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Principal component analysis approach for comprehensive screening of salt stress-tolerant tomato germplasm at the seedling stage

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Salt stress is a major abiotic factor that affects the growth and yield of crops. The present study was carried out to assess the salt tolerance among the Arka Samrat, Arka Rakshak, YVU-1, S-22, YVU-2, and PKM-OP tomato germplasms using principal component analysis (PCA). Different salt (NaCl) concentrations like control, 0.04 M, 0.12 M, and 0.20 M were selected in order to classify them into sensitive and tolerant tomato germplasms based on 13 parameters. A significant variation was observed among the selected tomato germplasms towards salinity tolerance at the seedling stage. Shoot length, root length, fresh weight, and dry weight parameters of the seedlings were decreased linearly with an increase in the external NaCl concentration. Salinization of plants has shown to reduce K^+ content and increase in the Na^+ accumulation, Ca^{2+}, and Catalase activity. Salt stress also increased electrolyte leakage and reduced relative water content of all germplasms. The maximum parameters were less affected in Arka Rakshak and Arka Samrat compared to the remaining germplasms at higher salt stress. The PCA analysis of 13 morphological and physiological variables indicated that Arka Rakshak and Arka Samrat germplasms were salt-tolerant and PKM-OP was susceptible. Thus PCA analysis results are useful for the identification of resistance and sensitive germplasms at the seedling stage.

Keywords. Flame photometer; principal component analysis; salinity; seedling stage; sodium accumulation; tomato crop

1. Introduction

Salt stress is considered to be the most serious problem among the numerous abiotic stresses that negatively affect crop yield in arid and semi-arid regions (Khan *et al*. 2016; Ghafoor *et al*. 2015). Salinization leads to an accumulation of water-soluble salts by which fertile lands gradually transforms into infertile soils. At present, more than 20% of the world's irrigated land (6% of the total land area) has been affected by salinization (Mickelbart *et al*. 2015). Saline soils have an electrical conductivity (EC) of more than 4 dS/m are considered equivalent to approximately 40 mM NaCl (Munns and Tester 2008). The proportion of land impacted by salt stress alone or cumulatively with other stresses is expected to intensify in the immediate future. On the other hand, the current world population of 7.5 billion is projected to reach 9.7 billion by 2050 (*www.worldometers.info*). Hence, there is a need to increase crop yields to ensure global food security (Shahzad *et al*. 2012; Flowers 2004).

Globally, cultivated tomato (*Solanum lycopersicum* L.) is the most important horticultural crop, with an annual production of approximately 183.22 million tons and a value of about $US 88 billion (FAOSTAT 2015). *Solanum lycopersicum* was considered as

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moderately resistant to salt stress, with a 10% reduction of fruit yield for each unit of ECe escalation in the root zone (Maas and Hoffman 1977). It was reported that 50% of yield reduction will occur at about 8 dS/m stress (Subbarao and Johansen 1994). In general, tomato plants are sensitive to salinity stress at the young seedling stage as well as in the reproductive stage and the development of salt-tolerant varieties are the best way to overcome the yield reduction caused by salt stress (Foolad 2004). The salt-tolerant tomato germplasms are easy to cross with cultivated tomato and provide a rich source of resistance and tolerance genes for biotic and abiotic stresses, including salinity (Hajjar and Hodgkin 2007). Therefore, an efficient screening method for salt-tolerant germplasms can perhaps aid in the development of salt-tolerant cultivars and these varieties may grow better in the salt-affected region (Shen *et al.* 1997; Winicov 1998). Screening of tomato genotypes for salt tolerance under different salt stress has been carried out by many investigators and notable difference in their tolerance has been reported (Kumar *et al*. 2017; Rashed *et al*. 2016; Fariduddin *et al*. 2012). Nevertheless, breeding programs to develop salt-tolerant varieties have been dependent on the study of complex genetics and physiological traits and lack of proficient selection methods was noted which includes physiological traits (Singh *et al*. 2012).

Soil salinization alters the water potential of cells, resulting in ion imbalance which leads to morphological, physiological, biochemical, and molecular deviations in plants (Arzani and Ashraf 2016). Salt-tolerant germplasms can be defined as the capability of a plant to withstand the toxic effects of salt stress and to sustain its growth and yield. Seed germination and seedling establishment are the most sensitive stages for adaptation to salt stress during the life cycle of plant development (Donohue *et al*. 2010). Research on understanding the mechanisms of salt tolerance has long been a priority for unravelling the complex salt tolerance phenomenon (Kumar *et al*. 2017). Under stress conditions, various parameters have been considered as key indicators and their rate of change has been efficiently exploited in the assessment of plant's salt stress tolerance (Kumar *et al*. 2015; Singh *et al*. 2015).

Munns *et al.* (2000) suggested that physiological parameters would be more resourceful and more helpful in understanding the degree of salt tolerance. The analysis and inclusion of physiological parameters for the selection of salt-tolerant germplasm are more complicated due to complex genotype *vs* environmental interaction (Arzani 2008), but the inclusion of these characteristics is essential for the selection process. The PCA is a multivariate technique that analyzes data by extracting important information and represents it as a set of new orthogonal variables called principal components. PCA depends on the Eigen decomposition of positive semi-definite matrices and the singular value decomposition (SVD) of rectangular matrices (Abdi and Williams 2010). The PCA analysis can be successfully used to analyze the large data generated from the experiments to assess the genotypes (Raza *et al*. 2017; Chikha *et al*. 2016; Allel *et al*. 2016).

Keeping all these points, the present investigation was designed with the aim of evaluation and identification of the degree of salt tolerance among the tomato germplasm by including complex physiochemical parameters, such as catalase activity, Na^+, K^+ and Ca^{2+} ions, electrolyte leakage, and leaf water relation. To accomplish this, we tested the efficiency of principal component analysis (PCA)-based selection to identify the salt-tolerant and sensitive tomato germplasms at the seedling stage.

2. Materials and methods

2.1 *Plant material, growth conditions, and stress application*

The seeds of six tomatoes (*Solanum lycopersicum* L.) germplasm named Arka Samrat, Arka Rakshak, YVU-1, YVU-2, S-22, and PKM-OP were collected from 'Indian Institute of Horticulture Research (IIHR)', Bangalore, India, and 'Tirumala Traders' local market YSR Kadapa, Andhra Pradesh, India. Uniform and healthy seeds of all germplasms were sterilized with 4% sodium hypochlorite solution for five minutes, followed by repeated washings with distilled water, and seeds were sown in nursery trays. The nursery trays were sprayed with distilled water to maintain moisture and incubated in a culture room at 25 ± 2°C temperature under a 16h/8h light/dark cycle for 10 days. Of 10-day-old seedlings, salt stress was induced by supplementing 0.04 M, 0.12 M, and 0.20 M of NaCl solution and incubated for 20 days. After incubation, the salt-treated and untreated (control) seedlings (30 days old) were removed carefully for biochemical and physiological parameters analysis. For each treatment, a total of six biological replicates were used.

2.2 *Germination percentage and morpho-physiological and ion parameters measurements*

Germination percentage calculations were carried out as described in Ellis and Roberts (1981) and Ruan *et al.* (2002). Root length and Shoot length were measured using a common measuring scale. The fresh weight and dry weight of plants were measured using an electronic weighing balance. Leaf Relative water content (RWC), Electrolyte Leakage (EL), and Catalase activity were measured by the method described in Castillo (1996), Sairam *et al.* (2002), and Luck *et al.* (1963), respectively. One gram of dry plant material was homogenized in 10 ml of 0.5% HCl with motor and pestle and the homogenized samples were filtered using Whatman Grade I filter paper and the concentration of Na^+, K^+, and Ca^{2+} ions was measured using the ELICO 378-Flame photometer. A total of six replicates of morpho-physiological data were generated for PCA analysis.

2.3 *Data analysis*

A total of 13 morpho-physiological parameters data were used for Principal Component Analysis (PCA) (Addinsoft, *www.xlstst.com*). The mean values of the six replicate data were used to generate the correlation matrix and the matrix comprise values of 6 germplasms in rows and 13 variables/parameters in columns. The cumulative variability of each parameter along with Eigenvalues, principal component scores was calculated. A biplot that includes placement of traits based on their correlation with factors and the factor scores of the germplasms on the axes was presented diagrammatically to understand the interrelationships.

3. Results

The effect of different salt stress (control, 0.04M, 0.12M, and 0.20M) on Germination percentage (GM%), Shoot Length (SL), Root Length (RL), Fresh Weight (FW), Dry Weight (DW), Relative Water Content (RWC), Electrolyte Leakage (EL), Catalase activity (CAT), Na^+, K^+, Ca^{2+}, K^+/Na^+, and Ca^{2+}/Na^+ morphological and physio-biochemical variables were provided in figures 1 and 2, and tables 1 and 2.

3.1 *Germination percentage analysis*

The germination percentage values indicate that the selected tomato germplasms have the ability to germinate even at up to 0.20 M NaCl treatments (figure 1). At the control and 0.04M conditions, all the germplasms were showed more than 90% germination of seed (figure 1). The control (non-saline) and 0.04 M salt stress conditions seemed favorable for the germination of the selected germplasms (figure 1). At 0.12M NaCl salt stress, the germination percentage of six germplasm ranged from 94.6% (Arka Rakshak) to 64.7% (S-22). Among the six tomato varieties, Araka Rakshak germplasm showed the highest germination (66.4%) at 0.20 M salt stress followed by Arka Samrat

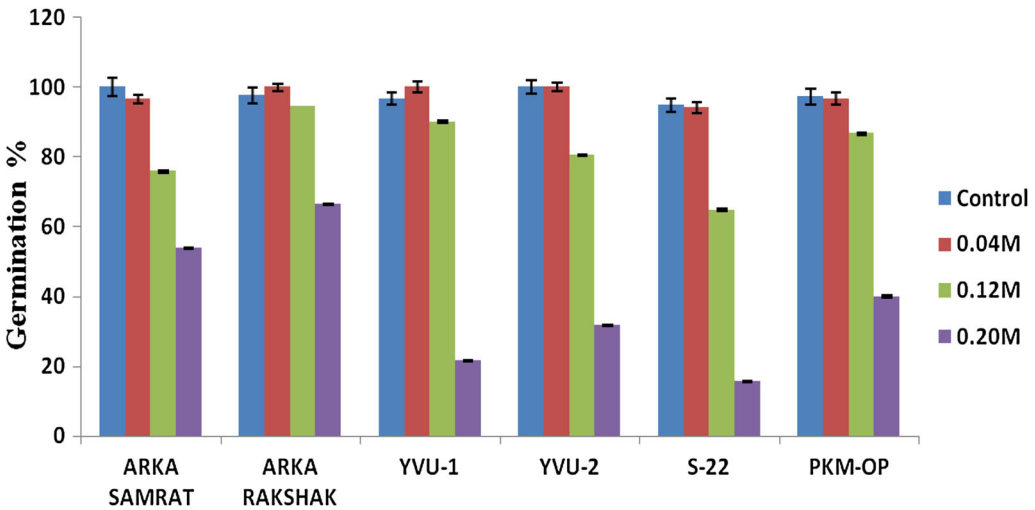

Figure 1. Effect of various salt concentrations on germination percentage of tomato germplasm. Each bar represents six replicates mean value along with the standard error.

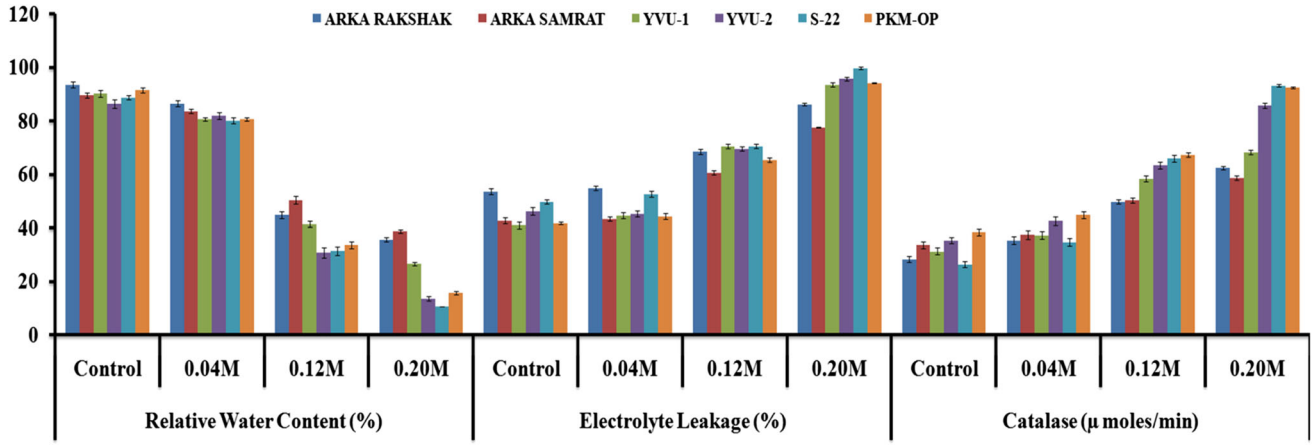

Figure 2. Effect of various salt stress concentrations on Relative Water Content (%), Electrolyte Leakage (%), and Catalase activity (µ moles/min). Each bar represents six replicates mean value along with standard error.

(53.9%), PKM-OP (40%), YVU-2 (31.8%), YVU-1 (21.7%), and S-22 (15.7%) (figure 1).

3.2 *Morphological and physiological variables*

Salt stress significantly reduced the root and shoots length of all genotypes (table 1). The root length of the germplasm ranged from 15–12 cm, 15–11 cm, 7.6–2.3 cm at control, 0.04 M, and 0.12 M salt stress conditions, respectively. At 0.20 M salt stress, Arka Rakshak (2.5 cm), Arka Samrat (1.2 cm), and YVU-1 (0.9 cm) were able to develop observable root lengths (table 1). The shoot length of germplasm ranged from 5.5 to 4.9 cm, 5.4 to 4.5 cm, and 3.7 to 1.1 cm, at control, 0.04M, and 0.12M salt stress conditions, respectively. At 0.20 M salt stress, Arka Rakshak (1.9 cm) and Arka Samrat (1.5 cm) were able to develop measurable shoot lengths (table 1). The fresh weight and dry weight were measured at control, 0.4, 0.12, and 0.20M salt stress stages, and the values were shown in table 1. The genotypes Arka Rakshak, Arka Samrat, and YVU-1 produced significant biomass at higher salt stress conditions. PKM-OP showed the lowest fresh and dry weight as stress progressed (table 1). As a result of salt stress, the RWC gradually decreased with increasing salt stress in the germplasm of tomatoes (figure 2). In tomato genotypes, the RWC ranged from 93.4% to 88.6% (S-22) at control, 86.5% to 80.1% at 0.04M salt stress, 50.3% to 30.6% at 0.12 M salt stress and 38.5% to 10.4% at 0.20M salt stress condition. The genotypes of Arka Rakshak and Arka Samrat were able to maintain substantial Relative Water Content where the lowest content was noted in PKM-OP (figure 2).

The Electrolyte Leakage trait values varied significantly among the studied tomato genotypes under different salt stress conditions (figure 2). As shown in the data, the six germplasms electrolyte leakage data ranged from 40.8% to 53.4% at control, 43.2% to 54.8% at 0.04M salt stress and 60.5% to 70.5% at 0.12 M salt stress (figure 2). Arka Rakshak and Arka Samrat genotypes displayed the lowest Electrolyte leakage and PKM-OP had the highest electrolyte leakage genotype (figure 2). Overall, Electrolyte leakage increased with increasing salt stress in all tomato germplasms. The activity of the enzyme antioxidant catalase enzyme activity was measured in six tomato germplasm after salt treatment (figure 2). At control conditions, PKM-OP was shown to be the highest, and S-22 had the lowest catalase activity (figure 2). When the seedlings experienced 0.04 M, 0.12 M, and 0.20 M salt stress, the tomato germplasms responded differently and among them, S-22 has shown the highest catalase activity (figure 2).

3.3 *Ions (Na^+, K^+, and Ca^{2+}) accumulation analysis*

The presence of salt affects the sodium ion content of the seedlings (table 2). All the studied genotypes showed an increased Na^+ accumulation with increasing salt stress (table 2). At 0.20M salt stress, the values of Na^+ were 171.7±0.2, 158.9±0.3, 176.1±0.1, 157±0.2, 195.5±0.1, and 205.9±0.1 ppm in Arka Samrat, Arka Rakshak, YVU-1, YVU-2, S-22, and PKM-OP, respectively (table 2). The germplasm of YVU-2 is definitely less rich in Na^+ content and high

Table 1. Effect of various salt stress concentrations on root length, shoot length, fresh weight, and dry weight

	Arka rakshak		Arka samrat		YVU-1	
NaCl Conc.	*RL* ± *SE*	*SL* ± *SE*	*RL* ± *SE*	*SL* ± *SE*	*RL* ± *SE*	*SL* ± *SE*
Root length (cm) and Shoot length (cm)						
Control	13 ± 0.9	5.5 ± 0.02	15 ± 0.04	5.3 ± 0.02	13 ± 0.02	5.4 ± 0.01
0.04M	15 ± 0.2	5.4 ± 0.02	14 ± 0.02	5.3 ± 0.02	13 ± 0.02	5.3 ± 0.02
0.12M	7.6 ± 0.2	3.7 ± 0.02	7 ± 0.02	3.4 ± 0.02	3.6 ± 0.03	2.9 ± 0.02
0.20M	2.5 ± 0.1	1.9 ± 0.02	1.2 ± 0.02	1.5 ± 0.02	0.9 ± 0.02	0
Fresh weight (mg) and Dry weight (μg)						
Control	68.4 ± 0.2	27.5 ± 0.7	63 ± 0.4	28.3 ± 0.4	55.3 ± 1	26.4 ± 0.4
0.04M	63.2 ± 1	26.4 ± 0.6	58.5 ± 0.6	25.7 ± 0.6	55.7 ± 0.6	25.5 ± 0.3
0.12M	37.4 ± 0.6	18.3 ± 0.6	32.8 ± 0.4	16.6 ± 0.6	26.6 ± 0.6	15.6 ± 0.7
0.20M	11.5 ± 0.4	8.5 ± 0.2	12.5 ± 0.4	8.4 ± 0.2	4.5 ± 0.2	4.7 ± 0.2
	YVU-2		S-22		PKM-OP	
NaCl Conc.	*RL* ± *SE*	*SL* ± *SE*	*RL* ± *SE*	*SL* ± *SE*	*RL* ± *SE*	*SL* ± *SE*
Root length (cm) and Shoot length (cm)						
Control	13 ± 0.02	5.4 ± 0.02	12 ± 0.02	5.4 ± 0.02	12 ± 0.02	4.9 ± 0.01
0.04M	13 ± 0.1	5.3 ± 0.02	11 ± 0.02	5.2 ± 0.02	13 ± 0.02	4.5 ± 0.02
0.12M	3 ± 0.02	1.1 ± 0.02	2.3 ± 0.02	1.1 ± 0.02	3.1 ± 0.02	1.9 ± 0.02
0.20M	0	0	0	0	0	0
Fresh weight (mg) and Dry weight (μg)						
Control	66.4 ± 0.6	27.4 ± 0.4	64.6 ± 0.5	28.4 ± 0.4	62.5 ± 0.5	25.4 ± 0.5
0.04M	62.6 ± 0.4	25.4 ± 0.4	57.3 ± 0.8	24.5 ± 0.6	56.5 ± 0.7	24.8 ± 0.5
0.12M	22.7 ± 0.5	13.4 ± 0.6	12.4 ± 0.5	12.6 ± 0.6	12.3 ± 1	11.3 ± 0.5
0.20M	0	0	0	0	0	0

Six individual samples mean values and their standard errors are represented as MEAN ± SE.

Table 2. Effect of various salt stress concentrations on Na^+ accumulation (ppm), K^+ content (ppm) and Ca^{++} content (ppm)

	Na+ Accumulation (ppm)				K+ Content (ppm)			
NaCl Conc.	Control	0.04M	0.12M	0.20M	Control	0.04M	0.12M	0.20M
ARKA SAMRAT	27.8 ± 2.2	37.1 ± 1.8	72.8 ± 0.9	171.7 ± 0.2	341.1 ± 2.1	294.5 ± 1.5	215.2 ± 1.1	151.8 ± 0.5
ARKA RAKSHAK	28.7 ± 2	43.1 ± 1.7	79.9 ± 0.8	158.9 ±0.3	325.9 ± ± 2.3	293.2 ± 2.1	206.3 ± 1.2	136 ± 0.3
YVU-1	24.4 ± 1.5	33.5 ± 1.9	87.7 ± 1	176.1 ± 0.1	355.1 ± 3.1	313.2 ± 1.6	209.6 ± 0.8	128.6 ± 0.5
YVU-2	32.6 ± 2.1	63.1 ± 1.6	92.1 ± 0.5	157 ± 0.2	357.5 ± 2.6	271.4 ± 1.5	203 ± 1.1	130 ± 0.1
S-22	31.1 ± 1.9	50.1 ± 1.5	111.6 ± 0.6	195.5 ± 0.1	277.1 ± 2.1	246.7 ± 1.4	202.3 ± 0.8	110.8 ± 0.4
PKM-OP	30.9 ± 2.1	42 ± 1.5	132 ± 0.5	205.9 ± 0.1	359 ± 2.4	309.1 ± 0.6	193.1 ± 0.7	115.5 ± 0.3

	Ca++ content (ppm)			
NaCl Conc.	Control	0.04M	0.12M	0.20M
ARKA SAMRAT	103.3 ± 1.5	123.1 ± 1.8	156.7 ± 1.1	175.3 ± 0.2
ARKA RAKSHAK	113.3 ± 2.1	122.7 ± 1.6	153.7 ± 0.9	180.5 ± 0.3
YVU-1	125.1 ± 2.1	138.9 ± 1.5	189 ± 1.4	227.9 ± 0.8
YVU-2	130.3 ± 1.8	142.2 ± 2	182.7 ± 1.1	217.6 ± 0.5
S-22	130.1 ± 2.2	144.8 ± 1.4	168.9 ± 0.2	205.8 ± 0.5
PKM-OP	163.5 ± 2.1	179.6 ± 1.8	225.6 ± 1.3	296.3 ± 0.8

Six individual samples mean values and their standard errors are represented as MEAN ± SE.

in PKM-OP germplasm. The K^+ ion content of seedlings under all stress conditions is shown in Table 2. Maintenance of K^+ in the presence of salt stress was significantly more important for the survival plants. The salt stress induced the K^+ reduction in all germplasms. The K^+ content of the studied genotypes ranged from 359 ppm (PKM-OP) to 277.1 ppm (S-22) at control condition; 313.2 ppm (YVU-1) to 246.7 ppm (S-22) at 0.04M salt stress; 215.2ppm (Arka Samrat) to 193.1 ppm (PKM-OP) at 0.12M salt stress; 151.8 ppm (Arka Samrat) to 110.8 ppm (S-22) at 0.20M salt stress (table 2). These results suggested that Arka Samrat germplasm has the ability to maintain a substantially higher K^+ content. The salt stress induces the slight accumulation of Ca^{2+} in all studied genotypes (table 2). The Ca^{2+} content was noted in the range 163.5 ppm (PKM-OP) to 103.3 ppm (Arka Samrat) at control; 179.6 ppm (PKM-OP) to 122.7 (Arka Rakshak) at 0.04 M NaCl stress; 225.6 ppm (PKM-OP) to 156.7 ppm (Arka Rakshak) at 0.12M salt stress; 296.3 ppm (PKM-OP) to 175.3 ppm (Arka Samrat) at 0.20M salt stress (table 2).

3.4 *PCA biplots analysis*

Thirteen variables of data collected from control, 0.04 M, 0.12 M, and 0.20 M salt-stressed plants were used to assess the salt tolerance capacity of germplasm by the Principal Component Analysis (PCA). Principal Component Analysis (PCA) has scattered germplasms in all four quarters of the biplot (figure 3). In the PCA biplots, the F1 and F2 components had an Eigenvalue greater than one and the cumulative variability has been increased with increasing salt stress (table 3). At control, 0.04 M, 0.12 M and 0.20 M stress condition 73.06%, 73.39, 84.96% and 87.92% cumulative variability was noted in biplot (figure 3 and table 3).

The germplasm ranking was determined based on factor scores obtained for each observation for the six

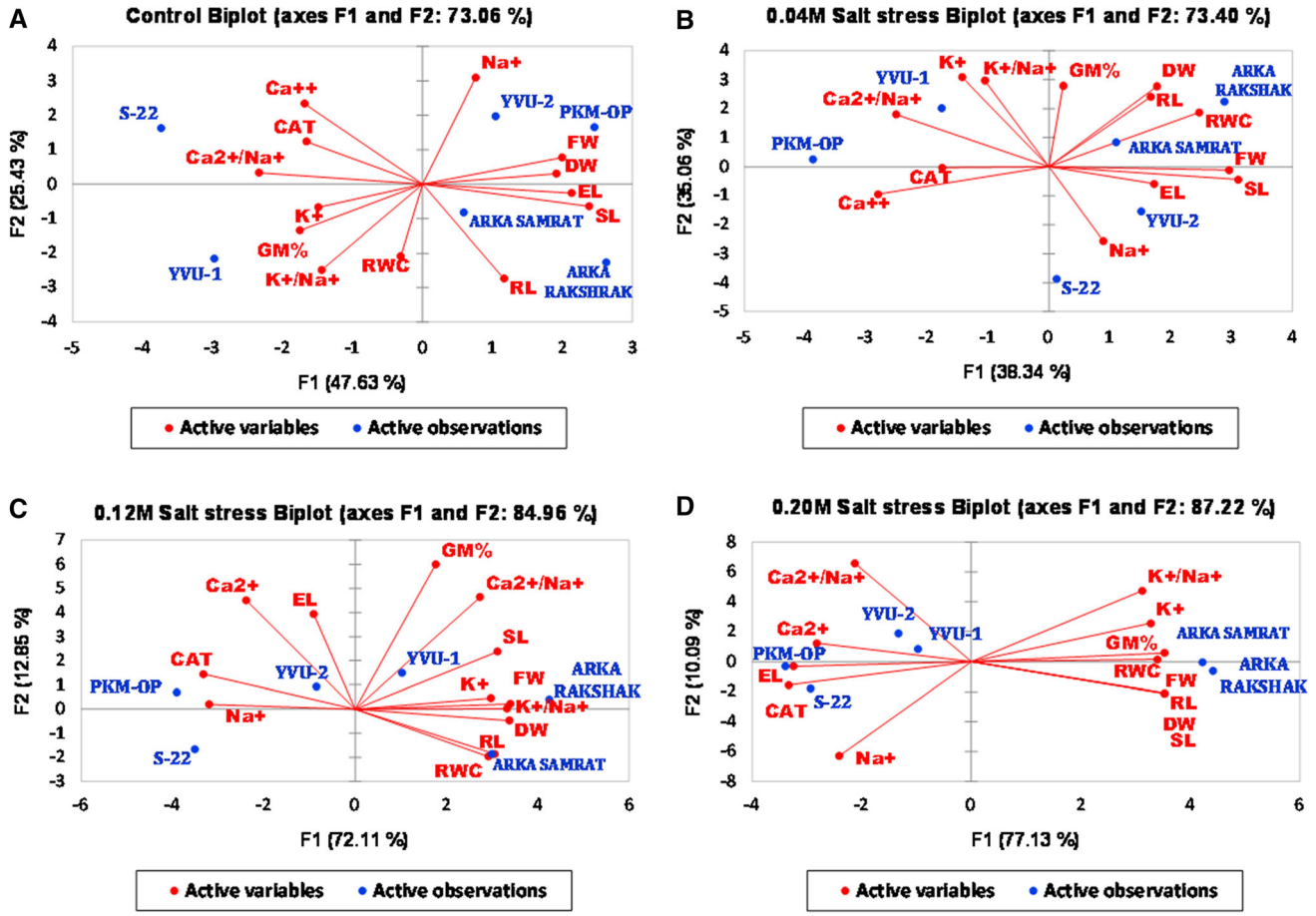

Figure 3. Principle Component Analysis (PCA) Bi-plots; (**A**) Control Bi-plot; (**B**) 0.04M Salt stress Bi-plot; (**C**) 0.12M Salt stress Bi-plot; (**D**) 0.20M Salt stress Bi-plot.

Table 3. Eigen values, variability (%), and cumulative (%) of F1 and F2 axes of PCA

	Control		0.04 M Salt stress		0.12 M Salt stress		0.20 M Salt stress	
	F1	F2	F1	F2	F1	F2	F1	F2
Eigen value	6.192	3.305	4.984	4.558	9.374	1.671	10.026	1.312
Variability (%)	47.634	25.427	38.339	35.058	72.105	12.851	77.126	10.095
Cumulative %	73.061		73.397		84.956		87.221	

tomato germplasm (table 4). The Principal Component Analysis (PCA) results based on an analysis of thirteen variables at 0.12M and 0.20M salt stress, predicted the Arka Rakshak to be the most resistant followed by Arka Samrat (table 4) and PKM-OP as the most sensitive germplasm (table 4). In all the biplots drawn at higher stress conditions, the Arka Rakshak and PKM-OP have projected diametrically extreme opposite ends of the biplots and was a pair accession with contrasting salt stress tolerance (figure 3).

4. Discussion

The selection of salt-tolerant and sensitive genotypes was considered to be one of the important objectives in the development of salt-tolerant varieties. In the present investigation, salt tolerance was assessed based on 13 morphological, physiological, and biochemical parameters, which were collected from 30-day-old seedling grown under laboratory conditions. The inclusion of complex physiological and biochemical parameters in the selection process is not practically possible, although these parameters play a crucial role in salt stress tolerance. Plant responses to salt stress can be divided into two stages. In the first stage, increased growth reduction is a quicker mode resulted due to the osmotic effect. However, the second stage is much slower due to the salt accumulation in leaves, leading to salt toxicity within the plants (Munns 2005).

Evaluation of genotypes for salinity tolerance at the seedling stage will save precious time in developing new varieties. The level of response of genotypes to salinity is influenced by the intensity of salt stress. In the present study we used severe (0.12 and 0.20 M NaCl) salt stresses to identify how plants responded in terms of assessable phenotypic variances among salt-tolerant and sensitive genotypes. In the current study, the tolerant genotypes (Arka Rakshak and YVU-2) were able to maintain their biomass and therefore capable to overcome salt stress. Kumar *et al.* (2017) reported Arka Rakshak showed better germination percentage, germination rate, shoot length, and root length than other germplasm at four different concentrations of NaCl (50, 75, 100, and 150 mM) and hence, in the present investigation we selected the Arka Rakshak germplasm as a check. At 0.12 M and 0.20 M salt stress, the root length, shoot length, fresh weight, and dry weight variables of investigated tomato germplasms got adversely affected with varying levels. The germplasm with the lower relative decrease in fresh weight, dry weight, CSI, and RWC are considered to be most tolerant to salt stress, and the genotypes featuring higher relative decrease is considered to be prone to salt stress (Abdulla *et al.* 2016). Chikha *et al.* (2016) reported that total fresh weight and CO_2 assimilation can be used as appropriate descriptors for assessing salt tolerance in barley. The plant plumule, radical, biomass, and few physiological indices are negatively related with salinity (Kausar *et al.* 2012), which may be due to ionic toxicity, reduction in vitamins uptake (Akhtar *et al.* 2012), osmotic consequences of salinity (Iqbal *et al.* 1998) and water absorption (Ashraf *et al.* 2002).

The lethal effect of Na^+ at higher salt stress causes physical damage to roots, which reduces their ability to absorb water and nutrients, leading to a marked decrease in root and shoot growth along with the damage of carotenoids (Ruiz-Sola *et al*. 2014). Results of the present investigation clearly show that resistant germplasm (Arka Rakshak and YVU-1) showed lower uptake of Na^+, whereas sensitive germplasm (PKM-OP and S-22) showed higher uptake of Na^+ ions, which may be due to having varied salt avoiding mechanisms. The high Na^+ content in soil competes with K^+ for transport in plants, as both share the same transport mechanism, thereby reducing the absorption of K^+ (Munns and Tester 2008; Sairam and Tyagi 2004; Shahid *et al.* 2012). Asharf (1993) reported that sodium and chlorine accumulation in tolerant germplasm was lower than sensitive germplasm and potassium content was higher in tolerant germplasm. Such a reduction of potassium content under saline stress conditions was also reported among many

Table 4. Germplasm ranking based on PCA Factor scores at different salt stress conditions

Germplasm Rank	Control	0.04 M Salt stress	0.12 M Salt stress	0.20 M Salt stress
1	ARKA RAKSHAK (2.626)	ARKA RAKSHAK (2.880)	ARKA RAKSHAK (4.245)	ARKA RAKSHAK (4.411)
2	S-22 (2.455)	Yvu-2 (1.516)	ARKA SAMRAT (2.989)	ARKA SAMRAT (4.223)
3	YVU-2 (1.042)	ARKA SAMRAT (1.102)	YVU-1 (1.021)	YVU-1 (− 0.372)
4	ARKA SAMRAT (0.587)	S-22 (0.131)	YVU-2 (-0.844)	YVU-2 (− 1.329)
5	YVU-1 (− 2.976)	YVU-1 (− 1.757)	S-22 (− 3.507)	S-22 (− 2.939)
6	PKM-OP (− 3.734)	PKM-OP (− 3.872)	PKM-OP (− 3.904)	PKM-OP (− 3.395)

vegetable germplasms (Bybordi 2010). The salinity stress adversely damages the cell membranes at the seedling stage, which results in leakage of K^+ and exchange of Na^+ instead of Ca^{2+} which leads to an osmotic disturbance among plants (Ashraf *et al.* 2002).

We identified and selected tomato salt-tolerant and sensitive genotypes at the seedling stage using PCA. PCA results predicted the Arka Rakshak to be the most resistant followed by Arka Samrat and PKM-OP as the most sensitive germplasm. Multivariate analyses of morphological and physiological traits under higher stress conditions have shown to be an excellent tool for the classification and ranking of genotypes (Chikha *et al.* 2016). These statistical tools were also identified as potent for the assessment of stress conditions in crop species such as tomato (Raza *et al.* 2017), barley (Allel *et al.* 2016), wheat (Rana *et al.* 2015), rice (Chunthaburee *et al.* 2016), and almond (Sorkheh *et al.* 2012). PCA includes all parameters for analysis and discriminates the genotypes under the stress conditions (Jianjie *et al.* 2013; Chikha*et al.* 2016), and it allows the identification of probable groups and the establishment of associations among accession and traits (Martinez-Calvo *et al.* 2008). PCA three-way biplot effectively diagnosed the germplasm as salt-tolerant and salt-sensitive tomato genotypes (Raza *et al.* 2017). Allel *et al.* (2016) discriminate the barley landraces using principal component analysis and salt tolerance index (STI).

5. Conclusion

The present study tried to find the best screening method for salt tolerance in tomato genotypes. The results of this study have indicated that the principle component analysis (PCA) technique can be used as a tool for the selection and discrimination of tomato germplasm towards salt stress. Dry weight and Na^+ content variables have contributed more to PCA to differentiate the salt-tolerant and sensitive germplasm. Arka Rakshak (salt-tolerant) and PKM-OP (salt-sensitive) may be of great interest to elucidate the salt tolerance mechanism for resistant germplasm development. In addition, the graphs generated by the PCA analysis visualized the interrelationships of the variables. Overall, screening of germplasm in laboratory conditions at a large scale using PCA would be an appropriate method for the selection of genetically potential genotypes.

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