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Research article

External potassium (K^+) application improves salinity tolerance by promoting Na^+-exclusion, K^+-accumulation and osmotic adjustment in contrasting peanut cultivars

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ABSTRACT

Achieving salt-tolerance is highly desirable in today's agricultural context. Apart from developing salt-tolerant cultivars, possibility lies with management options, which can improve crop yield and have significant impact on crop physiology as well. Thus present study was aimed to evaluate the ameliorative role of potassium (K^+) in salinity tolerance of peanut. A field experiment was conducted using two differentially salt-responsive cultivars and three levels of salinity treatment (control, 2.0 dS m^{-1}, 4.0 dS m^{-1}) along with two levels (with and without) of potassium fertilizer (0 and 30 kg K_2O ha^{-1}). Salinity treatment incurred significant changes in overall physiology in two peanut cultivars, though the responses varied between the tolerant and the susceptible one. External K^+ application resulted in improved salinity tolerance in terms of plant water status, biomass produced under stress, osmotic adjustment and better ionic balance. Tolerant cv. GG 2 showed better salt tolerance by excluding Na^+ from uptake and lesser accumulation in leaf tissue and relied more on organic osmolyte for osmotic adjustment. On the contrary, susceptible cv. TG 37A allowed more Na^+ to accumulate in the leaf tissue and relied more on inorganic solute for osmotic adjustment under saline condition, hence showed more susceptibility to salinity stress. Application of K^+ resulted in nullifying the negative effect of salinity stress with slightly better response in the susceptible cultivar (TG 37A). The present study identified Na^+-exclusion as a key strategy for salt-tolerance in tolerant cv. GG 2 and also showed the ameliorating role of K^+ in salt-tolerance with varying degree of response amongst tolerant and susceptible cultivars.

1. Introduction

In today's context soil salinity happens to be one of the most important abiotic factors limiting plant growth and productivity globally. It encompasses almost 7% of world's total land area, which means about 800 million hectares of land is affected by soil salinity (Munns, 2005). Sodium, a natural constituent of earth crust, may promote growth in some plants at lower concentration but eventually become toxic to growth and development for most of the glycophytes if present in high concentration in growing medium (Munns and Tester, 2008). Although both Na^+ and K^+ bear high resemblance in ionic and physicochemical properties, but unlike Na^+, K^+ plays essential role in growth of all plant species (Schachtman and Liu, 1999). Many basic physiological processes are essentially dependent on K^+ and its specific transport and interactions with enzymes and membrane proteins (Britto and Kronzucker, 2008), which includes short-term maintenance of membrane potentials, pollen tube development and stomatal opening and closing in plants (Dietrich et al., 2001).

Under prolonged exposure to saline environment plants inclined to show K^+ deficiency symptoms due to reduced uptake and/or lesser tissue retention of K^+ in different plant parts along with a concomitant build-up of tissue Na^+ level (Munns et al., 2002). Thus under salt stress, it is very common to find plants with hindered growth and metabolism and skewed K^+/Na^+ ratio in actively growing plant tissues (Shabala and Cuin, 2008; Degl'Innocenti et al., 2009). Due to such imbalance, several interlinked

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physiological and biochemical processes are known to be suffered in plants. Previous reports suggested salinity induced decrease in photosynthetic activities as one of the major limiting factors for plant development in active growing phase and final productivity (Yan et al., 2012) owing to stomatal closure (Gama et al., 2009), destruction of chlorophyll pigment system (Parida et al., 2004), damage to the reaction centre of photosystem (Kalaji et al., 2011), either or all. Since, K^+ regulates the stomatal movements and in fact its higher supply found to improve plant water status and opening and closing of stomata under osmotic stress (Marschner, 2012). Hence, potassium is hypothesized to play an important role in alleviation of salinity stress. As very limited success had been achieved to develop salt-tolerant crop plants through breeding approaches (Schubert et al., 2009), thus utmost consideration should be given to physiological approaches *viz*. maintenance of K^+-homeostasis through altered crop management strategies (eg. external application of K^+) for the plants growing in saline environment.

Peanut (*Arachis hypogaea* L.), an important legume, consumed both as oilseed and confectionary purposes globally is known to be moderately salt sensitive. It shows restriction in growth and yield drop after crossing the threshold level of soil salinity (Meena et al., 2012). Although some previous studies reported that peanut could be grown with water having electrical conductivity (EC) up to 3.0 dS m^{-1}, but our recent studies showed the crop starts facing salinity stress above 2.0 dS m^{-1} EC value and significant plant mortality observed above 4.5 dS m^{-1} salinity level. Hence, soil salinity in the range of 3–4 dS m^{-1} during most of the cropping period was found to be ideal for screening of salinity tolerance in peanut (Singh et al., 2008).

Soil and water salinity has been a major threat in semi-arid agro-ecosystem from long past, either naturally or induced by poor quality (saline) irrigation. There is an emerging need to reclaim these saline lands and also to maintain a stable production and crop coverage by combating the salt stress. One of the feasible options lies in applying potassium fertilizers, which could be beneficial to plant growth by replacing Na^+ with K^+ in the exchangeable sites of clay particles. Also the adequacy of K^+ helps in well-functioning of enzymes and maintenance of cell turgor that ease the movement of water and solute in plants (Krauss, 2003), which proved to have beneficial role in overall physiology of the plants and stress tolerance (Cakmak, 2005). Thus higher availability of K^+ in saline environment induces enhanced activities of high-affinity potassium transporters (HKTs) and non-selective cation channels (NSCCs) resulting in increased K^+-uptake minimizing Na^+ uptake and preventing K^+ losses from the cell to maintain a K^+:Na^+ ratio optimum for plant metabolism (reviewed by Wakeel, 2013). However, to the best of our knowledge such beneficial effect of external K^+ application in salinity tolerance is yet to be tested in peanut crop in a systematic manner. Hence, the present study was carried with the hypotheses that (i) Does K^+ have any ameliorative effect on salinity stress tolerance in peanut? (ii) If yes, then how does the effect vary between tolerant and sensitive genotypes? And finally (iii) How K^+ improves salinity tolerance in this crop from overall physiological perspective. Thus in the present study we conclusively showed how the beneficial effect of supplementary K^+-application contributes to overall salt tolerance in sensitive and tolerant peanut genotypes and also the differential strategies for osmotic adjustment in these genotypes.

2. Material and methods

2.1. Study site and experimental condition

A field experiment was conducted in summer 2011 (February–May) in the research farm of ICAR-Directorate of Groundnut Research, Junagadh, India having soil classified as Vertic Ustochrepts, medium black, clayey, shallow and slightly alkaline (pH 7.8–8.0) in nature. The experiment was laid out in a split–split plot design with twelve treatment combinations and three replications by using three levels of saline irrigation water (I–0: control, I–1: 2.0 and I–2: 4.0 dS m^{-1}) as main plot, two peanut cultivars as sub plot and two levels of potassium treatment (K–0 = no potassium applied and K–30 = 30 kg K_2O ha^{-1} equivalent to 25 kg K^+ ha^{-1}) as sub–sub plot. The size of each plot was 7 m × 6 m where peanut seeds were sown at a spacing of 30 cm × 10 cm. The crop was grown following standard agronomic management practices and recommended doses of N (25 kg ha^{-1}) and P (50 kg ha^{-1}) fertilizers applied to all plots at the time of sowing. During the whole cropping season the plants were irrigated with an average interval of 10 days and salinity treatments were started in respective treatment combinations from 20 days after plants emergence (DAE). The irrigation water used for the present study belongs to the classes from C1S1 to C2S1 (USDA classification, Richards, 1954) having no sodium hazard (SAR< 10) and residual sodium carbonate (RSC< 1.00 me/l) with moderate soluble sodium percentage. The 2.0 (I–1) and 4.0 (I–2) dS m^{-1} salinity level in the irrigation water was created by dissolving required amount of commercially available sodium chloride salt (2.6 and 5.2 kg in 2000 L irrigation water to get 22 and 44 mM NaCl solution, respectively to achieve 2.0 and 4.0 dS m^{-1} salinity level).

2.2. Plant material and time of sampling

For the present study two contrasting *Spanish* bunch type peanut cultivars (TG 37A and GG 2), having similar crop duration was selected based on their differential sensitivity towards salinity stress. Most of the previous studies based on laboratory screening reported GG 2 as salt-tolerant cultivar, while TG 37A as salt-sensitive (Singh et al., 2008; Mungala et al., 2008). The cultivar thus selected was to define the role of external K^+ application in alleviating the salinity stress and their responses towards conjoint saline-K environment.

Both destructive and non-destructive sampling for estimation of different physiological and biochemical parameters and nutrient analyses were done between 60–65 DAE. Uniformly, the third fully matured leaf from the top was selected for measurement of leaf gas exchange parameters and SPAD reading from at least 10 similar looking plants from each replication. For destructive sampling (osmolyte accumulation and nutrient analyses), leaf samples were collected in triplicate from similar position of the plant from each experimental replication. The soil samples were also collected at the same time and were analyzed to see the changes in basic soil properties.

2.3. Agronomic parameter

The plant samples were collected at the maturity from each treatment combinations and dry biomass for both economic (pod) and non-economic (haulm) parts were recorded separately by taking mean of at least 5 individual plants from each replication.

2.4. Relative water content and leaf water potential

Leaf relative water content (RWC) was estimated by recording the fresh, turgid weight and dry weight following the formula: RWC = [(Fresh wt.–Dry wt.)/(Turgid wt.–Dry wt.)] × 100 (Weatherley, 1950). Mid-day leaf water potential (LWP) was measured from the representative leaf samples by thermocouple based psychrometric method (Rawlins, 1966). Briefly, random