MANAGEMENT OF SALT STRESS IN GROUNDNUT THROUGH UTILIZATION OF BIO-FERTILIZER

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CERTIFICATE

*This is to certify that thesis entitled, "**MANAGEMENT OF SALT STRESS IN GROUNDNUT THROUGH UTILIZATION OF BIO-FERTILIZER**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **JOYSREE DATTA**, **REGISTRATION NO.15-06542** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information as has been availed of during the course of this investigation has dully been acknowledged.

Date:

Place: Dhaka, Bangladesh

Anisur Rahman, Ph.D
Professor
Supervisor

DEDICATED TO
MY
BELOVED PARENTS

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MANAGEMENT OF SALT STRESS IN GROUNDNUT THROUGH UTILIZATION OF BIO-FERTILIZER

ABSTRACT

A pot experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during, January to June 2020 for the management of salt stress in groundnut by utilization of Bio-fertilizer. The experiment consisted of two factors, and conducted by following Randomized Complete Block Design with four replications. Factor A: comprised of four types of biofertilizer *viz;* B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza,* and Factor B consisted four levels of salinity *viz;* S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl. Different growth and yield parameters were observed for assessing the effect of salinity and role of biofertilizer to manage salt stress. Exposure of salinity decreased growth and yield of groundnut and the level of reduction increased with the increment of salinity. Application of 50, 100 and 150 mM NaCl decreased seed yield by 57, 83 and 96% respectively. Application of biofertilizer increased growth and yield of groundnut both in control and saline conditions. Under 50 mM NaCl treatment, the use of BARI Rhizobium RAh-803, BARI Rhizobium RAh-808, and Mycorrhiza increased seed yield (134, 401, and 280%, respectively) and stover yield (43, 61, and 65%, respectively) over the control treatment. Application of biofertilizer also reversed salt induced damages in groundnut under 100 and 150 mM salinity in same way. Among the biofertilizers, BARI Rhizobium RA_h-808 recovered salt induced damages through increasing growth, pod number, seed number, 100-seed weight as well as seed yield and stover yield. Growth and yield of groundnut decreased with increasing salinity levels. However application of biofertilizer manage salinity, by reducing salt induced damages. Among them, application of BARI Rhizobium RAh-808 (Salt tolerant) as a biofertilizer might be a suitable approach to groundnut cultivation under salt stress conditions.

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ABBREVIATIONS

Full word	Abbreviations
Agriculture	Agr.
Agro-Ecological Zone	AEZ
Bangladesh Bureau of Statistics	BBS
Biology	Biol.
Biotechnology	Biotechnol.
Botany	Bot.
Cultivar	Cv.
Dry weight	DW
Editors	Eds.
Emulsifiable concentrate	EC
Entomology	Entomol.
Environments	Environ.
Food and Agriculture Organization	FAO
Fresh weight	FW
International	Intl.
Journal	J.
Least Significant Difference	LSD
Liter	L
Triple super phosphate	TSP
Science	Sci.
Soil Resource Development Institute	SRDI
Technology	Technol.
Serial	Sl.

CHAPTER-I

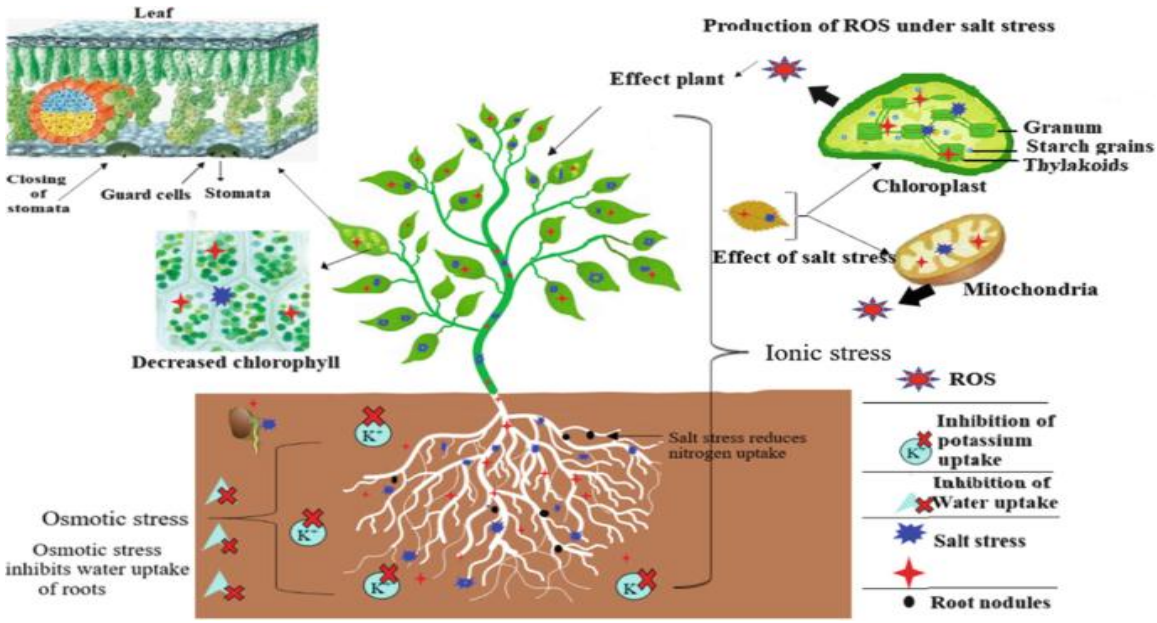
INTRODUCTION

Groundnut (*Arachis hypogaea* L.) or peanut is the sixth most important oilseed crop in the world cultivated throughout tropical and subtropical areas, followed by cereal crops. In Bangladesh, groundnut is the second most oilseed crop and has played a pivotal role in meeting the growing oil requirements in recent years and ensuring nutritional security for a population of over 160 million (Shakil, 2022). Nutritionally, groundnut seeds contain about 48-50% edible oil, 22–29% protein, and 20% carbohydrate, with an average yield of 2.30-3.00 t ha^{-1} (Dun *et al.* 2019). Groundnut is cultivated on about 32,000 ha of land, and the total groundnut production is about 47,000 Mt in Bangladesh (Azad *et al.*, 2020).Groundnut is a major crop in the char lands of Bangladesh, but because of poor yields, farmers derive a limited income from the crop. The productivity of groundnut depends on proper selection of variety, fertilizer management, environmental factors, metal contents in soil and other management practices (Mouri *et al*., 2018).

When plants are exposed to adverse environmental conditions, such as nutrient deficiency, lack of water, low or high temperature, ultraviolet radiation, salinity, insufficient oxygen, heavy metal toxicity, diseases, and pests, their growth is adversely affected. This condition is called stress. Stress can last for a long time or be temporary for a short time. Agricultural productivity is decreasing due to the detrimental impacts of climate change. Therefore, in order to extend sustainable agriculture and to increase crop products for food in the world, it seems necessary to use the appropriate solutions to decline the negative effects of stresses on agricultural plants (Qaim, 2020).

Salinity is one of the most important abiotic stresses that adversely affects growth and development in plants, limiting yield and quality. Salinity affects about 20% of all irrigated agricultural fields and over 7% of the world's land surface (Hussain *et al*., 2017). It is estimated that approximately 50% of arable land will be affected by salinity stress by the year 2050 (Shrivastava and Kumar, 2015). This is likely to impact the global food production needed to feed over 9.6 billion people, which the world population is estimated to reach by 2050. Increasing concentrations of salt in soil and or irrigation water is a major threat to agricultural production in arid and semiarid regions. It is

anticipated that because of the build-up of salinity in soil, there will be a drastic reduction in crop yield by inhibition of seed germination, seedling growth, flowering, and fruit set (Sairam and Tyagi, 2004). Almost all physiological processes like respiration, photosynthesis, nitrogen fixation and other metabolic and enzymatic processes are affected by soil salinity, resulting in stunted growth and a decrease in farm productivity (Ma *et al*., 2020).



(Source: Dey *et al*., 2021)

Figure 1. Effect of salt stress on plant

It also disrupts the cellular osmotic balance (Krasensky and Jonak, 2012), and increases oxidative stresses by generating reactive oxygen species (ROS). Soil salinity, usually NaCl, may also reduce plant growth by ion toxicity and water deficits (Wu *et al*., 2013). Crop losses are predicted to reach approximately US$27.3 billion annually (Qadir *et al*., 2014). In the changing climate scenario, the impact of salinization is likely to increase further, necessitating special efforts to maintain sustainable crop yield under salt stress (Suarez *et al*., 2015).

The susceptibility of peanut to salinity stress varies with growth stages. Peanuts have a low tolerance to certain salts. The foliar symptoms that develop after irrigation with saline irrigation water vary from a brown marginal leaflet burn to death of the leaf. Pod rot often increases when the sodium and potassium cations accumulate in the fruiting

zone(Aydinşakir *et al.*, 2015).However, salinity affects all stages of peanut growth and finally the yield (Ma *et al*., 2020).

Among several strategies advised to overcome the problem of salinity stress, the selection of crop species or cultivars with salt tolerance traits along with application of biofertilizer has been considered an economical and efficient strategy. In recent years, improvements in beneficial microorganisms have raised the tendency to use biofertilizers as valuable tools in sustainable agriculture. Biofertilizers have various benefits for plant growth. They regulate the soil texture and activate the soil biologically. It has been reported that many biofertilizers suppress plant pathogens and protect the plant against soil-borne diseases, so they are known as environmentally friendly. In terms of agricultural sustainability, biofertilizers do not harm the ecological system and do not contain harmful substances, they are proportionally cheaper when compared to commercial chemical fertilizers. Biofertilizers stimulate plant growth and produce phytohormones, thus increasing the yield and quality of the plant. In the fight against salinity, biofertilizer applications are widely preferred all over the world because they significantly increase salt tolerance (Xavier *et al.,* 2023).

One of the most effective alternatives among biofertilizer applications is mycorrhiza. Mycorrhizal fungi, which have the ability to establish a symbiotic relationship with plant roots, take carbohydrates that they cannot synthesize from the plant itself and contribute to the ability of plants to take in more water and nutrients by expanding their root domain thanks to their hyphae (Begum *et al.,* 2019). It has been reported that the positive effect of mycorrhiza is not only to increase the intake of water and nutrients but also to increase the tolerance of plants to abiotic and biotic stress conditions (Li *et al*., 2022).Mycorrhiza and beneficial bacteria have taken their place in the biofertilizer industry in recent years. The effectiveness of these fertilizers has positive effects on the nutrition of the plants by increasing the solubility of nutrients in the root area, with benefits, such as lowering the pH in the root zone, secretion of chelators, production of special ion carrier proteins (Dasgan *et al*., 2017). While the solubility and availability of nutrients, such as phosphate, Fe, Zn, and Mn, increase by decreasing the pH in the root zone, some bacteria also fix the nitrogen to the soil from the air.

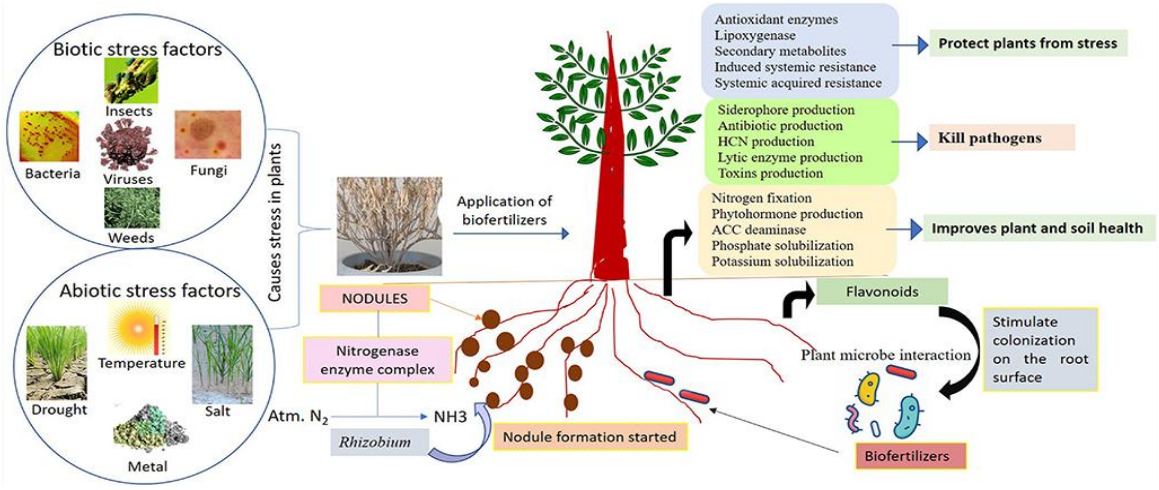


Figure 2. Role of biofertilizers for maintenance of crop productivity and soil health.

(Source: Chaudhary *et al*., 2022)

It is reported that plant growth promoting rhizobacter (PGPR) bacteria that promote plant growth produce hormones, fix atmospheric nitrogen, and dissolve phosphate (Ray *et al*., 2020). Usage of bioinoculants is enormously supportive in countering the lethal properties of soil salinity via improving the soil physicochemical properties and thus improved crop production (Jiménez-Mejía *et al*., 2022). Interaction between microbes and plants can overcome stress problem. Fortt *et al*. (2022) reported that the application of PGPR improved the growth of lettuce under salt stress via the production of indole acetic acid (IAA) and antioxidant enzymes which provide protection to plants. Gond *et al*. (2015) reported that inoculation of *Pantoea agglomerans* in tropical corn under salt stress (0–100mM) improves tolerance and growth of plants due to the up regulation of aquaporins.

Hence, keeping all the points in view, the present study entitled, "Management of salt stress in groundnut by utilization of Bio-fertilizer" was undertaken with the following objectives:

i. To know the effect of salinity on the performance of groundnut plant
ii. To find out the role of bio-fertilizer under salinity stress condition

CHAPTER II

REVIEW OF LITERATURE

In this section, an attempt was made to collect and study relevant information available regarding the management of salt stress in groundnut through the use of bio-fertilizer, in order to gather knowledge useful in carrying out the current piece of work. Because the available literature on this crop is limited, literature on other related crops was gathered and reviewed under the following headings:

2.1 Plant stress

The ideal growth conditions for a given plant can be defined as the condition that allows the plant to achieve its maximum growth and reproductive potential as measured by plant weight, height, and seed number, which together comprise the total biomass of the plant. Plants are subjected to various environmental stresses, such as water deficit, drought, cold, heat, salinity and air pollution. The study of functioning of plants under adverse environmental conditions is simply called 'Plant stress physiology'. Stress is simply any change in environmental condition that might adversely change the growth and development of a plant, and also prevents the plant from achieving its full genetic potential (Levitt, 1972).

2.2 Types of plant stress

Plant stress can be broadly classified into two main groups, *viz*., 'Biotic stress' and 'Abiotic stress'. The stress factors which occur by the communication among the plant and any living organisms, i.e., viruses, bacteria, fungi, parasites, insects, weeds etc. that results in either minor injury that the plant can overcome or major injury that the plant can demise is referred as biotic stress. The biotic stresses caused by bacteria, fungi and nematodes that are ever present in the environment are called potential biotic stresses. Abiotic stress such as drought, excessive soil salinity, excessive watering, extreme temperatures (cold, frost and heat), salinity and mineral toxicity, too much or too little light and nutrient deficiency in the soil negatively impact growth and development of

plants. These are external stress factors that can affect the plant growth for a longer duration (Kalita, 2022).

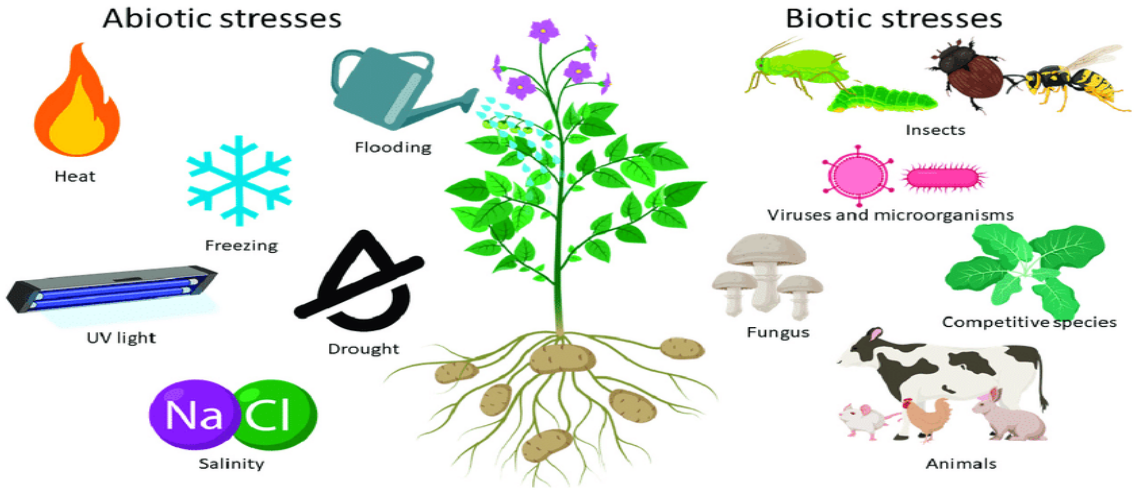


Figure 3. Different types of biotic and abiotic stresses that can affect plants

(Serrano *et al*., 2020).

2.3 Soil salinity

The presence of excess salts on the soil surface and in the root zone characterizes all saline soils. The main source of all salts in the soil is the primary minerals in the exposed layer of the earth's crust. During the process of chemical weathering, the salt constituents are gradually released and made soluble. The predominant salts near the site of weathering will be carbonates and hydrogen-carbonates of calcium, magnesium, potassium and sodium; their concentrations, however, are low. The released salts are transported away from their source of origin through surface or groundwater streams. The salts in the groundwater stream are gradually concentrated as the water with dissolved salts moves from the more humid to the less humid and relatively arid areas. The concentration of salts may become high enough to result in precipitation of salts of low solubility. Chloride and sodium ions are the predominant ions in the soil and water in these areas (Tavakkoli *et al*., 2010).

2.4 Classification of salinity

Generally, salinity classified as saline and sodic soils. Saline Soils containing sufficient neutral soluble salts to adversely affect the growth of most crop plants. The soluble salts are chiefly sodium chloride and sodium sulphate. But saline soils also contain appreciable quantities of chlorides and sulphates of calcium and magnesium. Sodic soils containing sodium salts capable of alkaline hydrolysis, mainly Na_2CO_3, these soils have also been termed as alkali in older literature (Choudhary and Kharche, 2018).

2.5 Characteristics of saline soils

The United States salinity laboratory (1954) defined the saline soil as a soil whose electrical conductivity (EC) of the saturation extract is more than 4 dS/m at 250C and the exchangeable sodium percentage (ESP) is less than 15. The pH of such soils is usually below 8.5. The characteristics of saline soils are that these soils predominantly contain neutral soluble salts consisting of chlorides and sulphates of sodium, calcium and magnesium. The pH of saturated soil paste is less than 8.2. Electrical conductivity of the saturated soil extract is more than 4 dS m^{-1} at 25^0C. Although Na is generally the dominant soluble cation, the soil solution also contains appreciable quantities of divalent cations, e.g. Ca and Mg. Soils may contain significant quantities of sparingly soluble calcium compounds, e.g. gypsum. In the presence of excess neutral soluble salts the clay fraction is flocculated and the soils have a stable structure. Permeability of soils to water and air and other physical characteristics are generally comparable to normal soils.

2.6 Salt stress responses in plants

Several environmental factors adversely affect plant growth and development and finally yield performance of a crop (Ngoune and Shelton, 2020). Salinity is one of the major abiotic stresses to crops, and almost 10% of the world's entire land area (950 Mha), 20% of the world's cultivated land (300 Mha), and approximately 50% of the total irrigated land (230 Mha) are consequently distressed with extreme salinity (Abiala *et al*., 2018). Important physiological and biochemical processes in plants are adversely affected by salinity in various ways through an intense concentration of salts and unavoidably leading

to a gradual reduction in plant growth. High salt concentration in rhizosphere of plant cell causes osmotic effect, which remains as a chief contributor to growth reduction during the preliminary stages of a plant life cycle. Amendment in K^+/Na^+ ratio arises when ions reach the plant cell through saline water, leading to augmented Na^+ and Cl^- ion, inflicting extensive damage of numerous physiological processes like protein metabolism and enzyme activities (Tester and Davenport, 2003). The interactions between salts and essential mineral nutrients may consequently result in significant nutrient deficiencies and disproportion. Ionic imbalances may also result in decreased uptake of various significant minerals like potassium, manganese, and calcium to the plants. However, in response to ionic and nutrient imbalances, salt-tolerant plants have uniquely developed the capability of accumulation and compartmentalization of Na^+ and Cl^- in their matured leaves, but sensitive species at absurdly high salinity stage cannot manage to compartmentalize the ions or Na^+ transport, leading to the ionic or osmotic effect. Considerable reduction in plant height has been documented under different abiotic stresses. Due to salinity, plants are exposed to serious water deficit conditions that reduces the leaf growth and leaf areas in several species such as wheat (Sacks *et al*., 1997), poplar (Wullschleger *et al*., 2005), and cowpea (Manivannan *et al*., 2007). One example of the physiological changes in response to salt is shedding of the older leaves of plants (Shao *et al*., 2008). The upsurge in root to shoot ratio due to salinity conditions was found to be associated with the ABA content of plants (Sharp and LeNoble, 2002).

2.7 Effect of salt stress on plant growth and development

Salt stress adversely impacts plants by hindering seed germination, growth and development, and flowering and fruiting (Park *et al*., 2013). The high concentrations of sodium in saline soil limits water uptake and the absorption of nutrients in the plant (Gong, 2021). Water deficiency and nutritional imbalance induce primary stresses, including osmotic stress and ionic stress. These primary stresses result in oxidative stress and can cause a series of secondary stresses (Zhu, 2002). Together, salt stress leads to various physiological and molecular changes and impedes plant growth by inhibiting photosynthesis, thus reducing the available resources and repressing cell division and expansion (Van Zelm *et al*., 2020). Salt stress affects light-harvesting complex formation

and regulates the state transition of photosynthesis (Chen and Hoehenwarter, 2015). Importantly, the enzyme activities or protein stabilities of the key enzymes in photosynthesis, such as ribulose-1,5-bisphophate carboxylase/oxygenase (RuBisCO), are affected through modulating the glycation under salt stress condition. Salt stress also influences sugar signaling and alters the levels of sugars, such as sucrose, fructose, and glycolysis (Shumilina *et al*., 2019).

Soil salinity affects various physiological and biochemical processes which result in reduced plant growth. Salt stress, affects the plant water relation at cellular and whole plant level causing specific as well as unspecific reactions and damages. A number of studies have shown that photosynthetic capacity of different species is reduced due to salinity (Ashraf, 2004; Dubey, 2005). The salt in the soil solution (the "osmotic stress") reduces leaf growth and to a lesser extent root growth, and decreases stomatal conductance and thereby photosynthesis (Munns, 1993).

Much of the injury on plants under abiotic stress is due to oxidative damage at the cellular level, which is the result of imbalance between the formation of reactive oxygen species (ROS) and their detoxification. Salt stress reduces the plant's ability to take up water, and this leads to reduction in growth. This is the osmotic or water-deficit effect of salt stress. Salts themselves do not build up in the growing tissues at concentrations that inhibit growth, as the rapidly elongating cells can accommodate the salt that arrives in the xylem within their expanding vacuoles. So, the salt taken up by the plant does not directly inhibit the growth of new leaves (Munns, 2005). Reductions in the rate of leaf and root growth are probably due to factors associated with water stress rather than a salt-specific effect (Munns, 2002). Hormonal signals, probably induced by the osmotic effect of the salt outside the roots are controlling the rate of cell elongation growth (Munns *et al*., 2000).

Toxicity occurs as a result of uptake and accumulation of certain toxic ions from the soil within a crop itself. These toxic constituents include mainly sodium, chloride and sulphate. The salt taken up by plant concentrates in the old leaves; continued transport of salt into transpiring leaves over a long period of time eventually results in very high Na+ and Cl- concentrations, and the leaves die. The cause of the injury is probably due to the

salt load exceeding the ability of the cells to compartmentalize salts in the vacuole. Salts then would rapidly build up in the cytoplasm and inhibit enzyme activity. Alternatively, they might build up in the cell walls and dehydrate the cell (Munns, 2005). High accumulation of Na+ in shoots also inhibits enzyme activity, and other metabolic processes such as protein synthesis and photosynthesis (Ashraf, 2004; Munns, 2005) thereby reducing leaf growth or causing leaf death and thus photosynthetic capacity of plant is reduced (Ashraf, 2004; Dubey, 2005). High accumulation of Na+ in the leaves reduced photosynthetic capacity in wheat (James *et al*., 2002).

Excessive amount of soluble salts in the root environment causes osmotic stress, which may result in the disturbance of the plant water relations in the uptake and utilization of essential nutrients. Ionic imbalance occurs in the cells due to excessive accumulation of Na+ and Cl- and reduces uptake of other mineral nutrients, such as K+, Ca^{2+}, and Mn^{2+} (Karimi *et al*., 2005), resulting in considerable nutrient imbalances and deficiencies (McCue and Hanson, 1990). As a result of these changes, the activities of various enzymes and the plant metabolism are affected (Munns, 2002). Excess Na^{+} and Cl^{-} inhibits the uptake of K^{+} and leads to the appearance of symptoms like those in K^{+} deficiency. The deficiency of K^{+} initially leads to chlorosis and then necrosis (Gopa and Dube, 2003). Both K^{+} and Ca^{2+} are required to maintain the integrity and functioning of cell membranes (Wenxue *et al*., 2003). . Exposure of plants to salinity stress can up-regulate the production of reactive oxygen species (ROS) such as H_2O_2 (hydrogen peroxide), O_2^{-} (superoxide), $1O_2$ (singlet oxygen) and OH^{-} (hydroxyl radical), resulting in oxidative damage to cells. Excess ROS causes phytotoxic reactions such as lipid peroxidation, protein degradation and DNA mutation (McCord, 2000, Wang *et al*., 2003; Vinocur and Altman, 2005; Pitzschke *et al*., 2006).

2.8 Effect of salt stress on groundnut

Satu *et al.* (2019) carried out an investigated to study the effects of salinity on the growth of BARI Groundnut-8 (*Arachis hypogaea* L.). The plants were grown in a series of plastic pots under controlled light and temperature conditions in the growth room. Salt (NaCl) solutions of different concentrations (0 mM, 50 mM, 100 mM, 150 mM, 200 mM,

and 250 mM) were added to the pots, with three replicates. Results showed that shoot height, number of plants, main root length and lateral root length significantly decreased with the increase of salt concentrations. Fresh weight as well as dry weight of shoots and roots also decreased with the increase of salt concentrations while leaf proline and protein concentrations increased. Overall results indicate that high salinity condition is not suitable for growing groundnut.

Mahlooji *et al.* (2018) studied salt tolerance in three barley genotypes under field conditions, to understand the important physiological traits, with three salinity levels (2, 10, and 18 dSm^{-1}). High salinity decreased K^+ concentration, K^+: Na^+ ratio but increased electrolyte leakage and Na^+ content. Under 10 and 18 dSm^{-1} salinity, salt-tolerant genotype had the maximum K^+, K^+: Na^+ ratio, and a minimum Na^+ content and electrolyte leakage, whereas salt-sensitive genotype had the lowest K^+ content, K^+: Na^+ ratio, and the highest Na^+ content and electrolyte leakage.

Aechra *et al*. (2017) studied that application of soil salinity having EC 1 dS m^{-1} recorded the maximum and significantly higher total and effective nodules, nodule index, number of pods per plant, number of seeds per pod, grain yield, straw yield and root mass of cowpea over rest of the treatments. Significant reduction in total and effective nodules per plant, plant height, nodule index, pods per plant, and grains per pod, grain and straw yield with an increase in levels of soil salinity.

Prakash (2017) conducted an experiment to study the effect of saline on germination and seedling attributes, four cultivated varieties of green gram were subjected with five levels of salinity viz., 0, 4, 8 and 12 dS m^{-1}. Genotypic variation was observed for germination and seedling characters among the varieties. The results revealed that with increase in salinity levels, greater reduction was observed for all the parameters. Germination per cent, seedling length, shoot, root and total dry matter production, seed vigour and salt tolerance index were found reduced in all the varieties studied with more reduction at higher salinity (12 dS m^{-1}) level rather than other lower salinity levels and shoot root ratio was found increased with increase in salinity.

Nivedita *et al.* (2016) tested biochemical response of *Solanum Melongena* to salinity stress in relation to stress factors. The experiment was conducted on 60 days old plants.

Four replicates were taken wherein two of the replicates were subjected to 25 mM NaCl and other two to 50 mM NaCl on every third day for duration of 10 days. The stress was found to reduce the dry and fresh weight and relative water content of the leaf tissue respectively.

Pot culture experiment was planned by Sharma and Dhanda (2015) to study mitigation of saline stress on mungbean by $CaCl_2$ treatment. It was observed that in the presence of individual NaCl and $CaCl_2$ treatment, the growth of plant was reduced with its some major changes in important stress related physiological contents (chlorophyll and carotenoids). In contrast combined treatment of NaCl and $CaCl_2$ reduced saline stress in these plants, increased their growth and yield.

Aydinşaki *et al.* (2015) carried out a study in order to determine the effects of different salinity levels (control, 1, 2, 4, 8 and 16 dS m^{-1}) on the growth, seedling development, and water use of peanut (Arachis hypogaea cv. NC-7). The study was conducted in 36 pots according to randomized block design in 6 replications. Saline water was prepared by adding NaCl, $MgCl_2$ and $CaCl_2$ into tap water. The tap water (ECi= 0.50 dS m^{-1}) was also used as control treatment. Peanut was harvested at flowering stage. Saline water less than 4 dS m^{-1} had positive effects on plant growth and development parameter while saline water more than 4 dS m^{-1} negatively affected the same crop parameters. Plant height and fresh weight decreased as much as 21.6% and 21.4%, respectively, after 4 dS m^{-1}; while root length decreased 30% after 8 dS m^{-1}, compared to control treatment. Increasing salinity caused an increase in Na concentration in leaves and roots.

Sehrawat *et al*. (2013) stated that high salt accumulation resulted in decreased osmotic potential of soil solution eliciting water stress in plants and further interactions of the salts with mineral nutrition caused nutrient imbalance and deficiencies, oxidative stress or even pathology eventually lead to plant death as a result of physiological changes, metabolic damage and growth arrest.

Ahmed (2009) conducted an experiment with 5 mungbean accessions/genotypes with the aim of ascertaining the effect of salt stress on the yield and its component. The decrease in seed yield per plant under salt stress was more pronounced, associated with a reduced number of seed per pod and 100 seed weight. Consequently salt stress was more effective

at vegetative, flowering and seed filling stages rather than seed development stage in all the five accessions/genotypes. Delayed maturity due to salt stress pushes the plant also be desiccation stress causing shrivelled seeds.

Shakil (2009) studied that the increasing salinity, decreased all the seed characteristics of economic yield that is number of pods per plant, number of seeds per pod, 100 seed weight, seed yield per plant in all the genotypes of mungbean at maturity.

Patrick *et al*. (2009) studied that four cultivars of bean (Lyamungo 90, Jesca, Flora de Mayo and CAB 19) were tested under differing NaCl concentration to assess their performance in a salt rich medium concentrations of NaCl (0, 2.5, 5.0, 10.0 mM). Results showed that higher NaCl concentrations reduced plant height, dry matter yield and also altered the leaf colour and promoted their leaf injury. The more severely affected bean cultivars were Lyamungo 90 and CAB 19 at > 5.0 mM NaCl compared to the control.

Maliro *et al*. (2008) studied that symptoms of leaf necrosis, presumably related to the destruction of chlorophyll in leaf cells resulting from ion toxicity when Na^+ and Cl^- exceed tolerable levels in tissues and the 'visual scores' of necrosis could be used as an index of resistance in chickpea.

Mohammed (2007) reduction in pigment contents may be due to the inhibitory effect of the accumulated ions (Na^+ and Cl^-) on the biosynthesis of the different pigment fractions and their degradation or due to the effect of NaCl on chloroplast structure. Earlier researchers reported salinity induced decrease in chlorophyll- a, chlorophyll- b, carotenoids and consequently photosystem II electron transport activity contents of mungbean leaf.

Mensah *et al*. (2006) carried out a study to know the effects of salinity on germination, growth and yield parameters as well as phenotypic variance and heritability of five groundnut genotypes (Ex-Dakar, RRB 12, RMP 12, RMP 91 and Esan Local). The results revealed that salinity significantly delayed germination and also reduced the final percentages at electrical conductivities greater than 2.60 mS/cm. Seedling emergence, radicle elongation, plant height and dry matter weight also tended to decrease with

increasing salinity. Agronomic characters such as number of leaves/plant and number of branches/plant were significantly reduced with salinities higher than 2.60 mS/cm

Hossain (2004) conducted an experiment to determine the effect of salinity treatments on 1000-seed weight of mungbean genotypes. He found that 1000-seed weight gradually decreased with increasing salinity.

Kumawat (2004) observed that increasing level of ECiw decreased the plant height, total number of nodul plant^{-1}, seed and straw yield and seed index of fenugreek.

Netwal (2003) reported that increasing level of soil salinity decreased the plant height, number of branches, number of pod plant^{-1}, number of seeds pod^{-1}, seed index, seed and stover yield and harvest index of cowpea.

2.9 Biofertilizer

In Asia, biofertilizer refers to the use of microorganisms to meet nutritional needs, whereas in other countries, the term microbial bio-inoculant is used (Mitter *et al.,* 2021). Biofertilizers are bio-based organic fertilizers that either could be from plant or animal sources or from living or dormant microbial cells that have the potential to improve the bioavailability and bio-accessibility of nutrient uptake in plants (Lee *et al.,* 2018; Abbey *et al.,* 2019). Bhardwaj *et al.* (2014) reported that live microbial mass is a major ingredient of biofertilizers. So biofertilizers are the preparations containing live microbes that help in enhancing soil fertility by fixing atmospheric nitrogen, solubilizing phosphorus or decomposing organic wastes or by elevating plant growth through the production of growth hormones with their biological activities" (Okur, 2018). Biofertilizers are generally applied in solid or dry forms, which are prepared after packing on suitable carriers such as clay minerals, rice bran, peat, lignite, wheat bran, humus, and wood charcoal. Carriers increase the shelf life and enable the easy handling of microbial inoculants (Bhattacharjee and Dey, 2014). The benefits of biofertilizers include low cost, enhanced nutrient availability, improved soil fertility, protect plants from soil-borne pathogens, sustainable agricultural production, enhanced biotic and abiotic stress tolerance, promote phytohormone production, improve soil health, causing

less environmental pollution, and its continued use improves the fertility of soil considerably (Chaudhary *et al*., 2021, 2022a).

2.10 Types of biofertilizers

Based on the source and raw material, global biofertilizer is marketed under two major categories like organic residue-based biofertilizer and microorganisms based biofertilizer. Green manure, crop residues, treated sewage sludge, and farmyard manure are generally organic-based biofertilizers. While on the contrary, microorganism-based biofertilizers contain beneficial microorganisms like bacteria, fungi, and algae.

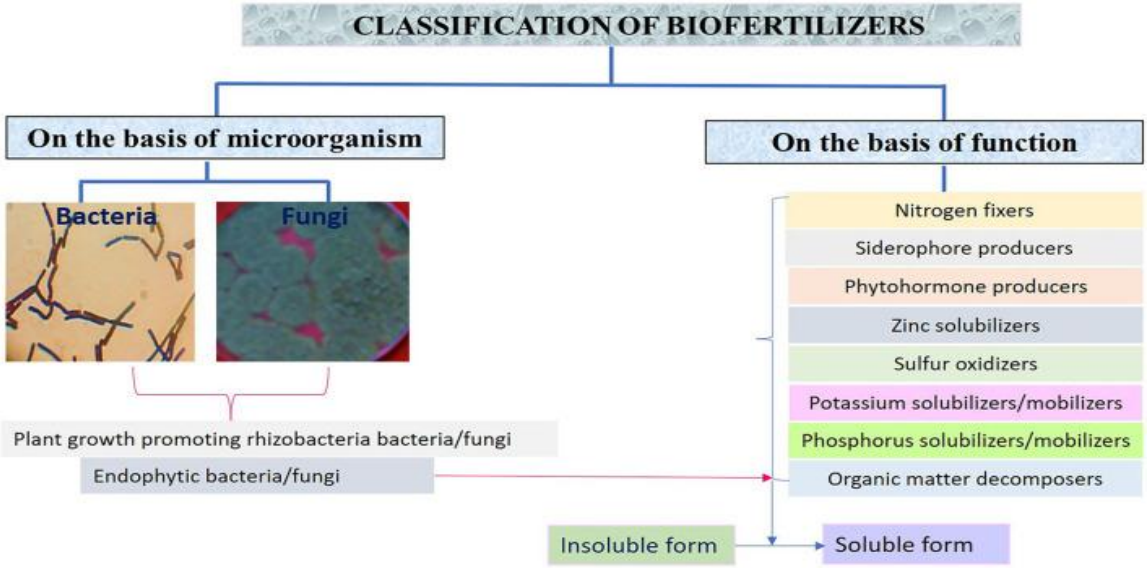


Figure 4. Types of biofertilizers on the basis of microorganism and functional characteristics

(Source : Chaudhary *et al.*, 2022)

Directly or indirectly, these biofertilizers mediate the performance of plant growth. Direct mechanisms that act upon plants directly include nitrogen fixation, phosphate solubilization, micronutrient solubilization, and the production of phytohormones (Chaudhary *et al*., 2021). The indirect mechanism generally protects the plant from the deleterious effect of the pathogens by releasing lytic enzymes, antibiotics, siderophores, and cyanide production (Mahmud *et al*., 2021).

2.11 Effect of biofertilizer on groundnut

El-Sherbeny *et al.* (2023) reported that the application of biofertilizer *Bradyrhizobium* sp. with plant residues significantly increased fresh and dry weight/m^2, pod and seed weight/plant^{-1},100-seed weight, and biological yield kg ha^{-1}, where the highest mean values of seed yield (4648 and 4529 kg ha^{-1}), oil % (52.29 and 52.21%), seed protein percentage (16.09 and 15.89%), as well as nitrogen derived from air (63.14 and 66.20%) in the first and second seasons were recorded under the application of *Bradyrhizobium* sp, respectively.

Paul and Dawson (2022)showed that seed inoculation with Trichoderma @5g/kg seed + 30cm × 15cm spacing significantly increased the growth attributes viz., plant height (46.47cm), no. of nodules/ plant (92.84), dry weight (27.56g/plant), CGR (60-90 DAS) (7.57g/m2/day), RGR (60-90 DAS) (0.017 mg $g^{-1}day^{-1}$).

Satpute *et al*. (2020) showed that the dual seed inoculation of Rhizobium spp. + PSB (Lignite based) as well as Rhizobium spp. + PSB (Liquid based) recorded the higher value of growth attributes viz., mean plant height (cm), plant spread (cm), number of branches, dry matter plant^{-1} (g), number of nodule plant^{-1} and weight of nodule plant^{-1} (g) of summer groundnut comparable to control treatment.

Dileepkumar and Singh (2019) conducted a field experiment on groundnut (*Arachis hypogaea* L.) under calcareous soil during summer 2016 at Instructional Farm, Department of Agronomy, Jawaharlal Agricultural University, Junagadh. Results of the experiment revealed that significantly higher yield attributes and yield were recorded with RDP @ 50 kg P2O5 ha^{-1} + 30 kg S ha^{-1} + phosphorous solubilizing bacteria.

Chatra *et al*. (2018) reported that groundnut fertilized with biofertilizer significantly higher pod yield (2.7 t ha^{-1}) and haulm yield (5 t ha^{-1}) was registered under seed inoculation with Rhizobium which was statistically at par with PSB.

Banu *et al.* (2017) revealed that the sources and level of sulphur as well as biofertilizer treatment significantly influenced all the yield attributing characters, pod and haulm yield. However, the sulphur applied at the rate of 40 kg ha^{-1} through gypsum with bio-

fertilizer treatment recorded an increase in pod and haulm yield over the elemental sulphur.

Sharma *et al*. (2014) observed that Rhizobium inoculation resulted in significantly higher test seed weight, protein, oil content and oil yield remained statistically at par with PSB.

Gunari *et al.* (2014) concluded that highest pod (2658 kg ha^{-1}) and haulm yield (3189 kg ha^{-1}) of groundnut obtained with the biofertilizer treatment T_3 (PPR4) which was significantly superior to control.

Kamdi *et al.* (2014) observed that application of vermicompost + Rhizobium in combination with Trichoderma seed treatment increases shelling per cent (76.40%) and oil content (43.20%).

Singh *et al.* (2013) concluded that seed inoculation with Rhizobium and PSB together significantly yielded maximum seed yield over uninoculated control.

Ravikumar *et al.* (2012) reported that the application of FYM (7.5 t ha^{-1}) + Rhizobium + PSB (10 kg each ha^{-1}) + Panchagavya spray recorded significantly recorded higher total number of pods, total number of mature pods, 100 kernel weight, shelling percentage, higher pod and haulm yields of groundnut.

Sajid *et al.* (2011) stated that the maximum number of pods (79.8 $plant^{-1}$) and maximum yield (1856 kg ha^{-1}) was observed in synthetic Rhizobium inoculated seeds.

From the results of experiment conducted by Kausale *et al*. (2009) on effect of integrated nutrient management on dry matter accumulation and yield of summer groundnut at South Gujarat condition, conformed that the dry matter per plant, pod and haulm yield of groundnut increased significantly with the application of dual inoculation of seed with *Rhizobium* + PSB.

Sethi and Adhikary (2009) observed that seed inoculation with *Rhizobium* significantly increased the pod yield of groundnut by 22 per cent over control.

2.12 Role of biofertilizers in salt stress management

Egamberdieva *et al*. (2022) reported that *Agrobacterium* and *Raoultella* showed production of IAA, HCN, and ACC under salt stress and improved growth of *Tetragonia tetragonioides* plants.

Fortt *et al*. (2022) reported that the application of PGPR (Plant-growth promoting rhizobacteria) improved the growth of lettuce under salt stress via the production of IAA and antioxidant enzymes which provide protection to plants.

Checchio *et al.* (2021) observed that *Azospirillum brasilense* improved resistance in corn plants via enhancing the production of antioxidant enzymes and glycine betaine.

Meena *et al.* (2020) reported that *Nocardioides* sp. improved seedling growth of *Triticum aestivum* under salt stress (0– 100mM) via increasing the CAT and POD genes.

Morsy *et al*. (2020) reported that the inoculation of *Penicillium* and *Ampelomyces spp*. improved drought and salinity stress tolerance in tomato plants via the production of osmolytes, stress-responsive genes, and antioxidant enzymes.

Gupta and Pandey (2019) observed that inoculation of *Paenibacillus sp*. protects and improved *Phaseolus vulgaris* plant growth under salinity stress via the production of IAA and ACC deaminase.

Ghaffari *et al*. (2018 reported that the inoculation of *Piriformospora indica* highly enhanced plant development and attenuated NaCl-induced lipid peroxidation which helps to build tolerance during salinity stress.

Zhang *et al.* (2016) showed that the inoculation of *Trichoderma longibrachiatum* T6 in wheat increased the levels of antioxidant enzymes (SOD, POD, and CAT) which helped to improve the stress tolerance in plants during salt stress.

Gond *et al.* (2015) reported that inoculation of *Pantoea agglomerans* in tropical corn under salt stress (0–100mM) improves tolerance and growth of plants due to the upregulation of aquaporins.

Qurashi and Sabri (2012) reported that the inoculation of *Planococcus rifietoensis* protects *Cicer arietinum* plants from salt stress (200mM) via EPS and biofilm production.

Waqas *et al*. (2012) reported that *Penicillium* and *Phoma glomerata* improved the rice plant growth under salinity stress via increased production of CAT, POD, and IAA. Application of *Pseudomonas* sp. improves.

Siddikee *et al*. (2011) observed that the inoculation of red pepper plant with three 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase-producing halotolerant bacteria *Brevibacterium iodinum*, *Bacillus licheniformis* and *Zhihengliuela alba* reduced ethylene production by 53, 57 and 44 %, respectively and ameliorated salt stress as evident by stimulation of plant growth.

Bano and Fatima (2009) observed that Some rhizobacteria increase production of compatible osmolytes by the inoculated plants. Increased production of proline along with decreased electrolyte leakage, maintenance of relative water content of leaves and selective uptake of K^+ ions resulted in salt tolerance in *Zea mays* coinoculated with *Rhizobium* and *Pseudomonas.*

Zhang *et al*. (2008) reported that some of the volatiles organic compounds (VOCs) emitted by PGPR down regulated hkt1 (High Affinity K^+ Transporter 1) expression in roots but upregulated it in shoots, orchestring lower Na^+ levels and recirculation of Na^+ in the whole plant under salt conditions.

Glick (2007) reported that under stress conditions, the plant hormone ethylene endogenously regulates plant homoeostasis and results in reduced root and shoot growth. In the presence of ACC deaminase producing bacteria, plant ACC is sequestered and degraded by bacterial cells to supply nitrogen and energy. Furthermore, by removing ACC, the bacteria reduce the deleterious effect of ethylene, ameliorating plant stress and promoting plant growth and yield.

Han and Lee (2005) reported that the inoculation of salt-stressed plants with PGPR strains can alleviate salinity by increasing antioxidant activity and concentration of antioxidative enzymes like glutathione reductase and ascorbate peroxidase. Combined inoculation of *Bradyrhizobium japonicum* with *Serratia proteamaculans* enhanced

antioxidant activity and concentration of proline and malondialdehyde, and also increased activity of antioxidative enzymes glutathione reductase and ascorbate peroxidase in soybean.

Ashraf *et al*. (2004) reported that the inoculation with EPS producing rhizobacteria also restricted Na^+ uptake by roots, probably caused by a reduced passive (apoplasmic) flow of Na^+ into the stele due to the higher proportion of the root zones covered with soil sheaths in inoculated treatments.

CHAPTER III

MATERIALS AND METHODS

The materials and methods used in the experiment were organized in this chapter, which includes a brief overview of the experimental location, groundnut variety, soil, climate, land preparation, experimental design, treatments, soil and plant sample collection cultural operations, and analytical methods. Here were the specifics of the research method.

3.1 Experimentation site description

3.1.1 Location

The research was carried out during the rabi season at the Sher-e-Bangla Agricultural University Farm, Sher-e-Bangla Nagar, Dhaka-1207, from January to June 2020. It is located at latitude 90.2^0N and longitude 23.5^0E. The precise location of the experimental site is depicted on a map (Appendix -I)

3.1.2 Soil

According to Bangladesh soil classification, the soil in the experimental field was from the Tejgaon series of AEZ No. 28, Madhupur Tract and was classified as Shallow Red Brown Terrace Soils. A composite sample was prepared prior to the experiment by collecting dirt from various locations across the field at depths ranging from 0 to 15 cm. Before testing for physical and chemical properties, the soil was air-dried, crushed, and sieved through a 2 mm sieve. Appendix II describes some of the soil's early physical and chemical characteristics.

3.2 Climatic condition

The experimental site's climate is subtropical, with three distinct seasons: the monsoon season from November to February, the pre-monsoon period or hot season from March to April, and the monsoon season from May to October. Appendix III shows the monthly average temperature, humidity, and rainfall during the crop growing season as collected from Weather Yard, Bangladesh Meteorological Department.

3.3 Experimental materials

3.3.1 Plant material

Binachinabadam-1 was used as the plant material for conducting the experiment. The important characteristics of these varieties are mentioned below:

Released: 2000

Developed: Bangladesh Institute of Nuclear Agriculture (BINA)

Plant height: Plants are dwarf

Leaves: Leaves are darker green, ovate shape with waxy layers

Resistant :Resistant to collar rot, *Cercospora* leaf spot and rust diseases.

Protein content: 28% %

Oil content: 47%

3.3.2 Earthen pot

Earthen pots of having 12 inches diameter and 12 inches height were used.

3.4 Experimental treatment

There were two factors in the experiment namely different salt stress termed as S and application of different microbial biofertilizer termed as B are mentioned below:

Factor A: Application of biofertilizer with 4 levels as

B_0 = Control

B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)

B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)

B_3 = *Mycorrhiza*

Factor B: Different salt concentration with 4 levels as

S_0 = Control

S_1= 50 mM NaCl

S_2 = 100 mM NaCl and

S_3 = 150 mM NaCl

3.5 Experimental design

The experiment was laid out in Randomized Complete BlockDesign (RCBD) with 2 factor and four replications. Total 64 unit pots were made for the experiment with 16 treatments.

3.6 Detail of experimental procedure

3.6.1 Seed collection

Seeds of Binachinabadam 1 were collected from Bangladesh Institute of Nuclear Agriculture (BINA).

3.6.2 Soil preparation for pot

Soil was collected, sun-dried, and crushed to create well-pulverized and healthy soil for the experiment. After that, the prepared soil was fertilized with the recommended dose of organic manures (Biofertilizer) and inorganic fertilizers. Furadan®5 G was added to the soil at the recommended dose in addition to the fertilizers to protect the seedlings from insects, mites, and nematodes. Each pot was filled with 10 kg of finely ground soil that contained fertilizers, insecticide, and manures.

Plate 1. Pot filled with soil

3.6.3 Fertilizer application

Fertilizer and manure dose for Binachinabadam 1 as follows:

Fertilizers	Dose (kg ha^{-1})
Cowdung	5000
Urea	25
Triple superphosphate	160
Muriate of potash	85
Gypsum	300
Boric acid	10

All fertilizers and manures were incorporated during final soil preparation

3.7 Seed treatment

As per our treatments, groundnut seeds were treated with moist biofertilizer for sowing.

3.8 Seed sowing technique

Before seed sowing, pot soil was irrigated with adequate amount of water to achieve the field capacity of soil for seed sowing. Following that, three healthy seeds were sown at a depth of 5 cm in each pot. The seeds were sown on January 31, 2020.

3.9 Intercultural operations

i) Gap filling and thinning

Gap filling and thinning was done at 7 DAS to maintain the uniform plant density in each pot.

ii) Weeding, mulching and irrigation

Regular observation and hand weeding kept the pots weed-free. Mulching and irrigation applications were done when needed.

iii) Application of NaCl

The salinity treatments were induced after establishment of seedlings. Four levels of NaCl were added on pot as per treatments in three equal instalments at 30, 35 and 40 DAS. The salinity was developed by adding respected amount of commercial NaCl solution. In order to induced salinity, 1 L salt solutions were prepared for each level of salinity and added in respective pot at 30 DAS. The same amount of salt solutions was

added at 35 and 40 DAS. So, for each level of salinity total 3 L salt solutions were added in respective pot. Three litre tap water was added for 0 mM NaCl in respective pot on specified date. Finally, 0, 8.77, 17.53 and 26.29 g NaCl were added in each pot to developed 0, 50, 100 and 150 mM salinity, respectively.

3.10 General observations of the experimental field

Regular observations were made to see the growth and visual differences of the crops. Incidence of white fly, ants were observed during vegetative growth stage and there were also some mites were present in the experimental pot. The flowering was not uniform.

3.11 Plant protection

The groundnut was sprayed with chloropyriphos to control insect-pests particularly white flies (*Bemisia tabaci),* the vector for yellow mosaic virus. Single spray was carried out as and when early symptoms of white flies were noticed.

3.12 Harvesting

Following the observation of some maturity indices such as leaf yellowing, leaf spots, pod hardening and toughening, and dark tannin discoloration inside the shell, then the crops were harvested from each pot. The harvested crops were tied into bundles according to treatments and carried to the threshing floor. The pods were then separated from the plants. The separated pods and stover were sun dried by spreading them on the threshing floor. The seeds were separated from the pod and dried in the sun for 3 to 5 days towards to achieving safe seed moisture (8%). Harvesting was completed on June 19, 2020 wherethe age of plants were 140 days.

3.13 Collection of data

The yield and yield contributing parameters were measured at harvest. Growth, and physiological parameters were recorded on specific date. Data were collected on the following parameters:

Crop growth parameters:

i. Plant height
ii. Number of branches plant^{-1}
iii. Number of leaves plant^{-1}

Physiological parameters:

iv. Leaf relative water content (LRWC)

Yield and yield contributing parameters:

v. Number of pods pot^{-1}
vi. Number of true pods pot^{-1}
vii. Number of seeds pot^{-1}
viii. 100-seed weight
ix. Seed yield pot^{-1}
x. Stover yield pot^{-1}

3.14 Procedure of recording data

i. Plant height (cm)

The height of the selected plant was measured from the ground level to the tip of the plant at 30, 50, 70, 90 DAS and at harvest respectively. Mean plant height of groundnut plant were calculated and expressed in cm.

ii. Number of branches plant^{-1}

The number of branches plants^{-1} from the each replicated was counted 50, 70, 90 DAS and at harvest respectively. The average was calculated and expressed as number of branches plant^{-1}.

iii. Number of leaves plant^{-1}

The number of leaves plants^{-1} from the each replicated was counted 30, 50, 70, 90 DAS and at harvest respectively. The average was calculated and expressed as number of leaves plant^{-1}.

iv. Leaf relative water content (LRWC)

Three leaflets were randomly selected from each pot and cut with scissors. Leaf relative water content (RWC) was measured according to Barrs and Weatherley (1962). Leaf relative water content was measured at 50 DAT. Leaf laminas were weighed (fresh weight, FW) and then immediately floated on distilled water in a petridish for 4 h in the dark. Turgid weights (TW) were obtained after drying excess surface water with paper towels. Dry weights (DW) were measured after drying at 80^0C for 48 h. Then calculation was done using the following formula:

$$\text{LRWC}\ (\%) = \frac{\text{FW- DW}}{\text{TW-DW}} \times 100$$

v. Number of pods pot^{-1}

Number of pods pot^{-1} was counted from all plants of each pot to find out the average pods number pot^{-1}.

vi. Number of true pods pot^{-1}

Number of true pods pot^{-1} was counted from the all plants of each pot to find out the average true pods number pot^{-1}.

vii. Number of seeds pot^{-1}

Number of seeds pot^{-1}was counted from the from the all plants of each pot to find outthe average number of seeds pot^{-1}.

viii. 100-seed weight (g)

100-seeds were counted which were taken from the seed stock of each pot, then weighed it in an electrical balance and data were recorded.

viii) Seed yield (g pot^{-1})

Seed yield was calculated from shelled, cleaned and well dried pod collected from each pot and expressed as g pot^{-1} on 8 % moisture basis.

ix) Stover yield (g pot^{-1})

Stover from the eat pot were sun-dried to constant weight and yield was recorded. The Stover yield pot^{-1} was calculated and expressed in g pot^{-1}.

3.15 Data analysis technique

The collected data were compiled and analysed statistically using the analysis of variance (ANOVA) technique with the help of a computer package program IBM SPSS Statistics software and the mean values were separated using Duncan Multiple Range Test (DMRT) at 5% level of significance.

CHAPTER IV

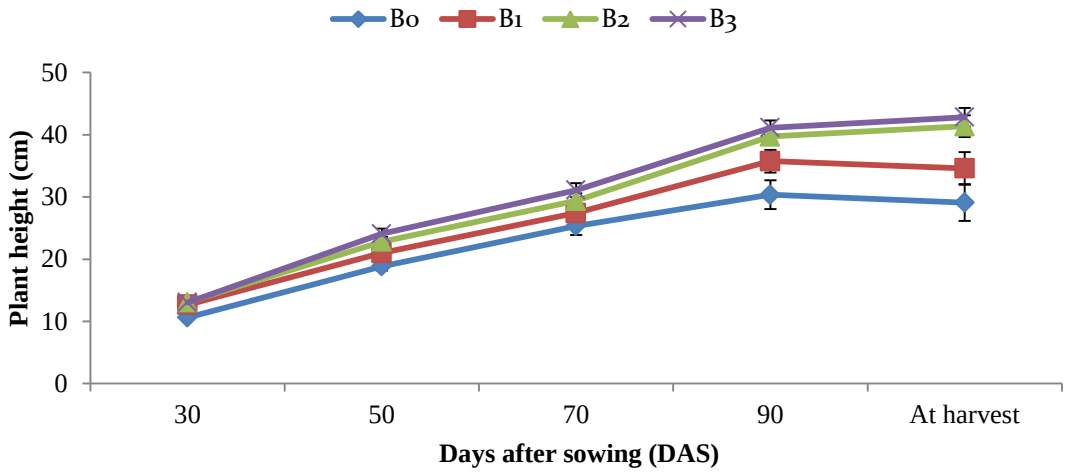
RESULTS AND DISCUSSION

Results obtained from the present study have been presented and discussed in this chapter with a view to study the management of salt stress in groundnut by utilization of Bio-fertilizer. The data are given in different tables and figures. The results have been discussed, and possible interpretations are given under the following headings.

4.1 Plant height (cm)

Effect of biofertilizer

Plant height is an essential character of the vegetative stage of the crop plant and indirectly impacts on yield (El-Sherbeny *et al.*, 2023). The present study revealed that the application of biofertilizer significantly influenced the plant height of groundnut at different days after sowing (DAS) (Figure 5). AT 30 DAS , the highest plant height (13.08 cm) was observed in B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatment which gave 22.95 % higher growth of plant height compared to control treatment that was statistically similar with B_3 (13.04 cm) and B_2 (12.68 cm) treatment. The lowest plant height (10.64 cm) was observed in control treatment (B_0). At 50, 70, 90 DAS and at harvest, the highest plant height (24.09, 31.1, 41.13 and 42.82 cm, respectively) was observed in B_3 (*Mycorrhiza*) treatment which were 29.72, 22.72,35.43 and 32.02% higher compared to control treatment. The use of biofertilizers improves soil fertility by fixing atmospheric nitrogen, solubilizing insoluble phosphates, producing plant growth-promoting substances in the soil and promoting nodulation ability, which increases nutrient absorption by plant that resulted increased plant height. Similar result was observed by Paul and Dawson (2022) who showed that groundnut seed inoculation with Trichoderma @5g/kg seed + 30cm × 15cm significantly increased the plant height (46.47cm) of groundnut.

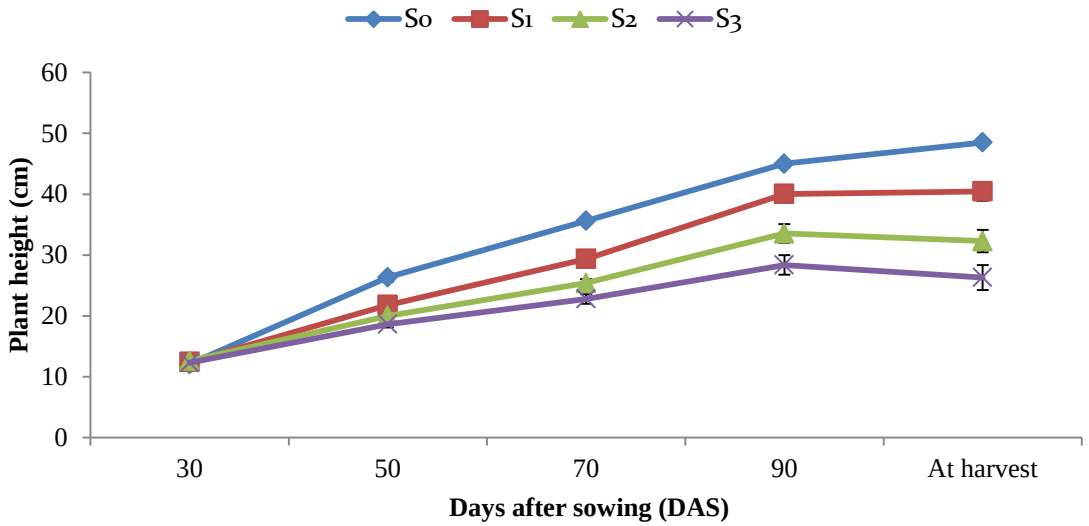


Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 5. Effect of biofertilizer on plant height at different days after sowing of groundnut

Effect of salt stress

Exposure of salinity had significant impact on plant height of groundnut at 50, 70, 90 DAS and at harvest (Figure 6). At 50, 70, 90 DAS and at harvest the highest plant height (26.34, 35.64, 45.01 and 48.51 cm, respectively) was observed in S_0 treatment and the lowest plant height (18.64, 22.80, 28.38 and 26.33 cm, respectively) was observed in S_3 (150 mM NaCl) treatment. Application of 150 mM NaCl decreased plant height by 32.99, 36.02, 36.94 and 45.72 % at 50, 70 and 90 DAS and at harvest, respectively, compared to control. Gradual decrease in plant height might be due to the nutrient unavailability caused by increased salinity or the inhibition of cell division or cell enlargement. The result obtained from the present study was similar with the findings of Aydinşaki *et al.* (2015) who reported that plant height of peanut decreased with the increment of salinity levels.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 6. Effect of salt stress on plant height at different days after sowing of groundnut

Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly affected plant height of groundnut at 30, 50, 70, 90 DAS and at harvest (Table 1). Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased plant height by 16, 41 and 42% respectively, compared with salt treated control (B_0S_1). Similarly, biofertilizer application increased plant height throughout the growth period under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased plant height at 50 (15, 28 and 33%, respectively), 70 (22, 31 and 43%, respectively), 90 (35, 70 and 100% respectively) DAS and at harvest (37, 101, and 123% respectively). Fortt *et al*. (2022) reported that the application of PGPR improved the growth of lettuce under salt stress via the production of IAA and antioxidant enzymes which provide protection to plants.

Table 1. Combined effect of biofertilizer and salt stress on plant height at different days after sowing of groundnut

Treatment combinations	30 DAS	50 DAS	70 DAS	90 DAS	At harvest
B_0S_0	10.63±0.43 b	22.17±0.68 de	32.96±0.62 c	42.10±0.67 b	46.10±0.70 b
B_0S_1	10.45±0.32 b	19.94±0.94 f	27.37±0.36 e-g	35.62±0.45 ef	32.62±0.52 e
B_0S_2	10.80±0.63 b	17.70±0.41 g	22.62±0.48 i	24.34±0.95 i	21.84±0.73 g
B_0S_3	10.70±0.40 b	15.68±0.51 h	18.37±0.39 j	19.42±0.59 j	15.92±0.68 h
B_1S_0	12.20±0.34 a	26.70±0.39 b	35.45±0.55 b	45.08±0.74 a	48.83±0.61 a
B_1S_1	12.80±0.40 a	20.81±0.55 ef	28.02±0.30 ef	38.88±0.62 cd	37.93±0.73 c
B_1S_2	13.10±0.44 a	18.46±0.47 g	23.75±0.35 hi	32.83±0.67 h	29.83±0.69 f
B_1S_3	12.63±0.43 a	18.02±0.74 g	22.47±0.42 i	26.22±0.58 i	21.74±0.64 g
B_2S_0	12.75±0.46 a	27.38±0.55 b	36.65±0.59 ab	45.83±0.76 a	49.08±0.52 a
B_2S_1	13.25±0.32 a	22.51±0.44cd	29.99±0.50 d	42.68±0.49 b	46.18±0.76 b
B_2S_2	13.28±0.37 a	21.43±0.35 d-f	26.76±0.21 fg	37.42±0.52 de	38.17±0.43 c
B_2S_3	13.05±0.33 a	20.01±0.17 f	24.10±0.40 h	33.01±0.79 gh	32.01±0.51 e
B_3S_0	12.83±0.12 a	29.11±0.41 a	37.52±0.54 a	47.02±0.54 a	50.02±0.55 a
B_3S_1	13.20±0.18 a	23.91±0.31 c	32.11±0.44 c	43.05±0.75 b	46.30±0.86 b
B_3S_2	13.33±0.39 a	22.49±0.23 cd	28.51±0.51 e	39.58±0.50 c	39.33±0.39 c
B_3S_3	12.80±0.36 a	20.86±0.42 ef	26.25±0.70 g	34.89±0.82 fg	35.64±0.65 d
Significance (P)	**	**	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

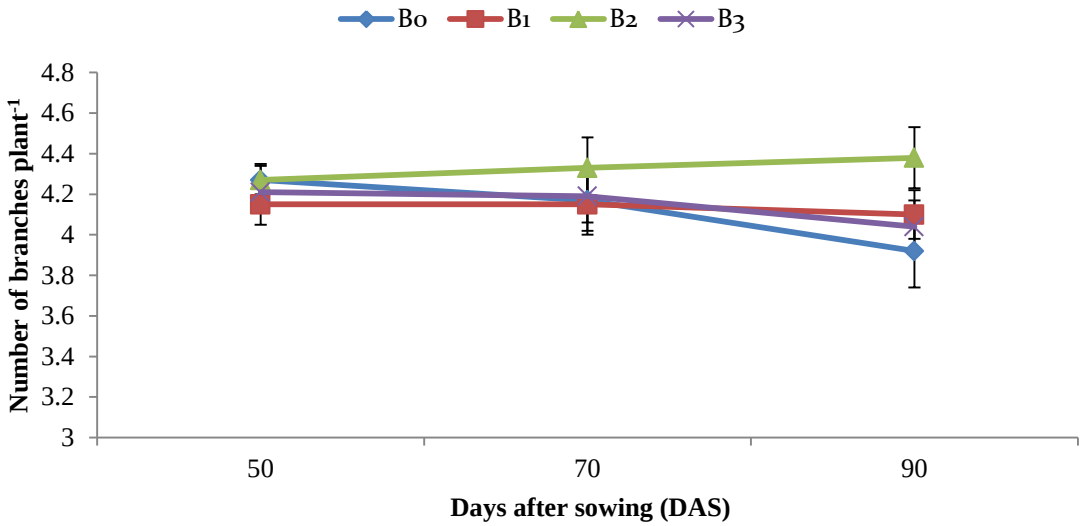
B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

4.2 Number of branches plant^{-1}

Effect of biofertilizer

Application of biofertilizer had no impact on number of branches plant^{-1} of groundnut (Figure 7). Experimental result showed that the highest number of branches plant^{-1} of groundnut (4.27, 4.33 and 4.38) was observed in B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatmentat 50, 70 and at 90 DAS . The lowest number of branches plant^{-1} of groundnut at 50 and 70 DAS (4.15 and 4.15) was observed in B_1 (BARI Rhizobium RAh-803: Salt sensitive**)** treatment. At 90 DAS , the lowest number of branches plant^{-1} of groundnut (3.92) was observed in B_0 treatment.

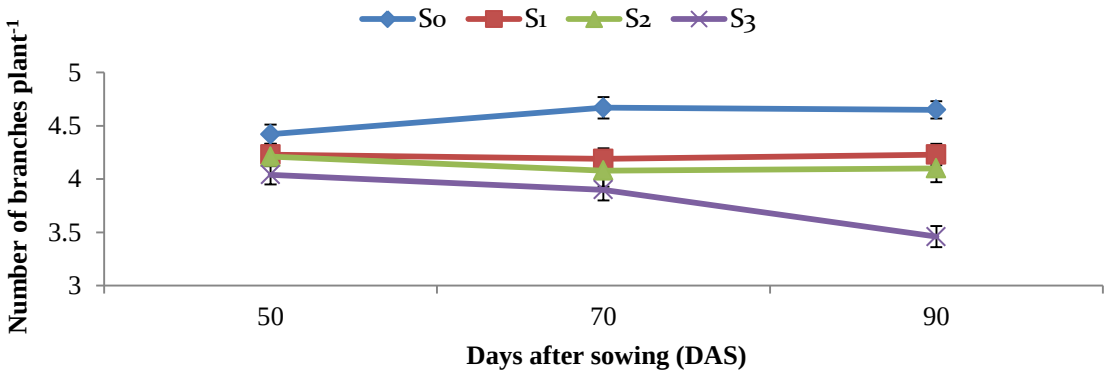


Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 7. Effect of biofertilizer on number of branches plant^{-1}at different days after planting of groundnut

Effect of salt stress

Number of branches plant^{-1} of groundnut was significantly affected by salinity at 50, 70, and 90 DAS (Figure 8). At 50, 70 and 90 DAS , the highest number of branches plant^{-1} (4.42, 4.67 and 4.65) was observed in control treatment (S_0) and the lowest number of branches plant^{-1} (4.04, 3.90 and 3.46) was observed in S_3 treatment. Application of 150 mM NaCl decreased the number of branches plant^{-1} of groundnut by 9, 16 and 26 % at 50, 70 and 90 DAS compared to control. Our results were similar with the findings of Mensah *et al.* (2006) who reported that agronomic characters of groundnut such as number of leaves plant^{-1} and number of branches plant^{-1} were significantly reduced with salinities higher than 2.60 mS/cm.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 8. Effect of salt stress on number of branches plant^{-1} at different days after planting of groundnut

Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly affected the number of branches plant^{-1} of groundnut at 70 and 90 DAS (Table 1). At 30 DAS the highest number of branches plant^{-1}of groundnut (4.50) was observed in B_2S_0 treatment combination while the lowest number of branches plant^{-1}of groundnut (3.92) was observed in B_1S_3 treatment combination. At 70 and 90 DAS respectively the highest number of branches plant^{-1}of groundnut (4.75 and 4.75) was observed in B_2S_0 treatment combination while the lowest number of branches plant^{-1}of groundnut (3.75 and 3.08) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased the number of branches plant^{-1} by 2,12 and 0.2% respectively, compared with salt treated control (B_0S_1) at 90 DAS . Similarly, biofertilizer application increased number of branches plant^{-1} throughout the growth period under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased number of branches plant^{-1} by 16, 19 and 13% respectively at 90 DAS . Fortt *et al*. (2022) reported that the application of PGPR improved the growth of lettuce under salt stress via the production of IAA and antioxidant enzymes which provide protection to plants.

Table 2. Combined effect of biofertilizer and salt stress on number of branches plant^{-1} at different days after sowing of groundnut

Treatment combinations	50 DAS	70 DAS	90 DAS
B_0S_0	4.33±0.24	4.59±0.21 a-c	4.67±0.24 ab
B_0S_1	4.25±0.08	4.25±0.32 a-c	4.08±0.16 a-d
B_0S_2	4.25±0.025	4.09±0.34 a-c	3.84±0.35 cd
B_0S_3	4.25±0.08	3.75±0.25 c	3.08±0.08 e
B_1S_0	4.50±0.22	4.67±0.24 ab	4.67±0.14 ab
B_1S_1	4.00±0.05	4.08±0.16 a-c	4.17±0.10 a-d
B_1S_2	4.17±0.17	4.00±0.41 a-c	4.00±0.19 b-d
B_1S_3	3.92±0.25	3.83±0.21 bc	3.58±0.16 de
B_2S_0	4.50±0.17	4.75±0.28 a	4.75±0.08 a
B_2S_1	4.33±0.41	4.25±0.16 a-c	4.58±0.25 ab
B_2S_2	4.25±0.16	4.17±0.29 a-c	4.50±0.29 a-c
B_2S_3	4.00±0.24	4.17±0.21 a-c	3.67±0.24 de
B_3S_0	4.33±0.14	4.67±0.14 ab	4.50±0.17 a-c
B_3S_1	4.33±0.14	4.17±0.21 a-c	4.09±0.21 a-d
B_3S_2	4.17±0.17	4.08±0.29 a-c	4.09±0.21 a-d
B_3S_3	4.00±0.13	3.84±0.10 bc	3.50±0.22 de
Significance (*P*)	NS	*	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

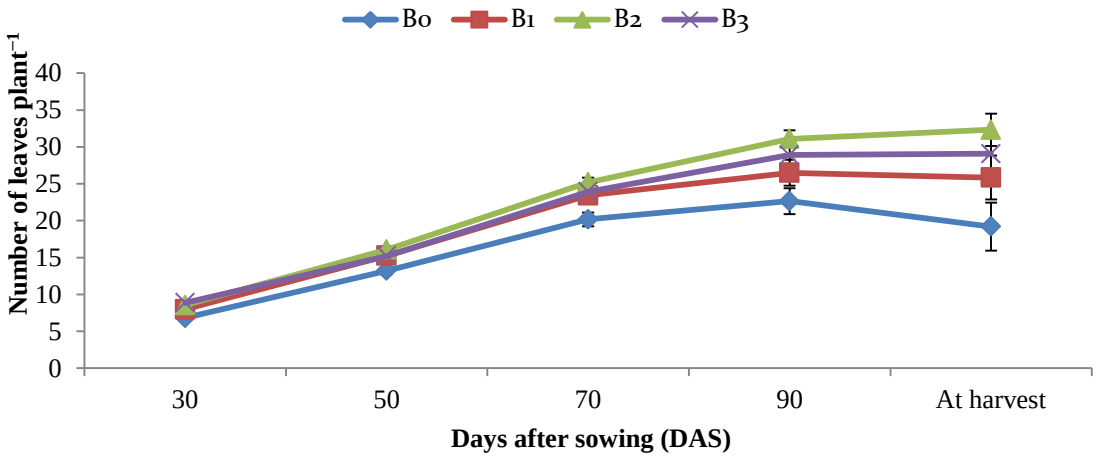
S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

4.3 Number of leaves plant^{-1}

Effect of biofertilizer

Number of leaves plant^{-1} of groundnut varied significantly at different days after sowing due to biofertilizer application (Figure 9). The result revealed that at 30 DAS the highest number of leaves plant^{-1} (8.88) was observed in B_3 (*Mycorrhiza)* treatment which gave 30.39 % higher number of leaves plant^{-1} comparable to control treatment and it was statistically similar with B_2 (8.56) treatment. while the lowest number of leaves plant^{-1} (6.81) was observed in B_0 (control) treatment. At 50, 70, 90 DAS and at harvest, the highest number of leaves plant^{-1} (16.08, 25.19, 31.10 and 32.33) was observed in B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatment which were 21.72, 24.89, 37.30 and 68.29 % higher number of leaves plant^{-1} compared to control treatment while the lowest

number of leaves plant^{-1} (13.21, 20.17, 22.65 and 19.21) was observed in control (B_0) treatment. The reason for the increase in vegetative growth (leaf number) in plants treated with biofertilizer may be due to the ability of the bacterial inoculation to dissolve the precipitated phosphate compounds and release them to any soil solution available H_2PO_4 and HPO_4^{-2} by lowering the soil pH then it leads to increased absorption of nutrients thereby increased vegetative growth of the plant. The result was similar with the findings of Paul and Dawson (2022) showed that seed inoculation with biofertilizer gave the highest values of number of leaves plant^{-1} of groundnut.



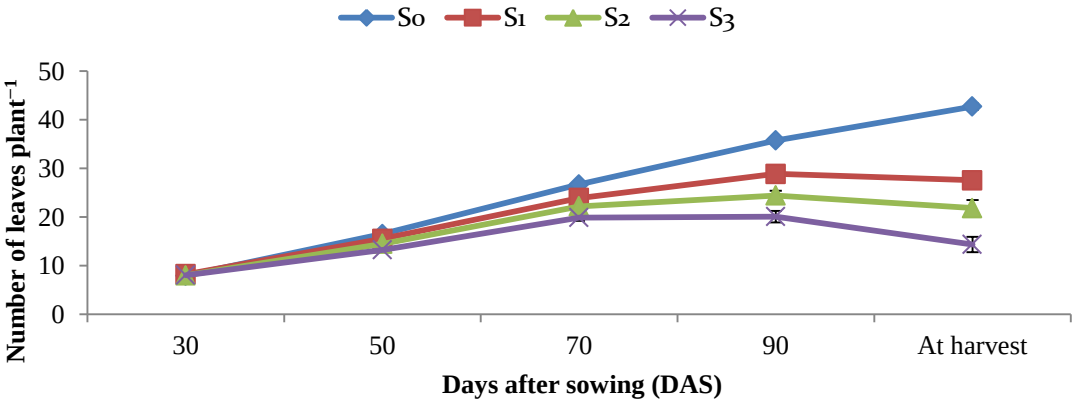
Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 9. Effect of biofertilizer on number of leaves plant^{-1} at different days after planting of groundnut

Effect of salt stress

Exposure of salinity had significant impact on number of leaves plant^{-1} of groundnut at 50, 70, 90 DAS and at harvest (Figure 6). At 30 DAS different salinity treatment had shown non significant effect on number of leaves plant^{-1} of groundnut and the highest number of leaves plant^{-1} of groundnut at 30 DAS (8.25) was observed in S_1 treatment, while the lowest number of leaves plant^{-1} of groundnut (7.94) was observed in control treatment (S_0). At 50, 70, 90 and at harvest respectively the highest number of leaves plant^{-1} (16.50, 26.71, 35.75 and 42.73) was observed in S_0 treatment which was

statistically similar with S_1 (15.50) treatment at 70 DAS . The lowest number of leaves plant^{-1} (13.25, 19.90, 20.08 and 14.35) was observed in S_3 treatment. Application of 150 mM NaCl decreased number of leaves plant^{-1} by 32. 13.25, 19.90, 20.08 and 14.35 % at 50, 70, 90 DAS and at harvest, respectively, compared to control. Gradual decrease in number of leaves plant^{-1} might be due to the nutrient unavailability caused by increased salinity or the inhibition of cell division or cell enlargement. The result obtained from the present study was similar with the findings of Mensah *et al*. (2006) who reported that in groundnut agronomic characters such as number of leaves/plant and number of branches/plant were significantly reduced with salinities higher than 2.60 mS/cm



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 10. Effect of salt stress on number of leaves plant^{-1}at different days after planting of groundnut

Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly affected number of leaves plant^{-1} of groundnut at 30, 50, 70, 90 DAS and at harvest (Table 3). At 30 DAS the highest number of leaves plant^{-1} of groundnut (9.50) was observed in B_3S_1 treatment combination while the lowest number of leaves plant^{-1} of groundnut (6.50) was observed in B_0S_3 treatment. At 50 and 70 DAS the highest number of leaves plant^{-1} of groundnut (17.42 and 28.08) was observed in B_1S_0 treatment combination. at 90 DAS the highest number of leaves plant^{-1} of groundnut (37.42) was observed in B_2S_0 treatment combination. At harvest respectively the highest number of leaves plant^{-1} of groundnut

(44.67) was observed in B_1S_0 treatment combination. While the lowest number of leaves plant^{-1} of groundnut (11.17, 15.67,13.83 and 5.09) at 50,70, 90 DAS and at harvest respectively was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased number of leaves plant^{-1} by 18, 29 and 40% respectively, compared with salt treated control (B_0S_1) at 30 DAS . Similarly, biofertilizer application increased number of leaves plant^{-1} throughout the growth period under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased number of leaves plant^{-1} by 176, 315 and 235 % respectively at harvest. Zhang *et al.* (2016) showed that the inoculation of *Trichoderma longibrachiatum* in wheat increased the levels of antioxidant enzymes (SOD, POD, and CAT) which helped to improve the stress tolerance in plants during salt stress.

Table 3. Combined effect of biofertilizer and salt stress on number of leaves plant^{-1} at different days after sowing of groundnut

Treatment combinations	30 DAS	50 DAS	70 DAS	90 DAS	At harvest
B_0S_0	6.75±0.48 cd	14.92±0.96 b-e	24.00±0.78 c-f	32.00±0.69 b	38.67±0.49 c
B_0S_1	6.75±0.49 cd	14.17±0.65 c-f	22.83±0.62 e-g	25.50±0.62 d	20.83±0.52 h
B_0S_2	7.25±0.25 bcd	12.58±0.37 fg	18.17±0.91 i	19.25±0.37 g	12.25±0.46 k
B_0S_3	6.50±0.65 d	11.17±0.29 g	15.67±0.56 j	13.83±0.61 h	5.09±0.57 l
B_1S_0	7.75±0.48 bcd	17.42±0.52 a	28.08±0.44 a	37.00±0.43 a	44.67±0.49 a
B_1S_1	8.00±0.41 abcd	15.67±0.69 a-d	23.08±0.42 d-g	26.59±0.57 d	24.08±0.60 g
B_1S_2	7.75±0.48 bcd	14.75±0.94 b-e	22.67±0.49 fg	23.50±0.52 e	20.58±0.37 h
B_1S_3	8.50±0.65 ab	13.17±0.62 e-g	19.92±0.42 h	18.92±0.71 g	14.08±0.80 j
B_2S_0	8.75±0.48 ab	17.33±0.95 a	28.58±0.44 a	37.42±0.42 a	44.42±0.46 ab
B_2S_1	8.75±0.48 ab	16.58±0.80 ab	25.25±0.37 bc	32.25±0.28 b	34.50±0.57 d
B_2S_2	8.25±0.48 abc	15.75±0.60 a-d	24.67±0.59 b-d	28.92±0.31 c	29.25±0.34 f
B_2S_3	8.50±0.29 ab	14.67±0.62 b-f	22.25±0.46 fg	25.83±0.70 d	21.17±0.44 h
B_3S_0	8.50±0.65 ab	16.33±0.68 a-c	26.17±0.55 b	36.59±0.77 a	43.17±0.40 b
B_3S_1	9.50±0.65 a	15.58±0.44 a-d	24.50±0.44 b-e	31.17±0.35 b	30.83±0.21 e
B_3S_2	8.75±0.48 ab	14.92±0.69 b-e	23.34±0.45 d-g	26.08±0.55 d	25.25±0.44 g
B_3S_3	8.75±0.48 ab	14.00±0.43 d-f	21.75±0.64 g	21.75±0.71 f	17.08±0.50 i
Significance (*P*)	**	**	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

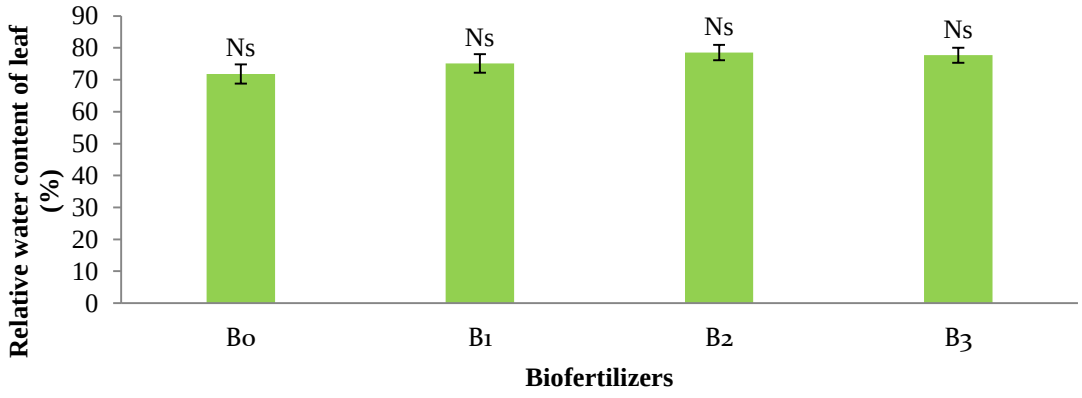
B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

4.4 Relative water content of leaf (%)

Effect of biofertilizer

Biofertilizer application had shown non significant effect on relative water content of groundnut leaf (Figure 11). Experimental result showed that the highest leaf relative water content (78.52 %) was observed in B_2 (BARI Rhizobium R_{Ah}-808: Salt tolerant) while the lowest leaf relative water content (71.83 %) was observed in B_0 treatment.



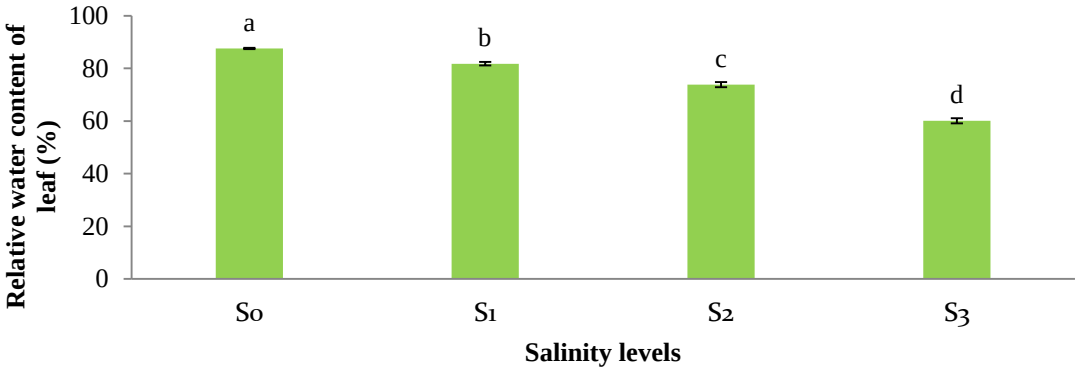
Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza.*

Figure 11. Effect of biofertilizer on relative water content of groundnut leaf

Effect of salt stress

Exposure to various salinity levels had shown significant impact on the relative water content of groundnut leaves. (Figure 12). The result showed that the highest leaf relative water content (87.57%) was observed in S_0 while the lowest leaf relative water content (60.11 %) was observed in S_3 (150 mM NaCl) treatment. Application of 150 mM NaCl decreased relative water content of groundnut leaves by 31.36 % compared to control. Relative water content is described as the amount of water in a leaf at the time of sampling relative to the maximal water a leaf can hold. It is an important parameter in water relation studies, e.g. it allows the calculation of the osmotic potential at full turgor (Hasan *et al*. (2017). With the increasing salinity levels the relative water content of groundnut leaf was drastically reduced. Nivedita *et al.* (2016) reported that reported that a

decrease in RWC indicates a loss of turgor that results in limited water availability for cell extension processes.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 12. Effect of salt stress on relative water content of groundnut leaf

Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly affected relative water content of groundnut leaf (Table 4). The highest leaf relative water content (88.19 %) was observed in B_2S_0 treatment combination which was statistically similar with B_1S_0 (88.19 %) treatment combination. While the lowest leaf relative water content (55.02 %) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased relative water content of groundnut leaf by 13, 8 and 7% respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased leaf relative water content under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased leaf relative water by 5, 16 and 5 % compared with salt treated control (B_0S_3) treatment. Bano and Fatima (2009) observed that some rhizobacteria increase production of compatible osmolytes by the inoculated plants. Increased production of proline along with decreased electrolyte leakage, maintenance of relative water content of leaves and selective uptake of K+ ions resulted in salt tolerance in *Zea mays* coinoculated with *Rhizobium* and *Pseudomonas.*

Table 4. Combined effect of biofertilizer and salt stress on relative water content of groundnut leaf

Treatment combinations	Relative water content of leaf (%)
B_0S_0	86.52±0.47 b
B_0S_1	77.78±0.32 e
B_0S_2	68.00±0.52 g
B_0S_3	55.02±0.23 j
B_1S_0	88.19±0.59 a
B_1S_1	81.36±0.36 d
B_1S_2	72.93±0.27 f
B_1S_3	58.09±0.28 i
B_2S_0	88.35±0.42 a
B_2S_1	84.35±0.46 c
B_2S_2	77.37±0.43 e
B_2S_3	64.01±0.31 h
B_3S_0	87.22±0.38 ab
B_3S_1	83.52±0.35 c
B_3S_2	76.79±0.29 e
B_3S_3	63.30±0.49h
Significance (*P*)	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

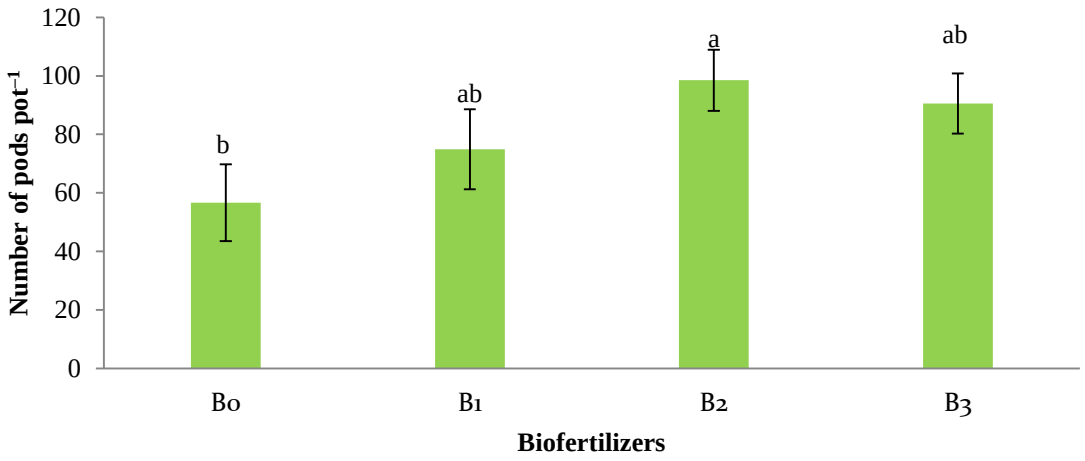
B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

4.5 Number of pods pot^{-1}

Effect of biofertilizer

Number of pods pot^{-1} of groundnut was significantly influenced due to biofertilizer application (Figure 13). The result showed that the highest number of pods pot^{-1} (98.50) was observed in B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatment, while the lowest number of pods pot^{-1} (56.69) was observed in B_0 treatment. Biofertilizers helps plant in better root proliferation, which facilitate more uptake of nutrients and water, higher leaf number and more area responsible for effective photosynthesis and enhanced food accumulation result in increased pod number of groundnut.Valetti *et al.* (2016) reported that biofertilizer inoculation increased peanut pod number and seed yield compared to non-inoculated treatment.

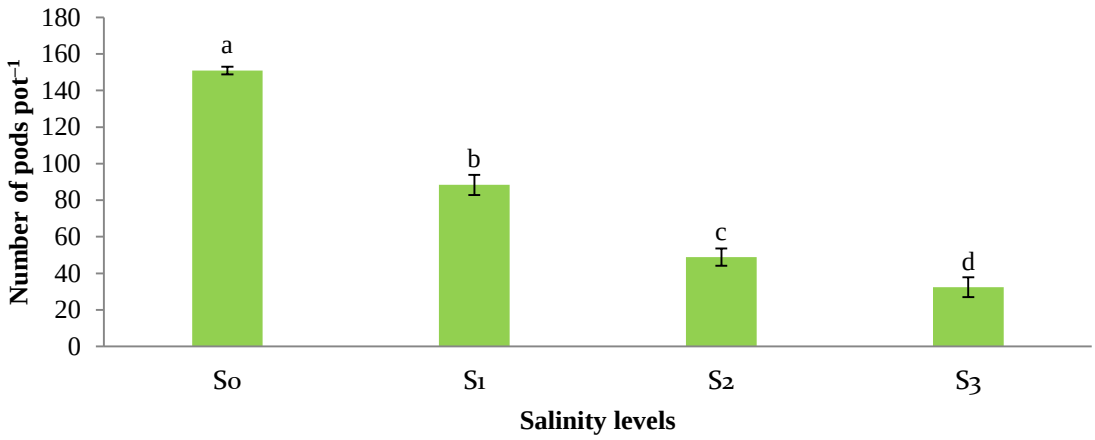


Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 13. Effect of biofertilizer on number of pods pot^{-1}of groundnut

Effect of salt stress

Exposure to various salinity levels had shown significant impact on the number of pods pot^{-1} of groundnut. (Figure 12). The result showed that the highest pods number pot^{-1}of groundnut (150.94) was observed in control treatment (S_0) while the lowest pods number pot^{-1}of groundnut (32.44) was observed in S_3 treatment. Application of 150 mM NaCl decreased number of pods pot^{-1} of groundnut by 78.50 % compared to control. Decreased number of pods pot^{-1} of groundnut was directly related to groundnut leaf chlorophyll content and photosynthesis activities. Under salt stress conditions, osmotic stress and ion imbalance create high Na+ and Cl- concentration in soil and plant tissues result in decreased pod number of groundnut compared to control treatment.The result obtained from the present study was similar with the findings of Aechra *et al*. (2017) who reported significant reduction pods per plant with an increase in levels of soil salinity.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 14. Effect of salt stress on number of pods pot^{-1}of groundnut

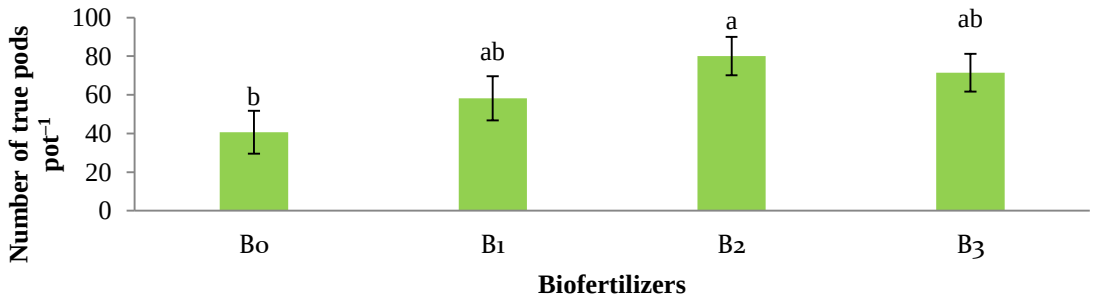
Combined effect of biofertilizer and salt stress

Application of biofertilizer in combination with various salinity levels, significantly influenced the number of groundnut pods in pot^{-1} (Table 5). The result showed that the highest number of pods pot^{-1} of groundnut (157.75) was observed in B_2S_0 treatment combination which was statistically similar with B_1S_0 (154.50) and B_3S_0 (151.75) treatment combination. While the lowest number of pods pot^{-1} of groundnut (9.00) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut pods by 58, 102 and 78% respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased pods number under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased pods number by 66, 513 and 472 % compared with salt treated control (B_0S_3) treatment.

4.6 Number of true pods pot^{-1}

Effect of biofertilizer

The application of biofertilizer had shown significant effect on the number of true pods pot^{-1} of groundnut (Figure 15). The highest number of true pods pot^{-1} (80.06) was observed in the B_2 (BARI Rhizobium RA$_h$-808: Salt tolerant) treatment, which was statistically similar to the B_1 (58.25) and B_3 (71.44) treatments. While the B_0 (Control) treatment had the lowest number of true pods pot^{-1} (40.69).

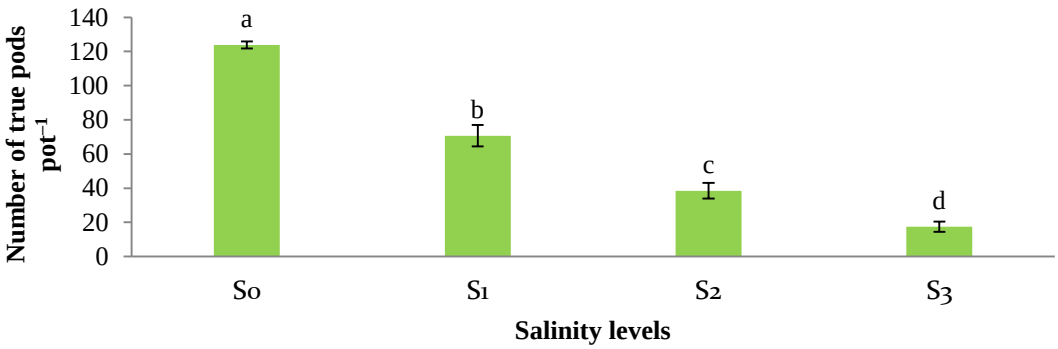


Note: B_0 = Control, B_1 = BARI Rhizobium RA$_h$-803 (Salt sensitive), B_2 = BARI Rhizobium RA$_h$-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 15. Effect of biofertilizer on number of true pods pot^{-1}of groundnut

Effect of salt stress

Exposure of different salinity levels significantly influenced the number of true pods (Figure 16). The results of the experiment revealed that the highest number of true pods pot^{-1} (123.88) was found in the control treatment (S_0), whereas the lowest pods number pot^{-1}of groundnut (17.38) was found in the S_3 (150 mM NaCl) treatment. Application of 150 mM NaCl decreased number of true pods pot^{-1} of groundnut by 85.97% compared to control.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 16. Effect of salt stress on number of true pods pot^{-1}of groundnut

Combined effect of biofertilizer and salt stress

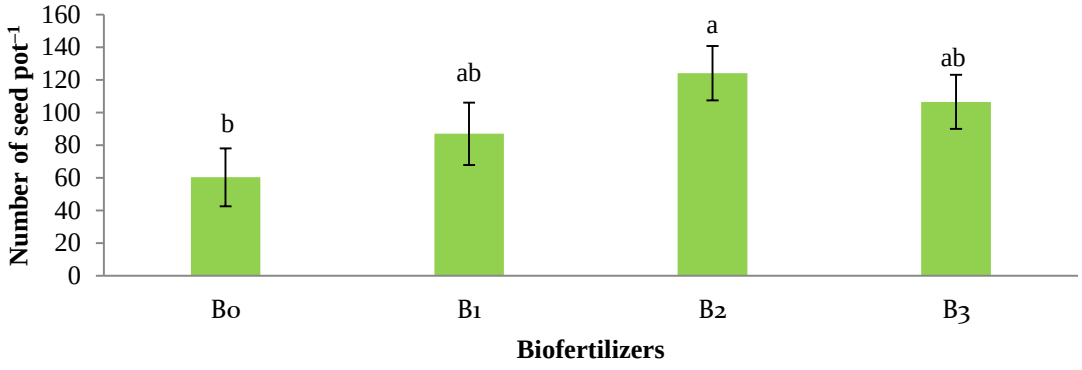
Application of biofertilizer in combination with various salinity levels, significantly influenced the groundnut true pods number pot^{-1} (Table 5). The experimental findings revealed that the highest number of true pod pot^{-1} of groundnut (132.00) was observed in B_2S_0 treatment combination while the lowest number of true pods pot^{-1} of groundnut (3.75) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut true pods by 85, 181 and 152% respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased pods number under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased pods number by 126, 713 and 613 % compared with salt treated control (B_0S_3) treatment.

4.7 Number of seed pot^{-1}

Effect of biofertilizer

The number of seed pot^{-1}of groundnut was significantly influenced by the application of biofertilizer (Figure 17). The B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatment produced the highest number of seed pot^{-1} (124.06), while the B_0 treatment produced the lowest number of seed pot^{-1} (60.31). The increase in yield parameters could be because of

certain growth-promoting substances secreted by the biofertilizers inoculants, which in turn might have led to good root development, better water absorption, and high uptake of nutrients from the soil body, which ultimately enhance seed formation and increased number of seed per pot. The result was quite similar with the findiings of Sharma *et al*. (2017) who showed that combined application of Zn, Mo, Rhizobium, and PSB gave the highest pod per plant of groundnut.

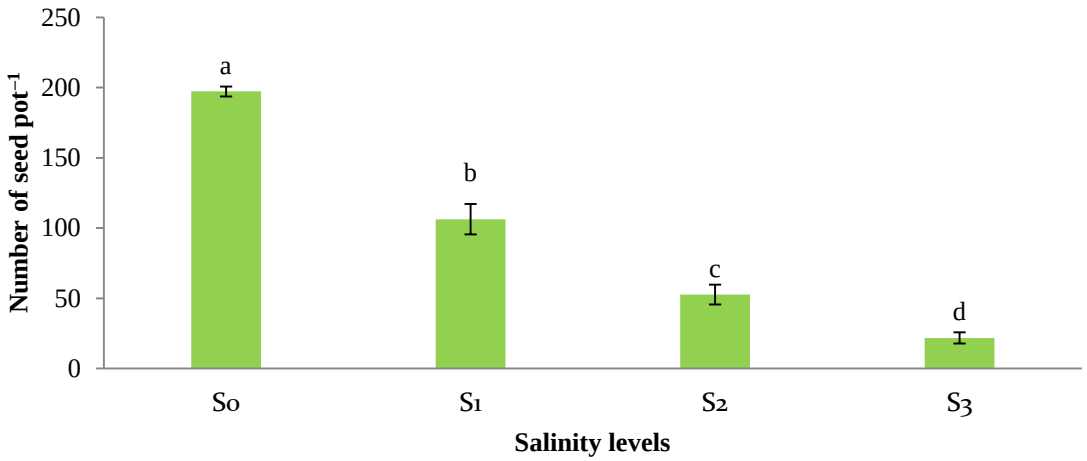


Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 17. Effect of biofertilizer on number of seeds pot^{-1}of groundnut

Effect of salt stress

Exposure of different salinity levels significantly influenced seed pot^{-1}of groundnut (Figure 18). The experimental findings revealed that the highest seed pot^{-1}of groundnut (197.25) was found in the control treatment (S_0), while the lowest seed pot^{-1}of groundnut (21.75) was found in the S_3treatment. Increased salinity level gradually decreased seed pot^{-1}of groundnut. Application of 150 mM NaCl decreased number of seed pot^{-1} of groundnut by 85.97% compared to control. Pushpavalli *et al.* (2015) showed that reduction in biomass of above-ground portion and decreased number of seeds in chickpea led to marked yield reduction in salt stress condition.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 18. Effect of salt stress on number of seeds pot^{-1}of groundnut

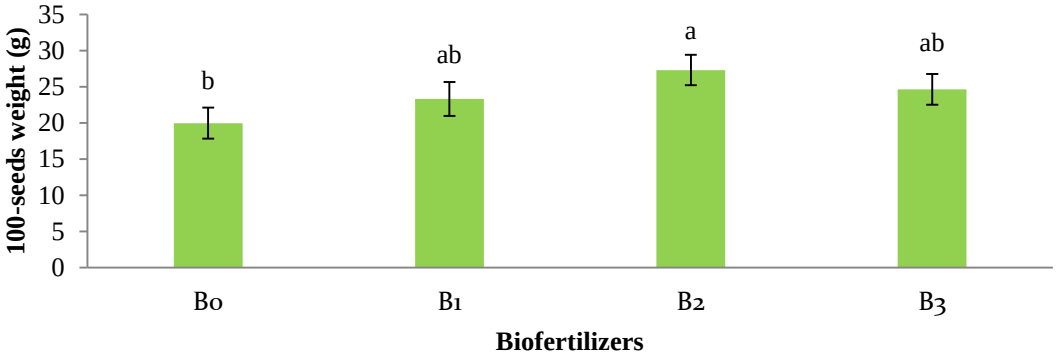
Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly influenced number of seed pot^{-1} of groundnut (Table 5). The result revealed that the highest number of seeds pot^{-1} of groundnut (211.50) was observed in B_2S_0 treatment combination, while the lowest number of seed pot^{-1} of groundnut (3.75) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut seed pot^{-1} by 95, 235 and 197 % respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased pods number under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased seed pot^{-1} by 143, 931 and 700 % compared with salt treated control (B_0S_3) treatment.

4.8 100-seeds weight (g)

Effect of biofertilizer

The 100-seeds weight of groundnut was significantly influenced by the application of biofertilizer (Figure 18). The results showed that the highest 100-seeds weight of groundnut (27.31 g) was observed in B_2 (BARI Rhizobium RA_h-808: Salt tolerant) treatment, while the lowest 100-seeds weight of groundnut (19.96 g) was observed in B_0 treatment. The use of inorganic fertilizers with combination of bio-fertilizer increases the growth of plant, leaves, root proliferation and also the availability of nutrients for plants, which ultimately increase the 100-seeds weight of groundnut. Sharma *et al*. (2014) observed that Rhizobium inoculation resulted in significantly higher test seed weight, protein, oil content and oil yield remained statistically at par with PSB.



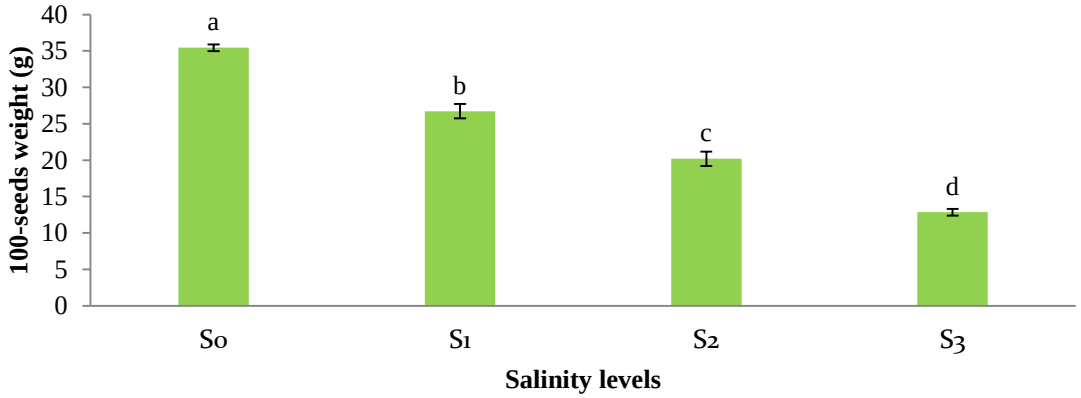
Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 19. Effect of biofertilizer on 100-seeds weight of groundnut

Effect of salt stress

Exposure of different salinity levels significantly influenced 100-seeds weight of groundnut (Figure 20). Experimental result showed that the highest 100-seeds weight of groundnut (35.44 g) was found in the control treatment (S_0) while the lowest 100-seeds weight of groundnut (12.85 g) was found in the S_3 treatment. Application of 150 mM NaCl decreased 100-seeds weight of groundnut by 63.74% compared to control. The variation of 100 seeds weight among different treatment due to reason that salt

availability in soil can disturb normal functioning of plant metabolism, consequently leading to stunted growth and low crop productivity.Sehrawat *et al*. (2013) stated that high salt accumulation resulted in decreased osmotic potential of soil solution eliciting water stress in plants and further interactions of the salts with mineral nutrition caused nutrient imbalance and deficiencies, oxidative stress or even pathology eventually lead to plant death as a result of physiological changes, metabolic damage and growth arrest result in poor yield of the plant.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 20. Effect of salt stress on 100-seeds weight of groundnut

Combined effect of biofertilizer and salt stress

Combined effect of biofertilizer and salt stress significantly influenced the 100-seeds weight of groundnut (Table 5). According to experimental results, the B_1S_0 treatment combination recorded the highest 100-seeds weight of groundnut (36.64 g) which was statistically similar with B_2S_0 (36.56 g) and B_3S_0 (35.99 g) treatment combination. Whereas the lowest 100-seeds weight of groundnut (10.50 g) was observed in B_1S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut 100-seeds weight by 19, 49 and 14 % respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased pods number under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI

Rhizobium RA_h-808 and Mycorrhiza increased 100-seeds weight by 17, 43 and 28 % compared with salt treated control (B_0S_3) treatment.

Table 5. Combined effect of biofertilizer and salt stress on number of pod pot^{-1}, number of true pod pot^{-1}, number of seeds pot^{-1} and 100-seed weight of groundnut

Treatment combinations	Number of pod pot^{-1}	Number of true pod pot^{-1}	Number of seeds pot^{-1}	100-seed weight (g)
B_0S_0	139.75±2.10 b	112.25±2.17 c	176.00±2.12 d	32.57±0.24 b
B_0S_1	55.25±1.80 h	34.50±1.26 h	45.75±1.65 i	21.50±0.20 e
B_0S_2	22.75±1.38 j	12.25±0.85 k	15.50±0.65 l	15.25±0.17 g
B_0S_3	9.00±0.71 l	3.75±0.48 l	4.00±0.41 n	10.50±0.35 j
B_1S_0	154.50±2.60 a	126.75±1.89 b	205.5±1.19 b	36.64±0.15 a
B_1S_1	87.50±2.22 e	64.00±0.71 f	89.50±1.32 g	25.75±0.16 d
B_1S_2	42.50±1.32 i	33.75±1.38 hi	43.25±0.85 jk	18.50±0.11 f
B_1S_3	15.00±0.71 k	8.50±0.65 k	9.75±0.48 m	12.33±0.22 i
B_2S_0	157.75±2.29 a	132.00±1.47 a	211.50±1.32 a	36.56±0.23 a
B_2S_1	112.25±2.87 c	97.25±1.11 d	153.50±1.32 e	32.14±0.26 b
B_2S_2	69.75±2.10 f	60.50±0.87 f	90.00±1.08 g	25.46±0.18 d
B_2S_3	54.25±2.56 h	30.50±1.04 ij	41.25±1.31 k	15.10±0.22 g
B_3S_0	151.75±2.59 a	124.50±1.85 b	196.00±1.29 c	35.99±0.32 a
B_3S_1	98.50±1.55 d	87.00±0.91 e	136.25±1.49 f	27.51±0.37 c
B_3S_2	60.50±2.22g	47.50±1.19 g	61.75±0.85 h	21.56±0.15 e
B_3S_3	51.50±2.66 h	26.75±1.89 j	32.00±1.58 k	13.47±0.21 h
Significance (*P*)	**	**	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

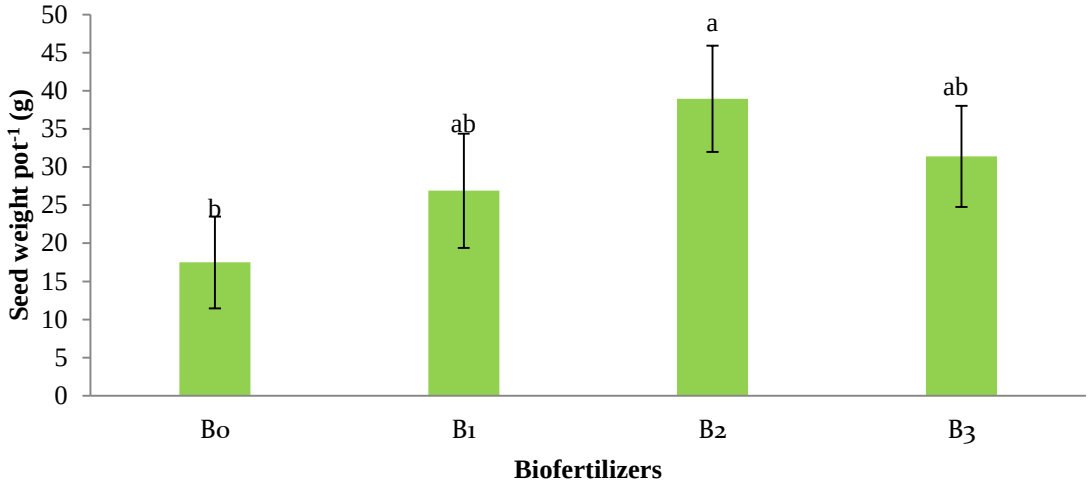
S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

4.9 Seed weight pot^{-1} (g)

Effect of biofertilizer

Application of biofertilizer significantly influenced the seed weight pot^{-1} of groundnut (Figure 21). The results showed that the highest seed weight pot^{-1} of groundnut (38.95 g) was observed in B_2 treatment which was statistically similar with B_1 (26.89g) and B_2 (31.41 g) treatment. While the lowest seed weight pot^{-1} of groundnut (17.48 g) was

observed in B_0 treatment. The increase in seed weight pot^{-1} of groundnut could be attributed to certain growth-promoting substances secreted by biofertilizer inoculants, which could have resulted in good root development, better water absorption, and high uptake of nutrients from the soil body, resulting in an increase in seed weight of groundnut. Pradhan *et al.* (2018) observed significant increase in pod yield of groundnut due to inoculation with PSB.

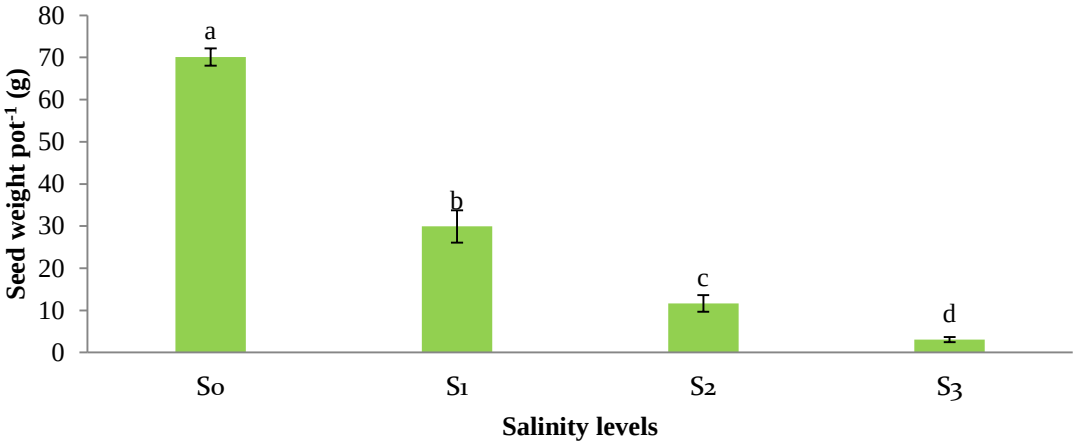


Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 21. Effect of biofertilizer on seed weight $pot^{-1}$of groundnut

Effect of salt stress

Exposure of salinity significantly influenced seed weight $pot^{-1}$of groundnut (Figure 22). The results showed that the highest seed weight pot^{-1} of groundnut (70.12 g) was found in the S_0 treatment. However, the lowest seed weight pot^{-1} of groundnut (3.04g) was found in the S_3 treatment. Application of 150 mM NaCl decreased seed weight $pot^{-1}$of groundnut by 95.66% compared to control. The reduction of seed yield under salt stress was due to reason that salt inhibit the rate of photosynthesis in plants which ultimately impact on plant growth, yield and yield contributing attributes.The result was similar with the findings of Rasool *et al.* (2013) who reported that salinity stress is most common that hampers the growth and biomass yield in chickpea.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 22. Effect of salt stress on seed weight pot^{-1}of groundnut

Combined effect of biofertilizer and salt stress

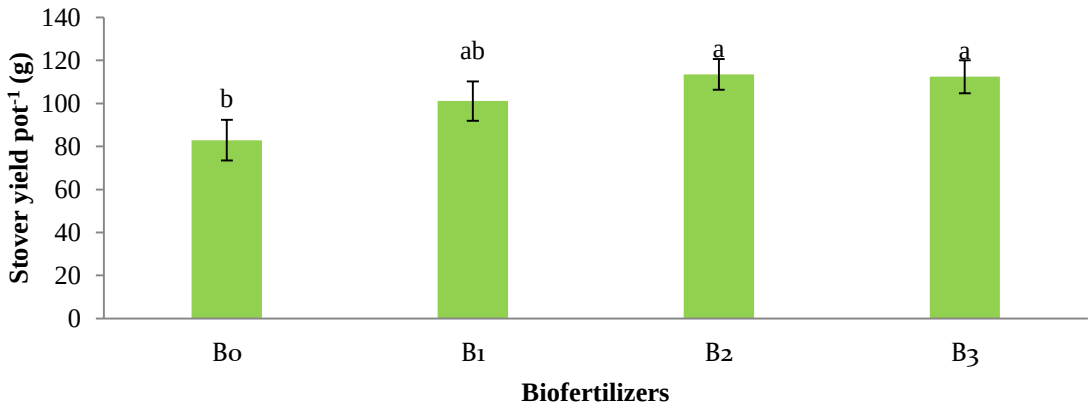
Combined effect of biofertilizer and salt stress had shown significant impact on seed weight pot^{-1} of groundnut (Table 6). The results showed that the highest seed weight pot^{-1}of groundnut (77.32 g) was observed in B_2S_0 treatment combination, while the lowest seed weight pot^{-1}of groundnut (0.42 g) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut seed weight pot^{-1} by 134, 401 and 280% respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased seed weight pot^{-1} under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased seed weight pot^{-1} by 188,1385 and 928% compared with salt treated control (B_0S_3) treatment. Glick (2007) reported that under stress conditions, the plant hormone ethylene endogenously regulates plant homoeostasis and results in reduced root and shoot growth. In the presence of ACC (Endophytic bacteria) deaminase producing bacteria, plant ACC is sequestered and degraded by bacterial cells to supply nitrogen and energy. Furthermore, by removing ACC, the bacteria reduce the deleterious effect of ethylene, ameliorating plant stress and promoting plant growth and yield.

4.10 Stover yield pot^{-1} (g)

Effect of biofertilizer

Effect of biofertilizer

Stover yield pot^{-1} of groundnut was significantly influenced due to biofertilizer application (Figure 23). The results showed that the highest stover yield pot^{-1} of groundnut (113 g) was observed in B_2 treatment, while the lowest stover yield pot^{-1} of groundnut (82.89 g) was observed in control treatment (B_0). The result was similar with the findings of Sharma *et al*. (2014) who reported that the combined application of Zn, Mo, Rhizobium, and PSB gave the highest pod per plant, test weight, pod yield, stover yield, oil content and harvest index of groundnut.



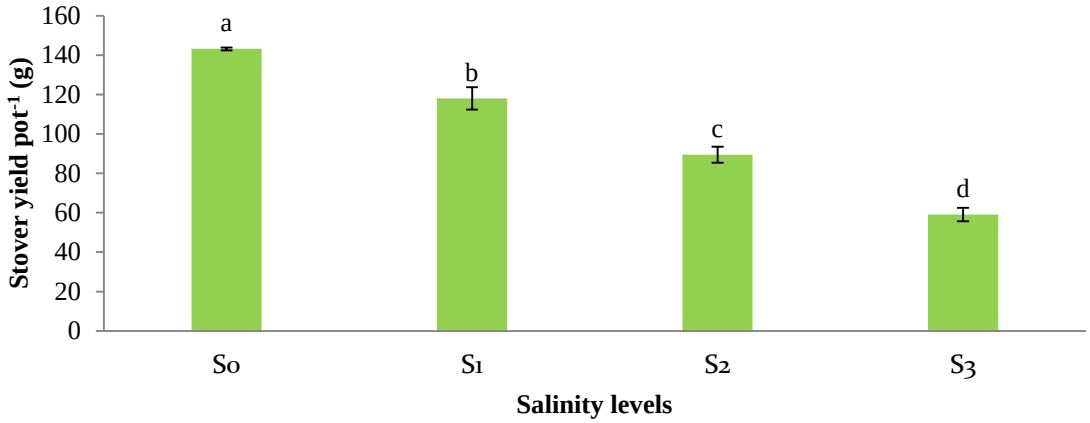
Note: B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza*.

Figure 23. Effect of biofertilizer on stover yield pot^{-1}of groundnut

Effect of salt stress

Exposure of different salinity level significantly influenced stover yield pot^{-1} of groundnut (Figure 24). According to experimental findings the highest stover yield pot^{-1} of groundnut (143.14 g) was found in the S_0 treatment. However, the lowest stover yield pot^{-1} of groundnut (59.13 g) was found in the S_3 treatment. Application of 150 mM NaCl

decreased stover yield pot^{-1}of groundnut by 58.69% compared to control. Netwal (2003) reported that increasing level of soil salinity decreased stover yield of cowpea.



Note: S_0 = S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl.

Figure 24. Effect of salt stress on stover yield pot^{-1}of groundnut

Combined effect of biofertilizer and salt stress

Stover yield pot^{-1} of groundnut was significantly influenced due to combined effect of biofertilizer and salt stress condition (Table 6). The present study revealed that the highest stover yield pot^{-1}of groundnut (144.84 g) was observed in B_1S_0 treatment combination which was statistically similar with B_0S_0 (141.22 g), B_2S_0 (144.28g) and B_3S_0 (142.24) treatment combination. While the lowest seed yield pot^{-1}of groundnut (44.05 g) was observed in B_0S_3 treatment combination. Under 50 mM salt stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased groundnut stover yield pot^{-1} by 43, 61 and 65% respectively, compared with salt treated control (B_0S_1) treatment. Similarly, biofertilizer application increased seed weight pot^{-1} under 1600 and 150 mM NaCl stress. Under 150 mM NaCl stress, application of BARI Rhizobium RA_h-803, BARI Rhizobium RA_h-808 and Mycorrhiza increased stover yield pot^{-1} by 11, 70 and 55% compared with salt treated control (B_0S_3) treatment.

Table 6. Combined effect of biofertilizer and salt stress on seed weight pot^{-1} and stover yield pot^{-1} of groundnut

Treatment combinations	Seed weight pot^{-1} (g)	Stover yield pot^{-1} (g)
B_0S_0	57.32±0.60 b	141.22±1.81 a
B_0S_1	9.84±0.40 e	82.73±2.06 f
B_0S_2	2.37±0.10 g	63.56±1.11 i
B_0S_3	0.42±0.03 j	44.05±1.41 k
B_1S_0	75.30±0.73 a	144.84±1.19 a
B_1S_1	23.06±0.46 d	118.58±1.57 c
B_1S_2	8.00±0.14 f	91.83±1.06 e
B_1S_3	1.21±0.08 i	49.04±1.72 j
B_2S_0	77.32±0.88 a	144.28±1.07 a
B_2S_1	49.32±0.12 b	133.84±1.54 b
B_2S_2	22.91±0.32 d	100.62±1.23 d
B_2S_3	6.24±0.26 g	75.08±1.04 g
B_3S_0	70.55±0.99 a	142.24±1.62 a
B_3S_1	37.48±0.46 c	137.02±0.99 b
B_3S_2	13.31±0.23 e	101.82±1.17 d
B_3S_3	4.32±0.26 h	68.36±1.29 h
Significance (*P*)	**	**

In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level of probability.

Note: Here,

B_0 = Control
B_1 = BARI Rhizobium RA_h-803 (Salt sensitive)
B_2 = BARI Rhizobium RA_h-808 (Salt tolerant)
B_3= *Mycorrhiza*
NS= Non Significant

S_0= 0 mM NaCl
S_1 = 50 mM NaCl
S_2 = 100 mM NaCl
S_3 = 150 mM NaCl

CHAPTER V

SUMMARY AND CONCLUSION

5.1 Summary

A pot experiment was conducted at Sher-e-Bangla Agricultural University, Dhaka during, January to June 2020 for the management of salt stress in groundnut by utilization of Bio-fertilizer. The experiment consisted of two factors, and conducted by following Randomized Complete Block Design with four replications. Factor A: comprised of four types of biofertilizer *viz;* B_0 = Control, B_1 = BARI Rhizobium RA_h-803 (Salt sensitive), B_2 = BARI Rhizobium RA_h-808 (Salt tolerant), B_3 = *Mycorrhiza,* and Factor B consisted four levels of salinity*viz;*S_0 = Control, S_1= 50 mM NaCl, S_2 = 100 mM NaCl and S_3 = 150 mM NaCl. Data on different parameters were collected for assessing results for this experiment and showed significant variation in respect of growth, yield and yield contributing characteristics of groundnut due to the effect of biofertilizer, salt stress and their combinations.

Biofertilizer helps to develop plant growth. The maximum plant height, number of branch plant^{-1}, number of leaves plant^{-1} and relative water content of leaf was observed by the biofertilizer treated pot whereas lowest value of these parameters were observed in control treatment. Biofertilizer treated pot significantly influenced yield and yield contributing characteristics of groundnut. The highest number of pods pot^{-1} (98.50), true pods pot^{-1} (80.06), seeds pot^{-1} (124.06), 100-seeds weight (27.31 g), seed weight pot^{-1} (38.95 g) and stover yield pot^{-1} (113 g) were recorded in B_2 treatment.

In case of different salt stress condition, plant growth deceasing with increasing salt level. The minimum plant height, number of branch plant^{-1}, number of leaves plant^{-1} and relative water content of leaf was observed by the S_3 (150 mM NaCl) treatment. Exposure of salt greatly reduced the yield and yield contributing parameters of groundnut. The lowest pods number pot^{-1}(32.44),pods number pot^{-1} (17.38), seeds pot^{-1} (21.75),100-seeds weight (12.85 g),seed weight pot^{-1} (3.04g) and stover yield pot^{-1} of groundnut (59.13 g) were recorded in S_3 treatment.

In case of combined effect plant growth, yield contributing characteristics and yield of groundnut significantly varied among different treatment combination. The highest number of pods pot^{-1} (157.75),true pods pot^{-1} (132.00), seeds pot^{-1} (211.50) and seed weight $pot^{-1}$of groundnut (77.32 g) were recorded in B_2S_0treatment combination.

5.2 Conclusion

Salinity inhibits groundnut development throughout its life cycle, resulting in lower yields. Plants, on the other hand, take a different and more organized approach to minimizing the toxic effect of this stress at a certain level. So possible ways to minimize this toxic effect according to this experiment is concluded here-

- In terms of yield contributing characteristics and yield, BARI Rhizobium RA_h-808 (Salt tolerant) as biofertilizer played an excellent role to overcome and help groundnut crop to tolerate the toxicity of salt stress in some certain levels and recorded the highest number of pods pot^{-1} (98.50), true pods pot^{-1} (80.06), seedspot^{-1} (124.06), 100-seeds weight (27.31 g), seed weight pot^{-1} (38.95 g) and stover yield pot^{-1} (113 g) comparable to other treatments.
- Exposure of salt decreased plant growth and yield of groundnut.
- In case of combined effect, the plant growth and yield (77.32 g) was maximum with the application of BARI Rhizobium RA_h-808 (Salt tolerant) along with the absence of salt stress condition.

Therefore, it might be concluded that the growth and yield of groundnut decreased with increasing salt levels and using BARI Rhizobium RAh-808 (Salt tolerant) as a biofertilizer can be a suitable approach to groundnut cultivation under salt stress conditions.

Recommendation

Further studies may be needed to ensure the role of biofertilizer in improving morphological, physiological and yield performance of groundnut under salt stress along with more growth parameters like seed nutrient content and other quality attributes of groundnut. Another combination of salinity and bio-fertilizer doses may be included for further study.

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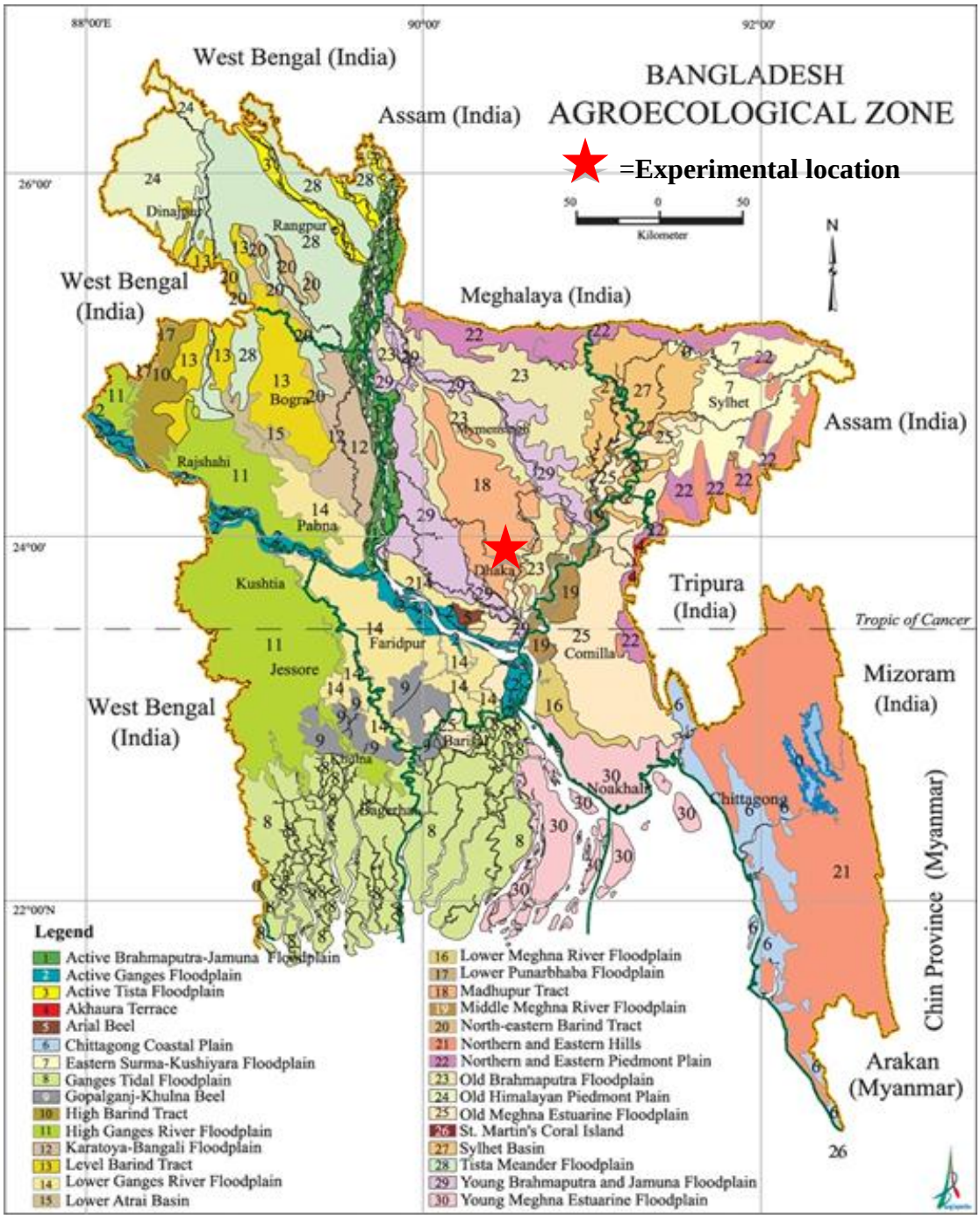
APPENDICES

Appendix I. Map showing the experimental location under study



Appendix II. Soil characteristics of the experimental field

A. Morphological features of the experimental field

Morphological features	**Characteristics**
AEZ	AEZ-28, Modhupur Tract
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Location	Sher-e-Bangla Agricultural University Agronomy research field, Dhaka
Soil series	Tejgaon
Topography	Fairly leveled

B. The initial physical and chemical characteristics of soil of the experimental site (0- 15 cm depth)

Physical characteristics	
Constituents	**Percent**
Clay	29 %
Sand	26 %
Silt	45 %
Textural class	Silty clay
Chemical characteristics	
Soil characteristics	**Value**
Available P (ppm)	20.54
Exchangeable K (mg/100 g soil)	0.10
Organic carbon (%)	0.45
Organic matter (%)	0.78
pH	5.6
Total nitrogen (%)	0.03

Sourse: Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka.

Appendix III. Monthly meteorological information during the period from January to June, 2020.

Year	Month	Air temperature (^{0}C)		Relative humidity (%)	Average rainfall (mm)
		Maximum	Minimum		
2020	January	25.5 ^{0}C	13.1 ^{0}C	41%	00 mm
	February	25.9 ^{0}C	14 ^{0}C	34%	7.7 mm
	March	32.9°C	20.1°C	61%	54 mm
	April	34.1°C	23.6°C	67%	138 mm
	May	33.4°C	24.7°C	76%	269 mm
	June	34°C	27.3°C	76%	134 mm

Source: Metrological Centre, Agargaon, Dhaka (Climate Division)

Appendix IV. Mean sum square values of the data for plant height at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of plant height				
		30 DAS	50 DAS	70 DAS	90 DAS	At harvest
Biofertilizer (B)	3	21.48**	82.69**	99.05*	372.63**	644.66**
Salinity (S)	3	0.78 NS	179.85*	499.78**	850.12**	1507.10**
B×S	9	4.53**	53.99**	121.49**	259.54**	458.95**
Error	45	0.60	1.04	0.91	1.78	1.62
Total	63					

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix V. Mean sum square values of the data for number of branch at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of branch number		
		50 DAS	70 DAS	90 DAS
Biofertilizer (B)	3	0.056 NS	0.12 NS	0.60 NS
Salinity (S)	3	0.37*	2.73**	3.88**
B×S	9	0.12 NS	0.39*	0.95**
Error	45	0.16	0.25	0.17
Total	63			

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VI. Mean sum square values of the data for number of leaves at different days after sowing of groundnut

Source of Variation	DF	Mean Sum square values of leaf number				
		30 DAS	50 DAS	70 DAS	90 DAS	At harvest
Biofertilizer (B)	3	13.21**	23.84**	73.73**	209.65**	502.47*
Salinity (S)	3	0.29 NS	30.89**	131.83**	715.63**	2313.41**
B×S	9	3.02**	11.36**	44.43**	190.90**	579.86**
Error	45	1.01	1.79	1.23	1.26	0.98
Total	63					

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VII. Mean sum square values of the data for leaf relative water content of groundnut

Source of Variation	DF	Mean Sum square values of leaf relative water content
Biofertilizer (B)	3	145.36NS
Salinity (S)	3	2263.55 **
B×S	9	489.94**
Error	45	0.64
Total	63	

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VIII. Mean sum square values of the data for yield attributes of groundnut

Source of Variation	DF	Mean Sum square values of yield attributes			
		Number of Pod pot^{-1} (No.)	Number of true Pod pot^{-1} (No.)	Number of Seed pot^{-1} (No.)	100-Sedd Weight (g)
Biofertilizer (B)	3	5458.44*	4704.64*	11962.52*	149.71*
Salinity (S)	3	44443.35**	34379.43**	94622.43**	1476.99**
B×S	9	10206.56**	8032.40**	22041.36**	332.08**
Error	45	17.38	7.03	6.36	0.22
Total	63				

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Appendix VIII. Mean sum square values of the data for yield of groundnut

Source of Variation	DF	Mean Sum square values of yield of groundnut	
		Seed Weight (g pot^{-1})	Stover Yield (g pot^{-1})
Biofertilizer (B)	3	1287.69*	3220.64*
Salinity (S)	3	14219.42**	21036.46**
B×S	9	3211.32**	5137.50**
Error	45	0.89	7.85
Total	63		

Ns: Non significant
** : Significant at 0.01 level of probability
*: Significant at 0.05 level of probability

Plates

Plate 2. Experimental view after sowing of seed

Plate 3. Experimental view after seedling emergence

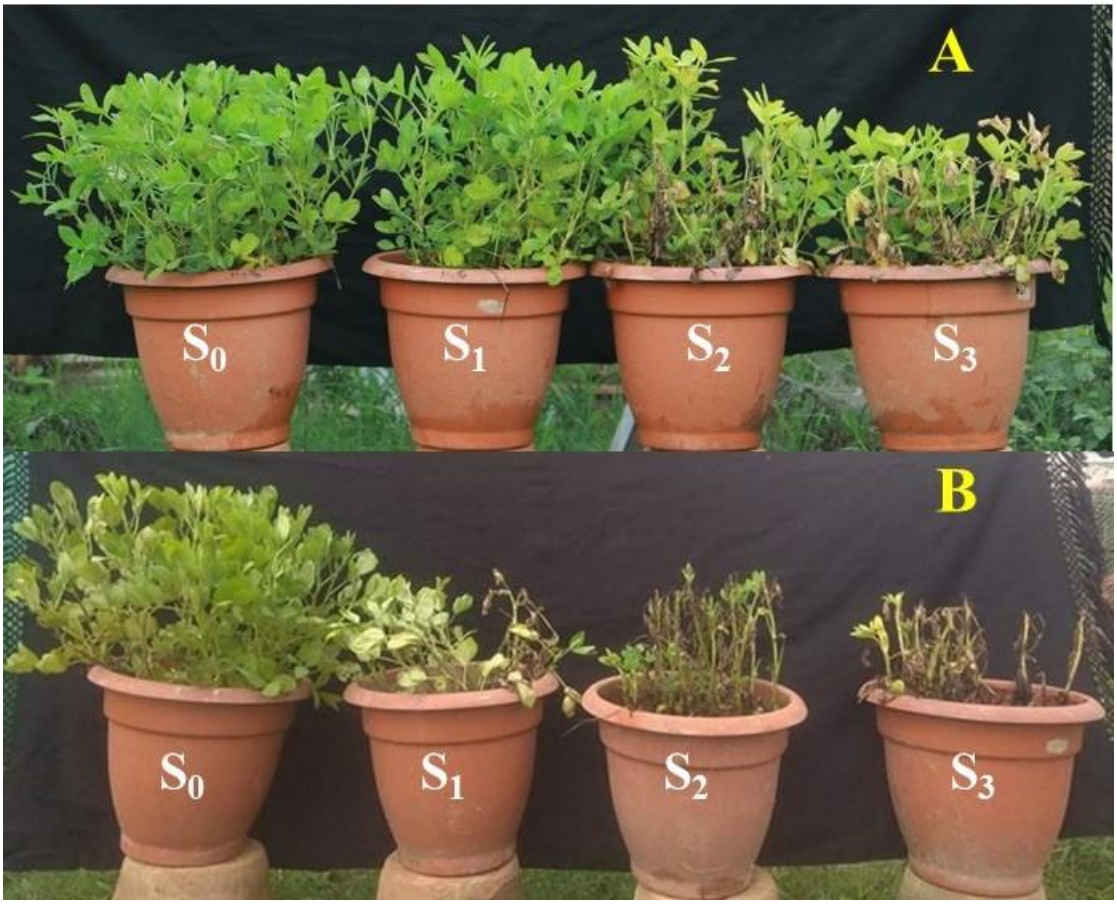


Plate 4. Effect of salinity on groundnut at 90 (A) and 120 (B) DAS

Plate 5. Role of biofertilizer on groundnut under salt stress