturbed the physiological and ionic state of cells by increasing stomatal resistance and significantly decreased growth and yield parameters (−66%). Under salinity, plant growth traits presented a negative correlation with yield components. P application had positive effect on growth parameters and physiological responses of the plants. Our results suggest that the tolerance of chickpea at (NaCl × P) combination is closely associated with ionic homeostasis and physiological activities of the plants. Phosphorus application allowed salinity tolerance by increasing leaf hydraulic statute, improvement of KUE and consequently enhanced grain yield of chickpea. (P × salinity) combination induced a positive correlation between vegetative traits and yield parameters like unstressed treatment. These results suggest that the use of suitable amounts of phosphorus fertiliser (i. e. 90 kg ha^{-1}) to saline soil is a beneficial starter for plant development, yield components and rehabilitation of degraded soils.

Introduction

Soil salinity is an overwhelming environmental factor threatening the world food production and agricultural sustainability. More than 50% of arable land could be salinated by 2050 (Jamil et al. 2011). Mediterranean regions are characterised by a semi-arid climate and saline soils (Libutti et al. 2018). Plants exposed to high salinity often suffer from osmotic stress, ionic toxicity of Na$^+$ and Cl$^-$, nutritional disorders and oxidative stress, which lead to the inhibition of plant growth (Munns and Tester 2008). Salt stress decreasing the usable water amount causes cell expansion to diminish as well as a sprout development to slow down reducing the ability of plants to absorb essential nutrients (Dadkhah and Grrifiths 2006).

Potassium participates in different physiological functions in plants such as enzyme activation, protein synthesis, photosynthesis, stomatal movement and water relation (turgor regulation and osmotic adjustment) (Marschner 1995). Cation transporters and channels are involved in Na$^+$ and K$^+$ homeostasis in plants (Assaha et al. 2017). A decrease of uptake of K could result in a direct competition between K$^+$ and Na$^+$ at sites of uptake in plasmalemma (Assaha et al. 2017). Under salinity, the tolerant plants keep higher K$^+$ and lower Na$^+$ concentrations in the cytosol, maintaining high tissue K$^+$/Na$^+$ ratios, and hence high cytosolic K$^+$/Na$^+$ ratios, which has become a key salt tolerance trait (Shabala and Pottosin 2014).

Phosphorus (P) is an important macronutrient that is involved in many important functions such as energy transfer, photosynthesis, nutrient movement, root formation, increasing water use efficiency and improving crops quality in the plants (Rafat and Sharifi 2015). The distribution of minerals in the soil is uneven and dynamic. Mineral nutrients do not act in an isolated mode, but rather interactively. The agricultural practices have indicated that ion utilisation efficiencies of crops

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are closely linked and mutually affected but the mechanisms of interaction between ions in the soil and signalling pathways into the plant are little known. The plants imply physiological mechanisms to satisfy their different mineral nutrients such as Ca^{2+}, K^+, Pi, ,N^+ and Mg^{2+} during various development stages. The Pi uptake from the soil relies primarily on the phosphatate transporter 1 (PHT1) of family transporters in plant roots (Shin et al., 2004; Misson et al., 2004). A recent report showed that external high K^+ concentrations inhibit Pi uptake in *Arabidopsis* by regulating phosphate uptake genes (Ródenas et al. 2019). While Rahmoune et al. (2001) reported that the rate of Na and P, in the soil and at plant level, increased with salt stress and this reflects synergetic interaction between Na and Pi.

Chickpea (*Cicer arietinum* L.) is one of the most essential food crops comprising 50% of the grain legumes consumed worldwide (Vance et al. 2003). The agronomical importance of chickpea is based on its high protein concentration for the human and animal diet, being used more and more as an alternative protein source. However, chickpea crop yield development processes are affected by biotic and abiotic factors. In fact, for all important crops, average yields are only a fraction – somewhere between 20% and 50% of record yields; these losses are mostly due to drought and high soil salinity, environmental conditions which will worsen in many regions because of global climate change (Shrivastava and Kumar 2015). The yield of the crops can be improved by stimulating physiological mechanisms involved in plant resistance to salt stress and/or by reducing the harmful effects of soil salinity. Although other works of literature have reported the positive role of phosphorus (P) in modulating the adverse effect of salinity, little experimental evidence exists that identifies the mechanism by which phosphorus and salt stress interact to improve the salt tolerance of chickpea.

The aim of this study was to evaluate the effect of (P × salinity) combination on (i) morphological traits, (ii) physiological behaviour of the plants and (iii) the contribution of phosphorus to determinate the relationships between growth parameters and yield components of chickpea growing under salt-stress to obtain suitable criteria for salinity tolerance.

Materials and methods

Experiment setup

The experiment was conducted at the Experimental Farm of ITGC (Institut Technique des Grandes Cultures, 2012) Algiers, Algeria, using Kabuli chickpea (*Cicer arietinum* L.) variety Flip 84-79C obtained from International

Center for Agricultural Research in the Dry Areas (ICARDA). Algiers is situated at latitude: 36° 43′ North, altitude: 24 m, longitude: 30° 84′ East. The area is in the sub-humid zone with mean annual temperature across the sites ranged between 10℃ and 30℃, and mean annual rainfall is about 672 mm with maximum rainfall in the period between November and February. The experimental design was a randomised complete block design with three replicates (plot size of 3 × 6 m). The area of each subplot was (1 × 1 m) and having four rows. Chickpea crop was sown with row to row distance of 0.20 m, plant to plant distance of 0.10 m and plant density was 40 plants per subplot. Physical and chemical parameters of soil collected were characterised based on many standard methods (Table 1).

Growth conditions and treatments

The NaCl concentrations applied in this study are often found in saline soils of Algeria (Djili 2000). At planting, watering solutions were prepared with different combinations of phosphorus and NaCl concentrations in deionised water: phosphorus (P) at (90 kg P ha^{-1}) as triple super-phosphate, salt concentrations (50 and 150 mM of NaCl) and combinations (50 mM × 90 kg P ha^{-1}, 150 mM × 90 kg P ha^{-1}). The control plots were irrigated with water without NaCl and phosphorus. Twenty-day-old chickpea seedlings were irrigated with different watering solutions. Thereafter, plants were irrigated as per requirement throughout the experimental period.

Morphological traits

Six plants in each subplot were taken at 60 DAS from each treatment (each replication) according to Chamekh et al. (2014) and Yan et al. (2016). Stem

Table 1. Soil physical and chemical properties of the experimental site.

Physical properties	Soil depth (cm)		
	0–20	20–40	40–60
Clay (g kg^{-1})	320	280	320
Silt (g kg^{-1})	600	600	600
Sand (g kg^{-1})	80	120	8
Soil texture		Silty clay	
Chemical properties			
K (mg kg^{-1})	0.216	0.212	0.216
Na (mg kg^{-1})	7.72	8.28	7.59
Mg (mg kg^{-1})	69.6	70.19	71.39
Ca (mg kg^{-1})	75.60	72.80	77.50
P Olsen (mg kg^{-1})	0.016	0.119	0.008
N (g kg^{-1})	1.1	1.0	1.0
pH	7.85	7.69	7.71
EC (µS cm)	101.05	91.17	89.8
C (mg kg^{-1})	165.9	-	-

number and root length were measured for all the collected plants Then they were subjected to oven drying at 70°C for 24 h to record the dry biomass (DB) in (g). Root mass ratio (RMR) was measured according to this formula:

$$RMR = \frac{RDW}{SDW + RDW}$$

where RDW was the dry weight and SDW was the shoot dry weight.

The harmful effects induced by salinity were computed in percent reduction over control (% ROC) with the following formula:

$$(\%ROC) = \frac{(\text{Value in control} - \text{value in saline/} \atop \text{Phosphorus conditions}) \times 100}{\text{Value in control}}$$

Water content, leaf succulence and stomatal opening

Under stress, stomatal conductance is a good indicator of the osmotic stress level and overall health of the plant. Replicas of the stomata were taken from varnish impressions of the leaf surfaces. Twenty replicates were observed using photonic microscopy and stomatal opening was measured using micrometric rule integrated into a microscope.

Leaf water content (WC) was expressed as a percentage (%) and calculated by the following formula:

$$WC\% = \frac{\text{fresh weight- dry weight}}{\text{fresh weight}} \times 100$$

Leaf succulence (LS) was estimated by dividing WC by leaf surface area (LA) as Debez et al. (2004):

$$LS \ (ml \ cm^2) = \frac{WC}{LA}$$

Based on the graph paper technique, leaf surface area (LA) was related to variable leaf dimensions: leaf length (LL) and leaf width (LW) as (Karimi et al. 2009)

$$LA(cm^2) = LL(cm) \times LW(cm)$$

Inorganic cation contents

Ion accumulation was estimated by the digestion of samples of dry matter in nitric acid (0.5% HNO_3), K^+ and Na^+ ions were measured according to Pauwels et al. (1992) and quantified by flame emission photometry. The potassium and sodium selectivity ($S_{K/Na}$), potassium absorption efficiency (KAE) and potassium use

efficiency (KUE) were calculated as (Debez et al. 2004)

$$S_{K/Na} = \frac{[K^+(K^+ + Na^+)]_{roots}}{[K^+(K^+ + Na^+)]_{soil}}$$

$$KAE(mmol \ K^+/mg \ DB_{roots}) = \frac{\text{Total plant } K^+ \text{amount}}{\text{average root DB}}$$

where the average root DB is the logarithmic average of the root dry biomass:

$$KUE(mg \ DB/mmol \ K^+) = \frac{\text{Whole plant DB}}{\text{Total } K^+ \text{amount}}$$

Yield measurements

After ripeness (5 months after DAS), 10 plants were taken from the central rows of each subplot for assessing grain yield components such as grain yield, pod number, pod length, seed weight, seed number per pod, biological yield and economical yield. Economic yield corresponds to grain yield and biological yield is the (grain yield + stover yield). These parameters were determined by weighting randomly 1000 grains with electronic balance and converting it into kg ha^{-1} according to Ali et al. (2018).

Statistical analysis

The interaction effects between salinity and phosphorus treatment for each character in each season were statistically analysed using STATISTICA version 6.0 following the analysis of variance (ANOVA). The mean differences were adjudged by the least significant difference (LSD) test at 5% level with standard error (SE). Simple correlation was used to determine the relationship between vegetative traits and yield components in the salinity and/or phosphorus treatment.

Results

Biometrical traits

ANOVA analysis showed variable effects of two salinity levels and (salinity × phosphorus P) interaction on shoot growth (shoot number: SN, shoot length: SL), root growth (RL) root mass ratio (RMR). Compared to control, high salinity (150 mM of NaCl) markedly reduced SN, SL, RL and RMR while 50 mM significantly reduced shoot growth particularly SN but it increased RMR (Table 2). Moreover, stem number was more affected by 150 mM of NaCl compared to150P treatment. Results indicated that (150P) treatment significantly increased SL, RL and RMR than (50P) treatments.

Table 2. Effect of salt stress and *P* fertilisation on dry plant growth: stem number (SN), stem length (SL), root length (RL), root/shoot length ratio (RL/SL) and root mass ration (RMR) of *C. arietinum* L. cv Flip 84-79C exposed to salinity (0 and 150 mM NaCl).

Factors	Treatments	SN	SL (cm)	RL (cm)	RL/SL	RMR(%)
	Control	6.33 ± 0.30^b	$33.33 \pm 4,00^a$	8.33 ± 0.30^a	0.24^b	9.00^c
NaCl (mM)						
	50	6.67 ± 0.70^b	17.00 ± 4.00^d	6.67 ± 0.70^b	0.39^a	10.00^c
	150	5.67 ± 0.22^b	24.67 ± 2.00^c	6.67 ± 0.70^b	0.27^b	6.80^d
NaCl × P						
	50xP	5.67 ± 0.22^b	24.67 ± 2.00^c	6.67 ± 0.70^b	0.27^b	11.90^b
	150P	7.67 ± 0.24^a	29.67 ± 1.00^b	8.00 ± 0.60^a	0.26^b	13.90^a

The plants were harvested at 60 DAS. Mean comparisons among treatments are the small letters. Means in the same category followed by one common letter are not significantly different in the LSD test ($p \leq .05$).

Leaf water content, leaf succulence and stomatal opening

Salinity and (salinity × P) combination increased leaf water content (LWC) but decreased leaf succulence (LSU) (Figure 1). The LWC and stomatal closure were significantly increased at 150 mM than 50 mM. Stomatal regulation is one of the key mechanisms allowing plants to optimise CO_2 assimilation versus evaporative water loss. Stressed plants closed their stomatal more than 49% and 58% at 50 and 150 mM respectively which decreased stomatal conductance. Compared to the stressed plant, (phosphorus × salinity) combination significantly reduced leaf succulence (20%) and increased stomata pore opening from 36% to 46% (Figure 1).

Inorganic cation content and homeostasis $k^+–Na^+$

In this study based on ANOVA data (Table 3), significant differences were found between salinity treatments and (salinity × P) interactions in K^+ absorption, accumulation of K^+ and Na^+, selectivity to K^+/Na^+ and K^+ use efficiency. Regardless of P, salinity increased the selectivity of K^+ over Na^+ ($S_{K/Na}$), K^+ absorption, Na^+ accumulation (KAE) but significantly decreased K^+ use efficiency
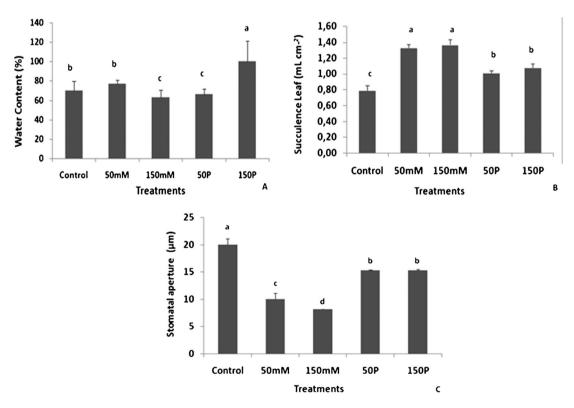

Figure 1. Water content (A), succulence leaves (B) and (C) stomatal aperture of chickpea (*C. arietinum* L) cv Flip 84-79C growing under salt stress (50, 150 mM of NaCl) and (salt × phosphorus) combinations (50P, 150P). The plants were harvested at the 60 DAS. Mean comparisons among treatments are the small letters. Means in the same category followed by one common letter are not significantly different in the LSD test ($p \leq .05$).

Table 3. Effect of salt stress and *P* fertilisation on selectivity of K^+ over Na^+ ($S_{K/Na}$), potassium absorption efficiency (KAE) and potassium use efficiency (KUE) in *C. arietinum* L. cv Flip 84-79C exposed to salinity (0 and 150 mM NaCl). The plants were harvested at 60 DAS.

Factors	Treatments	$S_{K/Na}$	KAE (mmol K^+ mg^{-1} DB roots)	KUE (mg DB $mmol^{-1}$ K^+)
	Control	0.34 ± 0.02^b	8.28 ± 0.3^b	1.47 ± 0.2^c
NaCl (mM)				
	50	4.87 ± 0.02^a	12.69 ± 0.5^a	0.78 ± 0.5^d
	150	4.02 ± 0.1^a	8.36 ± 0.1^b	1.59 ± 0.2^c
NaCl $\times$ P				
	50P	0.44 ± 0.07^b	5.46 ± 0.3^c	$1,87 \pm 0.09^b$
	150P	0.23 ± 0.04^b	2.05 ± 0.2^d	4.44 ± 0.5^a

Mean comparisons among treatments are the small letters. Means in the same category followed by one common letter are not significantly different in the LSD test ($p \leq .05$).

(KUE). At P supply, salinity markedly reduced ($S_{K/Na}$), KAE but caused highest level of K^+ use efficiency (KUE) with more pronounced effect at 150P combination.

Yield and yield components

Many crops are classified as salt sensitive and their productivity such as chickpea which can be severely affected by salinisation. Due to increasing salinity levels from 50 to 150 mM, the biological yield and yield parameters decreased from 10% to 70% compared to control. At low salinity, the pod number and seed number per pod decreased about 10% and 50% respectively while the decrease of yield was more pronounced at 150 mM. However, biological yield and seed weight were less affected than pod number and seed number per pod.

In this study, ANOVA analysis showed the positive effect of (P $\times$ salinity) combination on biological yield and yield associated traits ($p \leq 0.05$). Independently of P, low salinity reduced respectively above 14% and 40% a pod number and seed number per pod than control while high salinity reduced above 35% a biological yield, 50% a pod number and 70% seeds number per pod (Table 4). When simultaneously exposed to phosphorus and salinity, plants presented high yield and yield components specifically at high salinity. ANOVA

results indicated that (P $\times$ l50 mM of NaCl) interaction increased the pod number (30%) and seed number (90%) than salinity alone.

Correlation analysis

Means comparison of interaction effects of treatments indicated that under salt stress, agronomical parameters were negatively and significantly correlated with vegetative parameters but positively correlated with yield components ($p \leq 0.05$). Pod number was negatively correlated ($r = -0.79$) with stem length. Seed number per pod, economic yield and biological yield increased with the decrease of root length, stem number and dry biomass mentioned by $r = -0.67$ and $r = -0.73$ and $r = -0.50$ respectively (Table 5). Phosphorus addition induced significant positive correlation among plant growth and yield associated traits including the number of pods per plant, seed number per pod, biological and economical yield (Table 6). High relationship was noted ($r = 1.00$) between biological yield and shoot dry weight, and ($r = 0.80$) with shoot length and ($r = 0.78$) with shoot biomass.

Discussion

Salt stress is the major environmental factor affecting growth, physiology, nutritional value and plant production (Sogoni et al. 2021). There is an extensive literature that suggested crop's growth stage is important to consider under stressed soil conditions. In this study, the growth attributes (stem number (SN), stem length (SL), root length (RL), root/shoot length ratio (RL/SL) and root mass ration (RMR)) were affected by salt stress (Table 2). It is may be due to the osmotic stress and ion toxicity that cause a reduction in plant growth. This reduction is also due to the restriction of cell elongation and division that may lead to the inhibition of physiological and biochemical processes in the plants (Kumari and Parida 2018). Nevertheless, when comparing between low and high salinity, all plants irrigated with low salinity (50 mM) had high stem number,

Table 4. Percent of reduction over control of yield and yield components of chickpea (*C. arietinum* L) cv Flip 84-79C growing under salt stress (50, 150 mM of NaCl) and salt phosphorus combinations (50P, 150P). The plants were harvested at the maturity stage (5 months).

Factor	Treatments	Pod number (%)	Pod length (%)	Seed weight (%)	Biological yield (%)	Seed number per pod (%)
	Control	–	–	–	–	–
NaCl (mM)	50	14 ± 2.80^d	–	–	–	30 ± 1.73^b
	150	60 ± 2.00^a		14 ± 1.0^d	20 ± 2.00^c	70 ± 4.98^a
NaCl $\times$ P	50P	20 ± 1.15^c	–	–	10 ± 1.10^d	30 ± 2.31^b
	150P	30 ± 3.28^b	20 ± 2.31^c	5 ± 0.68^e	2 ± 0.10^e	–

Mean comparisons among treatments are the small letters. Means in the same category followed by one common letter are not significantly different in the LSD test ($p \leq .05$).

Table 5. Correlation coefficients among studied growth and agronomic traits of chickpea (*C. arietinum* L.) cv Flip 84-79C under different salinity stress. The plants were harvested at the maturity stage (5 months).

	PN	SPP	EY	BY	SB	SL	RL	SN	PB
PN	1	0.69*	0.69*	0.69*	−0.27	−0.79*	−0. 23	0.17	−0.38
SPP		1	0.25	0.25	−0.30	−0.67*	0.25	−0.42	−0.38
EY			1	1*	−0.42	−0.73*	−0.50*	0.48*	−0.41
BY				1	1*	0.42	−0.73	−0.50*	−0.41
SB					1	0.42	−0.12	0.48*	0.97*
SL						1	0.52*	−0.12	0.57
RL							1	−0.60*	0.25
SN								1	0.46*
PB									1

Significant correlations are indicated: *$p \leq 0.05$ probability levels, respectively. PN, Pod Number; SPP, Seed per Pod; EY, Economical yield; BY, Biological Yield; SB, Stem Biomass; SL, Stem Length; RL, Root Length; SN, Stem number; PB, Plant biomass.

Table 6. Correlation coefficients among studied growth and agronomic traits of chickpea (*C. arietinum* L.) cv Flip 84-79C under different salinity stress combined to *P* fertiliser. The plants were harvested at the maturity stage (5 months).

	PN	SPP	EY	BY	SB	SL	RL	SN	PB
PN	1	−0.28	0.71*	0.71*	0.65*	0.30	−0.55*	0.21	0.60*
SPP		1	0.34	0.34	0.22	0.36	0.11	−0.51*	0.23
EY			1	1*	0.79*	0.60*	−0.73*	0.18	0.76*
BY				1	1	0.80*	0.62*	−0.72*	078*
SB					1	0.86*	−0.32	0.23	1*
SL						1	0.23	0.38	0.90*
RL							1	−0.59*	−0.31
SN								1	0.27
PB									1

Significant correlations are indicated: *$p \leq 0.05$ probability levels, respectively. PN, Pod Number; SPP, Seed per Pod; EY, Economical yield; BY, Biological Yield; SB, Stem Biomass; SL, Stem Length; RL, Root Length; SN, Stem number; PB, Plant biomass.

RL/SL ration and root mass ration. This can be explained by the slight accumulation of ions contributed to osmotic adjustment by allowing plants to uptake water from the medium and/or to enhance enzymes activities and physiological reactions by low ions accumulation chloride and sodium.

Phosphorus addition (P) improved chickpea growth under salinity. The best growth attributes were recorded when (P: 90 kg/ha) was applied to 150 mM of NaCl (Table 2). The SN, SL, RL and RMR increased under 150P treatment. The positive effects of phosphorus supply could be due to the role of P in the activation of energetic mechanisms for the improvement of photosynthesis activity consequently reducing negative effects of salinity. It also may be due to the activation of cell division by Pi absorbed by SP plants. Inversely, other works have found that increased soil P uptake by the plant was mainly due to the better development of root system (Zribi et al. 2015; Tang et al. 2019).

The measurement of stomatal resistance provides a sensitive tool for determining the degree of stress in plants. Under 50 and 150 mM of NaCl, the chickpea plants showed high leaf succulence and stomatal closure. Stomatal resistance reflects the low leaf water potential and possibly low photosynthetic activity. This response is attributed to induce mechanism for cellular water management reducing the loss of water due to the drastic effects of sodium and chloride accumulation in cells. This response was also be explained by the accumulation of soluble sugars and other compatible solutes (e.g. proline) not only allow plants to decrease osmotic potential and maintain the cellular turgidity necessary for cell expansion under salinity stress conditions (osmotic adjustment) but also act as osmoprotectants, helping the cells to protect and maintain membrane integrity (Sarabi et al. 2017).

However, (P × salinity) treatment decreased leaf succulence but increased stomatal opening, confirming that P was efficient to alleviate the drastic effects of salinity and the reduction of succulence at P supply could be an indicator of salinity tolerance of the plants.

Salinity significantly increased the selectivity of K^+/Na^+, potassium absorption efficiency (KAE) but decreased potassium use efficiency (KUE). Inversely, K^+/Na^+ selectivity and KUE decreased but KUE increased at 50P and 150P treatments (Table 3). This result was concomitant with high root growth observed at these conditions and which could contribute to the uptake of K^+ ion into the cells to reduced Na^+ toxicity. According to Melgar et al (2006), the alleviation of salt toxicity is related to influence K^+/Na^+ selectivity controlling the Na^+ influx via non-selective ions channels by Ca^{2+} accumulation. Calcium acts as a secondary messenger in the regulation of signal transduction pathways for the response to

abiotic stress and in the promotion of K$^+$/Na$^+$ selectivity (Shabala et al. 2006). Our recent study has showed that the (P × NaCl) combination induced low Na$^+$ ion accumulation but high K$^+$ ion accumulation and high use phosphorus efficiency (PUE) in chickpea plants (Sadji-Ait Kaci et al. 2018) suggesting that K$^+$ absorbed by cells could restore a Na$^+$ and K$^+$ homeostasis necessary to growth and development of plants. Although the interaction between P and K is unclear, there is crosstalk between signaling pathways for plant responses to K and P (Wang et al., 2021). Our findings indicate the antagonistic relation Na–Pi for the uptake of the ions by the plants allowing better management and use of the absorbed Pi at the cellular level, results which are contrary to findings by Rubio et al. (2005), who showed synergistic effects may exist between Na$^+$ and P uptake.

Growth parameters and yield traits were significantly reduced by salinity compared to (Salinity × P) combinations (Table 4). Under salt stress, the reduction percentage was from 60% to 70% for pod number and grain number per pod respectively vs control while these yield components were enhanced about 60–100% for 50P and 150P plants. Seed weight and biological yield were also improved with the 150P treatment, indicated by only 2% reduction compared to the control.

Negative correlations between chickpea plant growth and yield traits were noted at salinity (Table 5). The plants with low biomass have expressed a high grain yield whereas; the increase of plant growth parameters induced a decrease in the yield and yield components. In this case, stressed plants would develop a response strategy by managing its energy potential in favour of vegetative growth or yield and its traits to avoid drastic effects of salt stress. Moreover, the significant negative relationship could be due to changes in many physiological and biochemical attributes, as well as energy alteration in the mechanisms of ion exclusion, adjustment osmotic and nutrient imbalance (Munns 2005).

Under (P × Salinity) combination, significant positive correlations were detected between plant growth parameters and yield components. The seed yield per plant was significantly and positively correlated, with mean shoot growth parameters and economical yield but significantly and negatively correlated with root length (Table 6). Adding phosphorus was as main cause for achieving high growth and yields suggesting that the SP plants have developed mechanisms to restore a hydraulic potential and ionic balance for optimal physiological functioning which enhanced the grain filling. These results are in accordance with those found in *C. artietinum* L. by Sadji-Ait Kaci et al. (2017).

The property of salinity tolerance is not a simple attribute, but it is an outcome of various features that depend on different mechanisms of the plant. The studied indices in this experiment can be useful in early screening for the salt sensibility of the plants. We have confirmed that phosphorus fertiliser particularly at (90 kg/ha) could improve soil fertility through the interactions between phosphorus and NaCl as a result optimised physiological state of plants ensuring cell homeostasis for maximum agronomic efficiency and salt tolerance of chickpea. We also conclude that the determination of K$^+$/Na$^+$ selectivity and correlations between vegetative traits and yield components might be the criterion of selection for plant tolerance to salinity.

Through this study, three hypotheses are possible to understand the salinity tolerance of the plants with or without P application: (i) the (P × Salinity) combination improved physiological statute of cells result in optimal plant growth, and consequently increase of yield and (ii) phosphorus application had modified the chemical characteristics of the saline soil reducing NaCl toxicity, finally (iii) P adding had stimulated phosphate solubilising microorganisms increasing P availability for the plants which became more tolerant to salt stress.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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