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Growth and development of salinity-exposed rice (*Oryza sativa*) rhizo-inoculated with *Bacillus subtilis* under different pH levels

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Abstract. The study investigated the effects of varying pH levels on the growth and development of salt-exposed rice (*Oryza sativa* L.) after inoculation with *Bacillus subtilis.* Germinated rice seedlings (var. FARO 44) were sown in garden soils amended to 100 mM NaCl, and were thereafter inoculated with *Bacillus subtilis*. The transplants were subsequently exposed to periodic wetting with 5 mL of pH-buffered water (pH 3, 5, 7, 9 and 11) every day, and with 5 mL of 100 mM NaCl every 4 days. The set up was monitored during a 30-day period. Results showed significant reduction in chlorophyll a and b as well as lycopene and tocopherol contents of leaves due to changes in the lipid-to-protein ratio of pigment-protein complex or increased chlorophyllase activity and drought stress. There were improved morphological characteristics such as plant height, sheath and foliar dimensions due to inoculation of *B. subtilis*. Increase in salinity resulted in a decrease in plant height, leaf length and sheath. Inoculation not only promoted rice growth, but also enhanced rice tolerance towards salinity owing to the fact that FARO 44 is a salinity-tolerant rice variety. A better understanding of the interaction between microbial inoculants and soil conditions is required to harness the desired benefits towards improving crop development.

Keywords: *Bacillus subtilis*, FARO 44, *Oryza sativa*, pH, rice, salinity.

Introduction

Rice (*Oryza sativa* L.) is a staple food which is commonly consumed in African countries and other parts of the world (Ajala and Gana, 2015). This staple food is consumed by about half of the human race (Udemezue, 2018). It is classified as the most widely consumed food because larger populations depend on it. In Africa, rice has the potentials of improving nutrition, boost food security, support sustainable land care and foster rural development (Ojo and Adebayo, 2012). Rice provides more than one-fifth of the total calories consumed by human universally (Udemezue, 2018). It requires a minimum growing season of four to five months (Ajala and Gana, 2015). All stages of the growth and development of rice plant are affected by salinity, the crop responses varying with growth stages, concentration and duration of exposure to salts (Das *et al*., 2015).

Soil salinity is a serious limitation to rice cultivation under irrigated agriculture due to poor quality of water (Shrivastava and Kumar, 2015). Over 20 % of cultivated land globally is adversely affected by high salt concentration which inhibits plant growth and yield (Kapoor and Pande, 2015). Salt concentration increases in the upper soil layer in warm and dry areas due to high water losses which surpass precipitation (Prusty *et al*., 2018). The sustainability of rice to salt stress differs with growth stage. It is relatively salt tolerant at germination and becomes very sensitive at young seedling stage (Gholizadeh and Navabpour, 2011). During late reproductive stage, it is relatively less sensitive, that is, grain ripening. The detrimental effects of high salinity on plants can be very devastating, causing significant reduction in plant growth, decrease in productivity and even the loss of plants. The accumulation of sodium ion (Na^+) in leaf tissues usually results in the damage of old leaves which shortens the lifetime of individual leaves, thereby reducing the yield of the crops (Negrão *et al*., 2017). Increased NaCl levels will result to a great decrease in shoot, root, and leaf biomass (Meloni *et al*., 2001). In the majority of cultivated plants, the yields start to diminish even at relatively low salinity in soil (i.e., at electrical conductivity, EC, >1 dS m^{-1}) (Chinnusamy *et al*., 2005). Presently, 30% of global paddy fields are affected by excessive salinity (Negrão *et al*., 2017).

There has been a huge awareness in eco-friendly and sustainable agriculture which emphasis the use of beneficial microorganisms. In fact, studies have revealed that local survival of plants to their environment is determined by genetic separation in closely associated microbes (Shrivastava and Kumar, 2015). Rhizosphere microbes have been shown to improve the growth of several crops grown in a large range of root-zone salinities, and this approach is necessary to enhance improvement of germplasm collections of salt-tolerant rice species. These microorganisms living in soils affected by extreme environmental factors can reduce stresses in plants (crop), thus opening a possible and shows potential scheme in sustainable agriculture. A number of studies are now proving the suggestion that plant growth promoting rhizobacteria (PGPR) enable agricultural plants to sustain its productivity under stressing conditions by various means including enhanced accumulation of plant growth regulators like auxins, improvement of root growth for enhanced nutrient acquisition as well as improved nitrogen and phosphorus utilization by plants (Paul and Lade, 2014). Improvement in agricultural sustainability in saline soils requires managerial practices that increase soil biological activity and thereby build-up long-term soil productivity and crop health. The FARO (Federal Agriculture Research Oryza) variety 44 was selected for this study because it is an improved lowland and shallow swamp high-yielding variety which is already in cultivation by farmers in Nigeria. Furthermore, they are improved *Oryza sativa* varieties released by the National Cereals Research Institute, Badeggi, Bida, Nigeria (Dalton and Guei, 2003). They are also among the rain-fed lowland super rice cultivars in Nigeria (Akinwale *et al*., 2012). Having previously noted that soil pH affects proliferation of useful soil bacteria, the aim of this study is to investigate the effects of varying pH levels on the growth and development of salt-exposed rice after rhizo-inoculation with *Bacillus subtilis*.

Materials and methods

Sample collection

Improved high-yielding rice variety (FARO 44) was obtained from Raymos Guanah Farms Ltd, Delta State, Nigeria. Rice seeds were sown in 40 Petri dishes at the rate of 5 seeds per petri dish, until they produced seed-leaves and elaborate roots at the first week after sowing. Prior to sowing *in-vitro* in Whatman's filter paper, each filter paper was adequately moistened with 100 mM NaCl using a sterile 5 mL syringe. Thereafter, top soil (Tab. 1) was obtained from the Departmental Botanic Garden, University of Benin, Benin City, Nigeria, and placed in small nursery bags at 10 kg each. The soils were then moistened with 100 mM NaCl solution. Prior to application of NaCl solution to soil, the water-holding capacity (WHC) was previously determined following the methods of Anoliefo *et al*. (2016), to be 0.161Lkg^{-1} soil. This was necessary because the WHC in this study formed the basis for which each measured volumes of salt solution was required to moisten the soil before sowing with bacterial-inoculated rice seedlings were transplanted 2 days after. Therefore, each 10 kg sun-dried soil received 1 L of 100 mM NaCl. Control plants were never exposed to salt solution before or during experiment, neither were they inoculated with test bacterium.

Bacterial growth and inoculation

The bacterial strain used in this study (*Bacillus subtillis*) was obtained from the Graduate Research Laboratory Culture Collection Unit of the Department of Microbiology, University of Benin, Benin City, Nigeria. This had been isolated from plant rhizospheres of *Chromolaena odorata* during a previous study (Ikhajiagbe and Akendolor, 2016). Pure isolate of *Bacillus subtilis* was prepared by streaking from the previously obtained stored isolate onto agar plates and incubated at 28 ^{o}C for 24 h. Upon growth after 24 hours, the isolate was inoculated in Nutrient broth which was used to grow the isolate, and then incubated for proliferation of cells. For inoculation, the roots of the test plant were immersed completely in bacterial medium for 24 h and thereafter transplanted immediately into each previously prepared nursery bag containing salt-exposed soil.

Application of pH solutions on rice transplants

The transplants were subsequently exposed to periodic wetting with 5 mL of pH-buffered water, which were previously prepared using pH buffers. The respective selected buffer solutions for pH 3, 5, 7, 9 and 11 respectively were added to distilled water until they attained the required respective pH values. This was confirmed by using a digital pH meter Model Mk-Vi with a combination electrodes. The transplants, divided into 5 major groups, were each exposed to pH 3, 5, 7, 9 and 11 every day, and with 5 mL of 100 mM NaCl every 4 days. Whereas one part of these groups were inoculated with *B. subtilis*, the other was not. The set up was observed for 30 days.

Plant parameters considered

Rice growth measurements were taken on a weekly basis. Parameters considered (plant height, sheath, leaf length and leaf breadth of rice seedlings) were measured as described by Lutts *et al*. (1996). Total carotenoids contents was analyzed according to Lichtenthaler and Buschmann (2001). Tocopherol and lycopene were also determined following the methods of Ayodele *et al.* (2014).

Statistical analysis

Statistical analysis was performed using SPSS-20. The data represented mean calculated from 3 replicates. The analysis of variance procedure (ANOVA) was used to compare the effects of NaCl and statistical significance was set at 95% confidence interval.

Results and discussion

After exposure to saline and alkaline stress, uninoculated plants started wilting whereas inoculated plants with bacterial cells alone resisted saline stress (before the laboratory analysis took place) prior to wilting (Tabs. 2 – 4). There was significant increase in plant height over the 4-week period from 8.67 cm to 21.21 cm in the control plant (Tab. 2). Plant height of rice transplants in the salt-exposed soils moistened at pH 3 did not significantly increase ($p>0.05$) during this period; they however died on the 4th week following exposure. However, at pH 3, when rice transplants were rhizo-inoculated with *B. subtillis*, plant height was improved beyound the 4th week (13.50 – 19.67 cm), comparable with the control. Generally, plant height at 4 weeks after exposure in rice transplants exposure to pH 7 (no inoculation), pH 9 (no inoculation), pH 5 (rhizo-inoculated), and pH 7 (rhizo-inoculated) were comparable with control plant in spite of exposure to 100 mM NaCl (21.21 – 26.16 cm).

There was minimal increase in length of leaf sheath throught the 4-week exposure period ($p>0.05$) (Tab. 3). At the forth week, the shortest leaf sheath was seen in the salinity-exposed transplant constantly wetted with pH 11-buffered water (2.00 cm), compared with 9.00 cm of sheath length in salinity-exposed transplants rhizo-inoculated with *B. Subtilis*. Leaf length was impeded at pH 11 for both the bacterium-inoculated and non-inoculated transplants (6.00 – 6.50 cm^2) compared to those moistened lower pH-buffered (11.50 – 17.16 cm^2) (Tab. 4). Salt stress is an abiotic stress factor that causes various deleterious effects on the overall plant growth and development (Ghanem *et al*., 2008). The present study showed that the inoculation of *B. subtilis* strain enabled the morphological development of the test plant.

Table 1. Physical and chemical properties of garden soil used for the experiment

Parameters	Value
pH	5.27
Electrical conductivity (μs cm^{-1})	301.21
Total organic carbon (%)	0.49
Total Nitrogen (%)	0.18
Exchangeable acidity (meq/100 g soil)	0.22
Na (meq/100 g soil)	10.90
K (meq/100 g soil)	1.48
Ca (meq/100 g soil)	14.32
Mg (meq/100 g soil)	12.01
NO^-_2 (mg kg^{-1})	16.43
NO^-_3 (mg kg^{-1})	30.01
Clay (%)	5.13
Silt (%)	7.06
Sand (%)	87.81
Fe (mg kg^{-1})	1011.92

Table 2. Plant height of rice transplants to salt stress under varying pH regimes

	Plant height (cm) Weeks				**p-value**
	1	2	3	4	
Control	$10.33^{ab/A}$	$8.67^{a/A}$	$18.67^{b/B}$	$21.21^{bc/B}$	<0.001
No PGPR					
pH 3	$9.17^{a/A}$	$7.67^{a/A}$	$10.50^{a/A}$	$0^{a/B}$	<0.001
pH 5	$10.83^{ab/A}$	$11.67^{ab/A}$	$12.33^{a/AB}$	$15.00^{b/B}$	0.138
pH 7	$12.50^{ab/A}$	$15.83^{ab/AB}$	$19.17^{bc/BC}$	$24.67^{c/C}$	0.085
pH 9	$15.33^{ab/A}$	$15.33^{ab/A}$	$18.50^{b/AB}$	$23.83^{c/B}$	0.104
pH 11	$10.33^{ab/A}$	$15.67^{ab/B}$	$15.33^{ab/B}$	$15.00^{b/B}$	0.399
PGPR					
pH 3	$13.50^{ab/A}$	$17.33^{ab/B}$	$15.17^{ab/AB}$	$19.67^{b/B}$	0.054
pH 5	$17.17^{b/A}$	$20.00^{b/AB}$	$22.00^{bc/BC}$	$26.16^{c/C}$	0.091
pH 7	$16.00^{ab/A}$	$21.33^{b/B}$	$24.17^{c/B}$	$25.67^{c/B}$	0.138
pH 9	$8.17^{a/A}$	$14.00^{ab/B}$	$16.17^{ab/B}$	$16.16^{bc/B}$	0.331
pH 11	$9.50^{ab/A}$	$10.33^{ab/A}$	$11.17^{a/AB}$	$13.50^{b/B}$	0.411
P. value	0.137	0.08	0.181	<0.001	-

Mean values followed by the different similar lowercase alphabetic supercripts in the same column do not differ from each other ; similarly,means with uppercase alphabetic superscript on same row do not differ significantly (p>0.05)

Table 3. Leaf sheath length of rice transplants to salt stress under varying pH regimes

	Leaf sheath (cm) Weeks				**p-value**
	1	2	3	4	
Control	$4.00^{ab/A}$	$3.83^{a/A}$	$3.67^{a/A}$	$5.01^{b/A}$	0.624
Npgpr					
pH 3	$4.33^{abc/A}$	$4.16^{a/A}$	$3.50^{a/A}$	$0^{a/B}$	<0.001
pH 5	$3.3^{ab/A}$	$4.00^{a/A}$	$5.33^{a/AB}$	$7.00^{c/B}$	0.418
pH 7	$6.67^{bc/A}$	$7.00^{a/A}$	$7.00^{a/A}$	$8.83^{c/A}$	0.231
pH 9	$6.67^{bc/A}$	$6.00^{a/A}$	$7.33^{a/A}$	$8.33^{c/A}$	0.529
pH 11	$5.00^{abc/A}$	$7.00^{a/A}$	$5.67^{a/A}$	$2.00^{ab/B}$	0.138
PGPR					
pH 3	$5.16^{abc/A}$	$7.33^{a/A}$	$8.00^{a/A}$	$8.50^{c/A}$	0.329
pH 5	$7.67^{c/A}$	$6.33^{a/A}$	$7.83^{a/A}$	$9.00^{c/A}$	0.388
pH 7	$6.67^{bc/A}$	$6.83^{a/A}$	$7.83^{a/A}$	$8.67^{c/A}$	0.702
pH 9	$2.83^{a/A}$	$4.83^{a/A}$	$5.16^{a/A}$	$6.16^{bc/A}$	0.222
pH 11	$3.00^{ab/A}$	$3.50^{a/A}$	$4.67^{a/AB}$	$5.67^{bc/B}$	0.096
P. value	0.041	0.475	0.304	<0.001	

Mean values followed by the different similar lowercase alphabetic supercripts in the same column do not differ from each other ; similarly,means with uppercase alphabetic superscript on same row do not differ significantly (p>0.05)

Table 4. Leaf length of rice transplants to salt stress under varying pH regimes

	Leaf length (cm) Weeks				**p-value**
	1	2	3	4	
Control	5.83$^{a/A}$	4.50$^{a/A}$	7.00$^{a/AB}$	9.01$^{b/B}$	0.282
Npgpr					
pH 3	5.16$^{a/A}$	5.50$^{ab/A}$	7.00$^{ab/A}$	0$^{a/B}$	<0.001
pH 5	6.00$^{a/A}$	8.16$^{abc/A}$	9.33$^{ab/AB}$	11.50$^{b/B}$	<0.001
pH 7	6.00$^{a/A}$	12.83$^{bc/B}$	14.33$^{b/BC}$	15.83$^{b/C}$	<0.001
pH 9	9.83$^{a/A}$	11.16$^{abc/AB}$	13.33$^{b/B}$	15.33$^{b/B}$	0.067
pH 11	5.33$^{a/A}$	8.67$^{abc/A}$	7.33$^{ab/A}$	6.00$^{a/A}$	0.514
PGPR					
pH 3	7.83$^{a/A}$	9.50$^{abc/A}$	10.50$^{ab/AB}$	12.50$^{b/B}$	<0.001
pH 5	7.83$^{a/A}$	13.33$^{c/B}$	14.50$^{b/BC}$	17.16$^{b/C}$	0.038
pH 7	9.00$^{a/A}$	12.00$^{bc/B}$	13.50$^{b/BC}$	16.16$^{b/C}$	<0.001
pH 9	8.00$^{a/A}$	9.00$^{abc/A}$	9.50$^{ab/A}$	10.50$^{b/A}$	0.013
pH 11	6.50$^{a/A}$	6.50$^{abc/A}$	6.67$^{ab/A}$	6.50$^{a/B}$	0.725
P. value	0.69	0.121	0.057	0	

Mean values followed by the different similar lowercase alphabetic supercripts in the same column do not differ from each other ; similarly,means with uppercase alphabetic superscript on same row do not differ significantly (p>0.05)

In the rhizosphere the synergism between various bacterial genera such as *Bacillus*, *Pseudomonas* and *Rhizobium* has been demonstrated to promote plant growth and development (Figueiredo *et al*., 2010). This indicates that the rhizoinoculation not only promoted rice growth by supplying nutrient and IAA, but also enhanced rice tolerance towards salinity. This is because some plant growth promoting rhizobacteria (PGPR) stimulate plant growth and development by enhancing nitrogen acquisition and utilization, improving secretion of phytohormones, and enhancing availability and utilization of phosphate (Hayat *et al*., 2010). PGPRs also enhance plant growth and development by protecting the plant against soil-borne diseases, most of which are caused by pathogenic fungi as reported by Lugtenberg and Kamilova (2009). Saline environment inhibits rice growth, this is because rice is a saline sensitive plant (Ashraf and Harris, 2004); also because the uptake of Ca^{2+}, K^+ and inorganic N and P are disrupted under high Na^+ concentration (Ashraf and Harris, 2004). Rhizoinoculation enhanced morphological characteristics of test plant (*Oryza sativa*) under saline condition

The contents of photosynthetic pigments including chlorophyll a, chlorophyll b and total carotenoids contents in rice plants grown under extreme pH combined with salt stress declined significantly, being especially susceptible to salt. Yang *et al*.(2008) studies revealed that, chlorophyll a, chlorophyll b and total carotenoids contents in the salt resistant wheat grown under alkaline salt stress (pH 9.9 and 60–75 mmol L^{-1} NaCl) were 2.5–5.0 times lower than those grown under salt stress only. In the present study however, chlorophyll-a contents of salt-exposed non-inoculated rice plants were higher at pH 5 during the 4th week of exposure (0.010 mg g^{-1}) compared to the control (0.006 mg g^{-1}) (Fig. 1). Similarly, chlorophyll-b contents of salt-exposed non-inoculated rice plants were higher at pH 5 (0.017 mg g^{-1}) compared to the control (0.002 mg g^{-1}) (Fig. 2). Inoculated rice plants at similar pH 5 had a chlorophyll content of 0.015mg g^{-1}.

Chlorophyll content is often measured in plants to assess the impact of environmental stress, as changes in pigment content are linked to visual symptoms of plant illness and photosynthetic productivity. The reported decrease in chlorophyll contents of salinity-affected transplants might be due to changes in the lipid protein ratio of pigment-protein complex or increased chlorophyllase activity as reported by Dogan and Demirors (2018).

There were minimal differences in carotenoid contents of exposed plants ($p>0.05$) (Tab. 3). Lycopene, which is one of the most important bioactive compound in plants due to its benefits to human health (Aanchal *et al*., 2019) increased under pH 5 and 9 conditions (Tab. 3), it reduced in pH 7 and 11 in the bags without PGPR, that is, the pH and NaCl (stress) could be responsible. There was a gradual decrease in the plants which were inoculated by the PGPR. Riggi *et al*. (2008) and Atkinson *et al*. (2011) found that drought stress lowered the lycopene content compared to well-watered tomato plants; however, the carotene content showed a positive increase. In contrast, Theobald *et al*. (2007) stated that the lycopene contents increased by more than 27% in water-stressed fruits. An increase in lycopene contents was also found in tomato fruits grown in Southern Italy by Favati *et al*. (2009). Moderate water stress induced an increase of the lycopene concentration of tomatoes (Sanchez-Rodriguez *et al*., 2012).

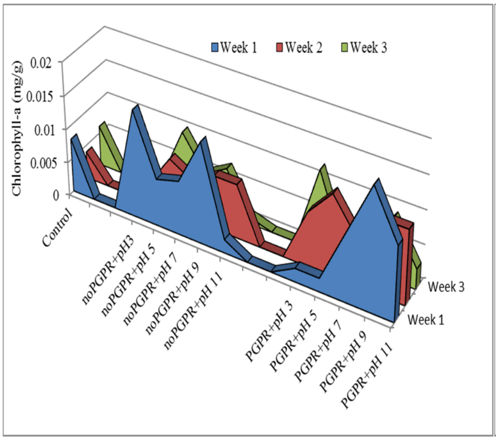

Figure 1. Cholorophyll-a content of rice transplant transplants exposed to salt stress under varying pH regimes

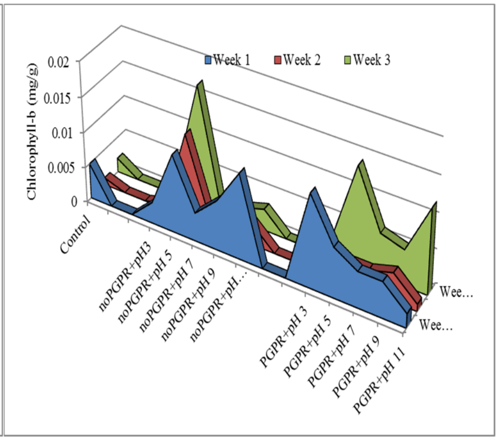

Figure 2. Cholorophyll-b content of rice transplant transplants exposed to salt stress under varying pH regimes

Table 5. Antioxidant response of the rice transplants exposed to salt stress under varying pH regimes

	Carotenoid (mg/kg)			Tocopherol (mg/kg)			Lycopene (mg/kg)		
	1	2	3	1	2	3	1	2	3
	Weeks			Weeks			Weeks		
***Control**	1137.1^{a}	1004.16^{cde}	985.61^{cd}	0.94^{bcd}	0.96^{b}	0.97^{bc}	2.35^{cd}	54.35^{b}	1.10^{e}
nPGPR									
pH 3	1100.7^{a}	985.50^{efg}	946.48^{de}	0.93^{bc}	0.99^{b}	0.98^{c}	2.78^{e}	1.91^{h}	5.65^{g}
pH 5	1108.7^{a}	983.84^{bcd}	991.70^{a}	0.96^{cd}	0.98^{b}	0.97^{bc}	2.39^{d}	91.03^{e}	91.22^{d}
pH 7	1130.7^{a}	1002.90^{bc}	1292.29^{b}	0.93^{b}	0.98^{b}	0.98^{c}	2.39^{d}	34.79^{a}	3.63^{f}
pH 9	1107.3^{a}	976.46^{g}	1004.28^{c}	0.96^{cd}	0.96^{b}	0.96^{bc}	2.01^{b}	72.73^{d}	32.32^{b}
pH 11	1109.3^{a}	951.44^{a}	1008.20^{e}	0.95^{bcd}	0.95^{b}	0.93^{b}	2.22^{c}	65.59^{c}	19.04^{b}
PGPR									
pH 3	1055.7^{a}	1024.13^{cde}	992.28^{b}	0.74^{a}	0.81^{a}	0.81^{a}	2.73^{e}	69.57^{d}	25^{ab}
pH 5	1080.7^{a}	994.52^{def}	962.09^{b}	0.94^{bcd}	0.97^{b}	0.98^{c}	2.39^{d}	1.91^{h}	60.09^{c}
pH 7	1056.4^{a}	972.44^{ab}	944.93^{cd}	0.96^{d}	0.94^{b}	0.94^{bc}	32.57^{a}	1.38^{f}	1.07^{i}
pH 9	1075.7^{a}	965.83^{fg}	996.37^{de}	0.96^{cd}	0.94^{b}	0.95^{bc}	24.99^{a}	62.43^{c}	6.56^{h}
pH 11	1116.7^{a}	935.89^{fg}	1027.99^{e}	0.96^{d}	0.95^{b}	0.95^{bc}	34.78^{a}	1.75^{g}	2.27^{j}
P. value	0.288	0.084	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001

Mean values followed by the different similar alphabetic supercripts in the same column do not differ from each other (p>0.05)

Table 6. Correlation coefficient of parameters

	Plant height	**Sheath**	**Leaf length**	**Leaf breadth**	**Chloro phyll a**	**Chloro phyll b**	**Caro-tenoid**	**Toco-pherol**	**Lyco-pene**
Plant height	1								
Sheath	0.869**	1							
Leaf length	0.910**	0.820**	1						
Leaf breadth	0.828**	0.741**	0.783**	1					
Chlorop hyll a	-0.28	-0.06	-0.29	-0.33	1				
Chlorop hyll b	0.03	0.07	0.09	0.20	0.06	1			
Caroten oid	-0.18	-0.25	-0.25	-0.09	-0.27	-0.27	1		
Tocoph erol	0.03	-0.23	0.06	0.04	-0.556**	0.11	0.14	1	
Lycope ne	-0.07	-0.15	-0.14	-0.07	-0.1	0.03	0.667**	0.12	1

****. Correlation is significant at the 0.01 level (2-tailed)**

Pearson correlation matrix for all parameters of test plants indicated a significant correlation among each of chlorophyll a (r = -0.330, p<0.05) and carotenoid (r = -0.272, p<0.05) (Tab. 4). PCA, as a multivariate technique, can group individuals or objects on the basis of their characteristics. Individuals with similar descriptions are mathematically congregated within the same cluster (Ahmadikhah *et al.*, 2008). Distance, similarity and relatedness of varieties are the foundation of this method. The biplot showed that test plant parameters were not particlualry affected specific experimental conditions (Fig. 3). However, plant morphological parameters, tocopherol and chlorophyll contents were closely associated together. Tocopherol is a plant antioxidant associated with protection of the chlorophyll molecule. Chlorphyll is also assoctaed with improved plant development as this molecule is the basis for plant productivity because of its importance in cellular energetics. Therefore, the association of morphological parameters, chlorophyll contents and tocopherol underline the importance of the latter in plant survival capacities under the experimental condition. Direct exposure of the test plants to combined effects of pH and salinity would result in oxidative damage, and also may lead to impaired cellular ionic homeostasis (Yadav, 2010). It is therefore suggested that such a plant may have utilized this antioxidant as a defence strategy.

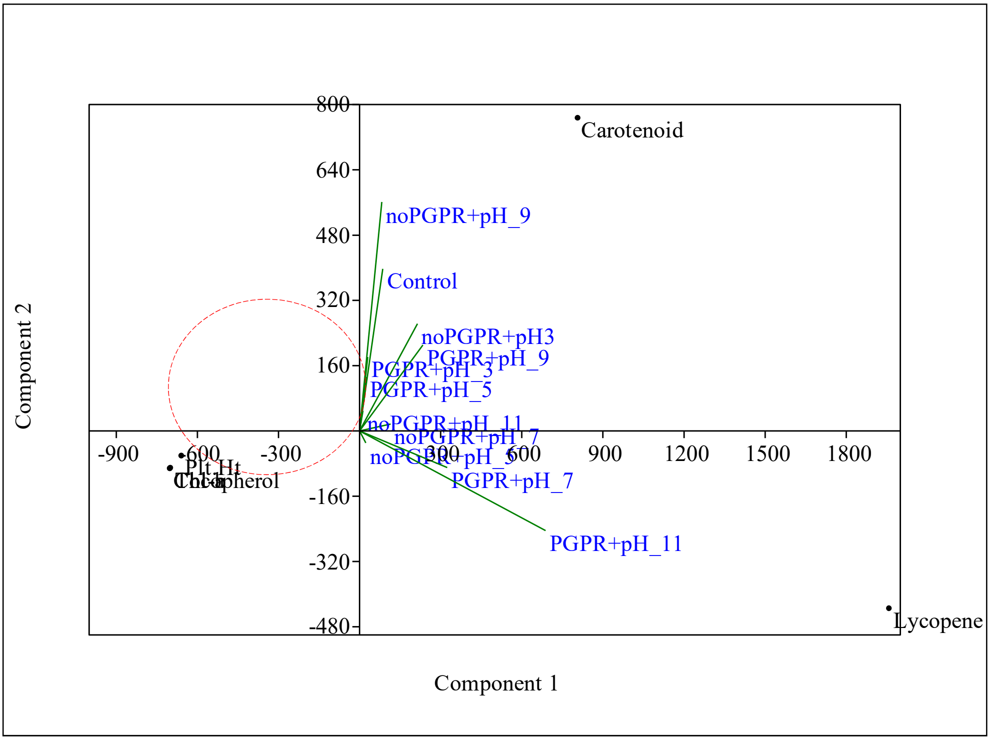

Figure 3. Pricipal component biplot showing association among selected characteristics of the test plant under experimental condition

Conclusions

The negative growth impact of salinity in plants may have significant implications for crop yield. The study investigated the effects of bacterial rhizoinoculation on growth and dvelopment of rice plants under salinity and varying pH conditions. This is predicated upon the fact that soil pH infuences microbial proliferation and hence its capability to support plant development under stress conditions. In the present study, growth enhancement of rice transplants under salinity condition was achieved rather at pH 5 and than at neutral pH.

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