INFLUENCE OF SALINITY LEVELS ON SEED GERMINATION, GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa)*

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CERTIFICATE

This is to certify that the thesis entitled **"INFLUENCE OF SALINITY LEVELS ON SEED GERMINATION, GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa)*"** submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE (M.S.)** in **AGRONOMY**, embodies the result of a piece of bona fide research work carried out by **MALIHA NARJIS**, Registration No. **12-04969** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

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

Dated:

Dhaka, Bangladesh

Prof. Dr. Parimal Kanti Biswas
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Dedicated to
My
Beloved Parents

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The Author

INFLUENCE OF SALINITY LEVELS ON SEED GERMINATION, GROWTH AND YIELD OF QUINOA (*Chenopodium quinoa*)

ABSTRACT

A laboratory experiment was conducted to test the germination of quinoa seeds of two varieties and a pot experiment was conducted at the Agronomy net house of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2017 to March 2018 to evaluate the influence of salinity levels on seed germination, growth and yield of quinoa (*Chenopodium quinoa*). Two varieties of quinoa *viz*. V_1 (Titicaca) and V_2 (Vikinga) and seven salinity levels *viz*. S_0 (control), S_1 (EC 5 dS/m), S_2 (EC 10 dS/m), S_3 (EC 15 dS/m), S_4 (EC 20 dS/m), S_5 (EC 25 dS/m) and S_6 (EC 30 dS/m) were considered for the present experiment. The experiments consisting of 14 treatment combinations that was laid out in Randomized Complete Block Design (factorial) with three replications. Data on different growth parameters, yield components and yield of plants were recorded. The collected data were statistically analyzed. Number of branches plant^{-1}, number of inflorescence plant^{-1}, length of inflorescence plant^{-1}, germination rate, 1000-seed weight, yield plant^{-1}, husk weight plant^{-1}, straw weight plant^{-1}, biological yield plant^{-1} and harvest index were not significantly affected by variety. In case of salinity levels, number of branches plant^{-1} was not significantly affected but rest of the studied parameters were significantly influenced by different salinity levels. Results showed that the highest germination rate (3.33 and 3.67 out of 4 seeds at 2 and 7 DAS, respectively), number of inflorescence plant^{-1} (12.0), length of inflorescence plant^{-1} (11.92 cm), 1000-seed weight (2.57 g), yield plant^{-1} (1.69 g), husk weight plant^{-1} (0.91 g), straw weight plant^{-1} (2.44 g) and biological yield plant^{-1} (4.99 g) were found from the salinity level S_4 (EC 20 dS/m). Regarding combined effect of variety and salinity levels, all the parameters under the study was significantly affected. The highest germination rate (3.67 and 4.00 out of 4 seeds at 2 and 7 DAS, respectively), number of inflorescences plant^{-1} (12.3), length of inflorescence plant^{-1} (12.67 cm), 1000-seed weight (2.61 g), yield plant^{-1} (1.71 g), husk weight plant^{-1} (0.95 g), straw weight plant^{-1} (2.66 g) and biological yield plant^{-1} (5.12 g) was found from the treatment combination of V_1S_4. The lowest germination rate (1.67 and 2.67 out of 4 seeds at 2 and 7 DAS, respectively), number of inflorescence plant^{-1} (5.33), length of inflorescence plant^{-1} (4.00 cm), 1000-seed weight (2.00 g), yield plant^{-1} (1.12 g), husk weight plant^{-1} (0.52 g), straw weight plant^{-1} (0.83 g) and biological yield plant^{-1} (3.04 g) were found from the treatment combination of V_2S_6 but the lowest harvest index (33.40%) was found from the treatment combination of V_2S_4.

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ABBREVIATIONS AND ACRONYMS

AEZ	=	Agro-Ecological Zone
BBS	=	Bangladesh Bureau of Statistics
BCSRI	=	Bangladesh Council of Scientific Research Institute
Ca	=	Calcium
cm	=	Centimeter
cv.	=	Cultivar
CV %	=	Percent Coefficient of Variation
DAS	=	Days After Sowing
DMRT	=	Duncan's Multiple Range Test
dS/m	=	Deci Siemens per metre
e.g.	=	exempli gratia (L), for example
et al.,	=	And others
etc.	=	Etcetera
FAO	=	Food and Agriculture Organization
g	=	Gram (s)
GM	=	Geometric mean
i.e.	=	id est (L), that is
K	=	Potassium
L	=	Litre
LSD	=	Least Significant Difference
M.S.	=	Master of Science
m^2	=	Meter squares
mg	=	Miligram
ml	=	MiliLitre
NaCl	=	Sodium Chloride
No.	=	Number
P	=	Phosphorus
SAU	=	Sher-e-Bangla Agricultural University
USA	=	United States of America
var.	=	Variety
WHO	=	World Health Organization
µg	=	Microgram
^oC	=	Degree Celceous
%	=	Percentage

CHAPTER I

INTRODUCTION

Quinoa is the common name for *Chenopodium quinoa*, a flowering plant in the family Amaranthaceae. It is a herbaceous annual plant grown as a grain crop primarily for its edible seeds. It is not a grass, it is a pseudo cereal rather than a true cereal.

Quinoa (*Chenopodium quinoa* Wild.) has been cultivated in the Andean region for several thousand years, being one of the main grain crops supplying highly nutritious food for the farmers. This may lead quinoa to play a key role in the future (FAO, 1998).

The thirty-seventh session of the General Conference of FAO adopted a resolution recommending the declaration of 2013 as the International Year of Quinoa.

Agriculture in the Andean highlands is characterized by a high degree of risk due to a range of adverse climatic factors such as drought, frost, wind, hail, and soil salinity. Water shortage is a major constraint to plant production due to the combined effect of low rainfall, a relatively high evapotranspiration rate, and poor soils with a low water-retaining capacity. Frost is important in the highlands of the Andes, especially in the southern part of Peru and in Bolivia, with significant diurnal temperature variations, and with frost at night up to 200 days a year. High levels of salt in the soils are of special importance in the salt deserts of Bolivia and other regions of the altiplano, but are generally an increasing problem in dry regions, where irrigation is applied.

The growth and production of quinoa is not necessarily restricted to the Andean mountains. Quinoa may have a potential in other mountainous regions in the developing world, such as the Himalayas and the central mountain region of Africa (Jacobsen, 2001).

Quinoa is a crop that demonstrates a range of requirements for humidity and temperature, with different ecotypes adapted to different conditions. Some genotypes of quinoa are grown under conditions of severe drought, suggesting resistance to this adverse factor (Tapia, 1997).

The seed crop quinoa belongs to the Amaranthaceae, a plant family that comprises by far the highest proportion (44%) of halophytic plant species (Flowers *et al*., 1986). Quinoa originates from the Andean region of South America, where soil quality is poor and climatic conditions are harsh. The plants had to adapt accordingly in order to withstand frequent drought (Garcia *et al*., 2003; Jacobsen *et al*., 2009), frost (Jacobsen *et al*., 2005, 2007), hail and wind at an elevation of 3500–3900 m above sea level (Jacobsen *et al*., 2003). Quinoa is a facultative halophytic plant species with varieties being able to cope with salinity levels as high as those present in sea water (electrical conductivity (EC) 40 dS/m).

The total area of Bangladesh is 147, 570 square km. The coastal area covers about 20% of the country and over thirty percent of the net cultivable area. It extends inside up to 150 km from the coast (Petersen and Shireen, 2001).

The interest in this seed crop is increasing all over the world (Jacobsen, 2003), not only because of its stress tolerance, but also due to its exceptional nutritional quality (Repo-Carrasco *et al*., 2003; Vega-Galvez *et al*., 2010; Stikic *et al*., 2012). The seed has an outstanding composition of essential amino acids, rich in vitamins (A, B2, E) and the minerals calcium, magnesium, iron, copper, zinc and lithium, and it represents a valuable source of carbohydrates and essential fatty acids for human nutrition (Koziol, 1992; Ranhotra *et al*., 1993; Repo-Carrasco *et al*., 2003).

Quinoa is a highly nutritious food product, being cultivated for several thousands years in South America, with an outstanding protein quality and a high content of a range of vitamins and minerals. Other positive aspects of quinoa are the saponins found in the seed hull and the lack of gluten. Quinoa is

one of the main food crops in the Andean mountains, but during recent times there has been increased interest for the product in the United States, Europe, and Asia. Quinoa has been selected by FAO as one of the crops destined to offer food security in the next century.

The genetic variability of quinoa is huge, with cultivars of quinoa being adapted to growth from sea level to 4000 meters above sea level from 40°S to 28°N latitude and from cold, highland climate to subtropical conditions. This makes it possible to select, adapt, and breed cultivars for a wide range of environmental conditions. A major constraint for growth in northern parts of Europe, Canada, and in high altitude region is the short growth season, because quinoa requires a maximal developmental time of 150 days in order to secure seed harvest. Hence, early maturity is one of the most important characteristics if quinoa is grown under these conditions. In southern Europe, the United States in certain parts of Africa and Asia there is good potential for increased production of quinoa. Quinoa has a significant, worldwide potential as a new cultivated crop species and as an imported commodity from South America. The main uses of quinoa are for cooking, baking, etc.; various products for people allergic to gluten; animal feed, green fodder and pellets; modified food products such as breakfast cereals, pasta, and cookies.

The wild quinoa, fat-hen (*Chenopodium album*), has since the iron Age been a secondary crop in Denmark. More recently in Denmark, attention has been given to quinoa for people with coeliac disease as an alternative to the four cereals, wheat, rye, oat, and barley, which all contain gluten. In addition, it has been elaborated products, such as bread, cakes, and biscuits, for the general consumer. Projects on the production of green pellets from quinoa have been conducted (Jacobsen, 1997; Jacobsen and Bach, 1998; Jacobsen and Stolen, 1993; Jacobsen *et al*., 1994, 1996, 1997; Lomholt, 1996).

Yield loss due to saline soils is a common problem all over the world as most crop plants are glycophytes and, hence, sensitive to salinity. A 97.5% of the world's water is saline, and large land areas are naturally saline. Human activities exacerbate the problem in many affected regions (Munns and Tester, 2008). The present study was undertaken with the following objectives:

1. To study the possibility of growing quinoa in Bangladesh weather condition,
2. To find out the salinity tolerance level of quinoa, and
3. To determine the yield of quinoa.

CHAPTER II

REVIEW OF LITERATURE

In the face of diminishing fresh water resources and increasing soil salinisation, it is relevant to evaluate the potential of halophytic plant species to be cultivated in arid and semi-arid regions, where the productivity of most crop plants is markedly affected. Quinoa is a facultative halophytic plant species with the most tolerant varieties being able to cope with salinity levels as high as those present in sea water. This characteristic has aroused the interest in the species and a number of studies have been performed with the aim of elucidating the mechanisms used by quinoa in order to cope with high salt levels in the soil at various stages of plant development. Some of the informative and important works and research findings related to salt stress, so far been done at home and abroad, have been reviewed in this chapter under the following heads:

2.1 Salt stress

Salinity is one of the most brutal environmental factors limiting the productivity of crop plants because most of the crop plants are sensitive to salinity caused by high concentrations of salts in the soil. A considerable amount of land in the world is affected by salinity which is increasing day by day. More than 45 million hectares (M ha) of irrigated land which account to 20% of total land have been damaged by salt worldwide and 1.5 M ha are taken out of production each year due to high salinity levels in the soil (Pitman and Läuchli, 2002; Munns and Tester, 2008). On the other hand, increased salinity of agricultural land is expected to have destructive global effects, resulting in up to 50% loss of cultivable lands by the middle of the twenty- first century (Mahajan and Tuteja, 2005).

Most of Bangladesh‘s coastal region lies on the southwest coastal region of the country. Approximately 30% of the crops land of Bangladesh is located in this

region (Mondal *et al*., 2001) and continuous to support crops productivity and GDP growth. But in the recent past, the contribution of crops to GDP has decreased because of salinity. In total, 52.8% of the cultivable land in the coastal region of Bangladesh was affected by salinity in 1990 (Karim *et al*., 1990) and the salt affected area has increased by 14600 ha per year (SRDI, 2001). SRDI had made a comparative study of the salt affected area between 1973 to 2009 and showed that about 0.223 million ha (26.7%) of new land has been affected by varying degrees of salinity during the last four decades and that has badly hampered the agro-biodiversity (SRDI, 2010). Farmers mostly cultivate low yielding, traditional rice varieties. Most of the land kept fallow in the summer or pre-monsoon hot season (March-early June) and autumn or post-monsoon season (October- February) because of soil salinity, lack of good quality irrigation water and late draining condition. In the recent past, with the changing degree of salinity of southwest coastal region of Bangladesh, crop production becomes very risky and crop yields, cropping intensity, production levels of crop and people‘s quality of livelihood are much lower than that in the other parts of the country. Cropping intensity in saline area of Bangladesh is relatively low, mostly 170% ranging from 62% in Chittagong coastal region to 114% in Patuakhali coastal region (FAO, 2007).

In most of the cases, the negative effects of salinity have been attributed to increase in Na^+ and Cl^- ions in different plants hence these ions produce the critical conditions for plant survival by intercepting different plant mechanisms. Although both Na^+ and Cl^- are the major ions produce many physiological disorders in plant, Cl^- is the most dangerous (Tavakkoli *et al*., 2010). Salinity at higher levels causes both hyperionic and hyperosmotic stress and can lead to plant demise. The outcome of these effects may cause membrane damage, nutrient imbalance, altered levels of growth regulators, enzymatic inhibition and metabolic dysfunction, including photosynthesis which ultimately leading to plant death (Mahajan and Tuteja, 2005)

The available literature revealed the effects of salinity on the seed germination of various crops like *Oryza sativa* (Xu *et al*., 2011), *Triticum aestivum* (Akbarimoghaddam *et al*., 2011), *Zea mays* (Carpycy *et al*., 2009; Khodarahampour *et al*., 2012), *Brassica* spp. (Ibrar *et al.*, 2003; Ulfat *et al*., 2007), *Glycine max* (Essa, 2002), *Vigna* spp. (Jabeen *et al.*, 2003) and *Helianthus annuus* (Mutlu and Bozcuk, 2007). It is well established that salt stress has negative correlation with seed germination and vigor (Rehman *et al*., 2000). Higher level of salt stress inhibits the germination of seeds while lower level of salinity induces a state of dormancy (Khan and Weber, 2008).

Some crops are most sensitive under saline condition during vegetative and early reproductive stages, less sensitive during flowering and least sensitive during the seed filling stage. Seed weight is the yield component in all these studies. Dolatabadian *et al.* (2011) observed that salinity stress significantly decreased shoot and root weight, total biomass, plant height and leaf number but not affected leaf area while studying with *Glycine max*.

A high concentration of Na^+ and/or Cl^- accumulation in chloroplasts is also inhibited photosynthesis. As photosynthetic electron transport is relatively insensitive to salts, either carbon metabolism or photophosphorylation may be affected due to salt stress (Sudhir and Murthy, 2004). In fact, the effect of salinity on photosynthetic rate depends on salt concentration as well as plant species or genotypes.

Fisarakis *et al*. (2001) reported a positive growth inhibition caused by salinity associated with a marked inhibition of photosynthesis. There is evidence that at low salt concentration salinity sometimes stimulate photosynthesis. For instance, in *Brassica parviflora*, Parida *et al*. (2004) observed that rate of photosynthesis increased at low salinity while decreased at high salinity, whereas stomatal conductance remained unchanged at low salinity and decreased at high salinity.

The decrease in chlorophyll (chl) content under salt stress is a commonly reported phenomenon and in various studies, the chl concentration were used as a sensitive indicator of the cellular metabolic state (Chutipaijit *et al*., 2011).

Saha *et al*. (2010) observed a linear decrease in the levels of total Chl, Chl a, Chl b, carotene and xanthophylls as well as the intensity of Chl fluorescence in *Vigna radiata* under increasing concentrations of NaCl treatments. Compared to control, the pigment contents decreased on an average, by 31% for total Chl, 22% for Chl a, 45% for Chl b, 14% for carotene and 19% for xanthophylls. Associated with the decline in pigment levels, there was an average 16% loss of the intensity of Chl fluorescence as well.

According to Romero-Aranda *et al.* (2006) increase of salt in the root medium can lead to a decrease in leaf water potential and, hence, may affect many plant processes. Osmotic effects of salt on plants are the result of lowering of the soil water potential due to increase in solute concentration in the root zone. At very low soil water potentials, this condition interferes with plants' ability to extract water from the soil and maintain turgor. However, at low or moderate salt concentration (higher soil water potential), plants adjust osmotically (accumulate solutes) and maintain a potential gradient for the influx of water. Salt treatment caused a significant decrease in relative water content (RWC) in sugar beet varieties (Ghoulam *et al*., 2002).

A decrease in RWC indicates a loss of turgor that results in limited water availability for cell extension processes (Katerji *et al.*, 1997). Steudle (2000) reported that in transpiring plants, water is thought to come from the soil to the root xylem through apoplastic pathway due to the hydrostatic pressure gradient. However, under salt stressed condition, this situation changes because of the restricted transpiration. Under these situations, more of the water follows the cell-to-cell path, flowing across membranes of living cells (Vysotskaya *et al*., 2010).

Salt stress significantly reduced the yield of crops as indicated by many researchers. As reported by Greenway and Munns (1980), after some time in 200 mM NaCl, a salt-tolerant species such as sugar beet might have a reduction of only 20% in dry weight, a moderately tolerant species such as cotton might have a 60% reduction, and a sensitive species such as soybean might be dead. On the other hand, a halophyte such as Suaeda maritime might be growing at its optimum rate (Flowers *et al.*, 1986).

2.2. Germination and seedling establishment under salinity

Gomez (2010) reported that soil salinity is a major problem in today's agriculture. Quinoa has become an important crop because it exhibits high levels of salinity tolerance. In addition, its seeds contain an excellent balance of carbohydrates, lipids, amino acids and proteins for human nutrition. The quinoa germplasm includes almost 2500 accessions, some of which have been tested under salt stress. Here, we report the effect of NaCl on the germination of 182 previously untested accessions. When the seeds were irrigated with saline water at 30 dS/m EC, the stress appeared to be too high: all accessions showed less than 60% germination. In contrast, irrigation with 25 dS/m EC saline water allowed over 60% germination in 15 accessions. These latter accessions agricultural traits were then evaluated. Unexpectedly, salt treatment resulted in increased plant height, leaf dry mass and grain yield.

Bohnert *et al.* (1995) studied that seedling establishment is a critical process in a plants' life, especially in the presence of adverse environmental factors.

Malcolm *et al.* (2003) studied that when compared with glycophytes, halophytes can cope with high salt levels during germination.

Khan and Abdullah (2003) studied that even halophytes are relatively sensitive to salinity during the stages of germination and seedling emergence.

Jacobsen and Christiansen (2016) have studied that Quinoa emerged quicker than any weeds. Sowing with the precision drill used for the 50 cm row spacing resulted in a faster establishment of the quinoa plants compared to sowing at 12 cm row spacing where an ordinary cereal sowing machine was used. With precision drill full emergence was reached 2 weeks quicker than with the cereals sowing machine.

2.3. Growth parameters

By this time, leaf and root growth have settled down to a reduced steady rate. Leaf growth is often more reduced than root growth by salinity, a phenomenon in common with dry soil, the commonality indicating this is probably due to factors associated with water stress rather than a salt-specific effect. This is supported by the evidence that Na^+ and Cl^- are always below toxic concentrations in the growing cells themselves. For example, in wheat growing in 120 mM NaCl, with a 25% reduction in growth rate, Na^+ in the growing cells of leaves was only 20 mM at maximum, and Cl^- only 60 mM . K^+ was maintained at high levels. In roots, also, there is evidence that Na^+ concentrations in dividing or rapidly elongating cells are low and well below toxic levels. For example, in root tips of saltbush (*Atriplex amnicola*), Na^+ was only 40 mM at external NaCl concentrations of 400 mM.

Sanchez *et al*. (2006) reported that their results from greenhouse pot experiments showed that salt stress induced better absolute and relative growth rates, and that the plant developed adaptation mechanisms to drought through high water use efficiency and high root shoot ratios. The stomatal resistance and the leaf water potential increased with an increased stress level.

Anwar *et al.* (2018) reported that a greenhouse experiment was conducted to investigate the impact of water and salt stress in Quinoa plants (*Chenopodium quinoa* Wild.). Irrigation treatments using saline solutions of 0 (control), 50(T_1), 200 (T_2), 400 (T_3), 600 (T_4), and 800 (T_5) mM sodium chloride (NaCl)

were adopted. The results indicated that quinoa plants can tolerate water stress (50% FC) when irrigated with moderately saline water (T_1 and T_2, respectively). Salinity stress increases quinoa drought tolerance in terms of yield and biomass production.

Repo-Carrasco *et al.* (2006) studied on Quinoa (*Chenopodium quinoa* Wild.) and kañiwa (*Chenopodium pallidicaule* Aellen) are native food plants of high nutritional value grown in the Andean region and used as food by the Incas and previous cultures. Quinoa and kañiwa served as a substitute for scarce animal proteins and are still one of the principal protein sources of the region. The importance of these proteins is based on their quality, with a balanced composition of essential amino acids similar to the composition of casein, the protein of milk.

Cristiansen *et al.* (2010) reported that sensitivity to photoperiod in quinoa (*Chenopodium quinoa* Wild.) was studied under controlled conditions to enhance crop adaptation to environments outside its centre of origin. Two varieties, a traditional variety from Bolivia (Real), which will not mature under Danish conditions, and an early maturing variety (Q52), developed for Danish climatic conditions, were used in this reciprocal transfer experiment. Plants were moved from a short day length of 10 h (SD) to a long day length of 18 h (LD) and vice versa at set intervals from sowing to 100 days after sowing (DAS). A reaction of LD in time to flowering was observed only in the Bolivian variety Real. This study shows that flower induction is not a major problem for adaptation of quinoa to North European conditions but that a very strong, day length sensitive, stay green reaction is the main cause of the late maturity of South American introduction.

Jacobsen *et al.* (2006) reported that quinoa can grow with only 200 mm of rainfall in pure sand. Fourteen lines with improved drought resistance have been identified, and several drought-mediating mechanisms have been found.

The crop has also demonstrated unusually high salt tolerance; many varieties can grow in salt concentrations as high as those found in seawater (40 dS m^{-1}), and four lines have been identified with even higher tolerance. Quinoa also has a high degree of frost resistance, surviving −8°C for up to 4 hours, depending on phenological phase and variety.

Based on casual qualitative observations, grain sorghum [*Sorghum bicolor* (L.) Moench] is less tolerant to salt than the noxious weed and potential biomass energy crop, johnsongrass [*S. halepense* (L.) Pers.]. The objective was to quantitatively compare whole plant growth and physiological responses to salt stress of these two sorghum species. Salt stress was induced by adding incremental levels of NaCl to a vermiculite medium until concentrations of 0.1 and 0.2 M were attained. Leaf number and leaf area reduction and dry weight reduction in the culm and leaves in response to salinity compared to controls were greater in *S. bicolor* than in *S. halepense*. Larger leaf growth reductions in response to salinity in *S. bicolor* were associated with higher tissue levels of Na^+ and CI^-. *Sorghum halepense* had a lower Na^+/K^+ ratio in the leaves as well as in the roots; the cuim ratio was the same in both species. Higher ψ_p (0.65 MPa) and lower ψ_s(−2.17 MPa) *S. bicolor* leaves compared to the ψ_p (0.28 MPa) and ψ_s (−1.71 MPa) *S. halepense* leaves indicated more osmotic adjustment and more turgor maintenance in *S. bicolor* than in *S. halepense*; this response was due largely to CI^- and sucrose accumulation. The greater growth reduction observed in *S. bicolor* was associated with higher levels of CI^- higher Na^+/K^+ ratios, and a greater capacity for osmotic adjustment. A Na^+ exclusion mechanism appeared to be operative in both species but was more apparent in *S. halepense*.

John and Essam Abo-Kassem (2007) reported that salinity is among the most widespread and prevalent problems in irrigated agriculture. Many members of the family Chenopodiaceae are classified as salt tolerant. One member of this family, which is of increasing interest, is quinoa (*Chenopodium quinoa* Willd.)

which is able to grow on poorer soils. Salinity sensitivity studies of quinoa were conducted in the greenhouse on the cultivar, "Andean Hybrid" to determine if quinoa had useful mechanisms for salt tolerant studies. For salt treatment we used a salinity composition that would occur in a typical soil in the San Joaquin Valley of California using drainage waters for irrigation. Salinity treatments (EC_i) ranging from 3, 7, 11, to 19 dS m^{-1} were achieved by adding $MgSO_4$, Na_2SO_4, NaCl, and $CaCl_2$ to the base nutrient solution. These salts were added incrementally over a four-day period to avoid osmotic shock to the seedlings. The base nutrient solution without added salt served as the non-saline control solution (3 dS m^{-1}). Solution pH was uncontrolled and ranged from 7.7 to 8.0. For comparative purposes, we also examined Yecora Rojo, a semi-dwarf wheat, *Triticum aestivum* L. With respect to salinity effects on growth in quinoa, we found no significant reduction in plant height or fresh weight until the electrical conductivity exceeded 11 dS m^{-1}. The growth was characteristic of a halophyte with a significant increase in leaf area at 11 dS m^{-1} as compared with 3 dS m^{-1} controls. As to wheat, plant fresh and dry weight, canopy height, and leaf area did not differ between controls (3 dS m^{-1}) and plants grown at 7 dS m^{-1}. Beyond this threshold, however, plant growth declined. While both quinoa and wheat exhibited increasing Na^+ accumulation with increasing salinity levels, the percentage increase was greater in wheat. Examination of ion ratios indicated that K^+:Na^+ ratio decreased with increasing salinity in both species. The decrease was more dramatic in wheat. A similar observation was also made with respect to the Ca^{2+}:Na^+ ratios. However, a difference between the two species was found with respect to changes in the level of K^+ in the plant. In quinoa, leaf K^+ levels measured at 19 dS m^{-1} had decreased by only 7% compared with controls. Stem K^+ levels were not significantly affected. In wheat, shoot K^+ levels had decreased by almost 40% at 19 dS m^{-1}. Correlated with these findings, we measured no change in the K^+:Na^+ selectivity with increasing salinity in quinoa leaves and only a small increase in stems. In wheat however, K^+:Na^+ selectivity at 3 dS m^{-1} was much

higher than in quinoa and decreased significantly across the four salinity levels tested. A similar situation was also noted with Ca^{2+}:Na^{+} selectivity. We concluded that the greater salt tolerance found in quinoa relative to wheat may be due to a variety of mechanisms.

2.4. Yield parameters

Greenway and Munns (1980**)** reported that salt tolerance is usually assessed as the percent biomass production in saline versus control conditions over a prolonged period of time. Dramatic differences are found between plant species. For example, after some time in 200 mM NaCl a salt-tolerant species such as sugarbeet might have a reduction of only 20% in dry weight, a moderately tolerant species such as cotton might have a 60% reduction, and a sensitive species such as soybean might be dead.

Flowers *et al*. (1977, 1986) reported that a halophyte such as *Suaeda maritima* might be growing at its optimum rate. Salt tolerance can also be assessed in terms of survival, which is quite appropriate for perennial species, but for annual species, particularly for broadacre or horticultural crops, the rate of biomass production is more useful, as this usually correlates with yield.

Munns *et al*. (1995) reported that over short periods of time in salinity, it was found no differences between durum and bread wheat cultivars, nor between barley and triticale cultivars.

Munns *et al*. (1995) studied that including one that had proven to be the most sensitive (a durum wheat) and one (a barley) found to be the most tolerant). This led to consideration of time scale and the different mechanisms that may be important in controlling growth at different periods of time for plants exposed to salinity.

Koyro (2008) reported that *Chenopodium quinoa* was able to complete its life cycle and produced seeds even at seawater salinity. However, the growth

furthermore, the yield, number of seeds, weight and seed dry matter per plant were significantly reduced in the presence of salinity. The content of proteins (as well as total N) increased significantly in the seeds whereas the content of total carbohydrates (as well as total C) decreased remarkably leading to the overall picture of a decreased C/N ratio. At high salinity the passage of NaCl into the seed was hindered. There seems to be a correlation between these effects, the salinity resistance of the plant and a possible preadjustment to saline conditions of the produced seed. However, further studies are essentially needed and it is advisable to study more intense the influence of salinity on the regulation of grain-filling, usability, genomics, gene expression.

Razzaghi *et al.* (2011) reported that drought and salinity reduce crop productivity especially in arid and semi-arid regions, and finding a crop which produces yield under these adverse conditions is therefore very important. Quinoa (*Chenopodium quinoa* Willd.) is such a crop. Quinoa was exposed to five salinity levels (0, 10, 20, 30 and 40 dS/m) of irrigation water from flower initiation onwards. During the seed filling phase, the salinity levels were divided between two levels of irrigation, either full irrigation or non irrigated progressive drought. The intercepted photosynthetically active radiation was hardly affected by salinity (8% decrease at 40 dS/m) and did not suffer significantly between FI and PD. No negative effects of severe salinity could be detected. Salinity levels between 20 and 40 dS/m significantly reduce the seed yield by 33% compared with control treatment. Consequently, nitrogen harvested in seed was decreased by salinity although the total nitrogen uptake was increased. Both salinity and drought increased the water productivity of dry matter. It shows that quinoa (cv. Titicaca) acclimated to saline conditions when exposed to salinity levels between 20 and 40 dS/m.

2.5. Effect of salinity

Turki *et al.* (2014) conducted an experiment with thirty-six highly tolerant and 16 highly susceptible wheat varieties which were evaluated in the saline area in the field. The results showed that tolerant varieties could grow and develop biomass under saline conditions. In contrast, susceptible varieties could not even emerge in the stressed condition. They also showed that at seedling stage 100 mM NaCl decreased chlorophyll content, leaf length, number of tillers per plant, number of leaves per plant, shoot length and shoot fresh and dry weights, while at maturity stage plant height, the number of fertile spikes per plant and the number of seeds per spike were affected by at seedling stage 100 mM NaCl. The shoot fresh and dry weights were the most affected traits at seedling stage; however the number of fertile spikes and the number of seeds per spike were the most affected traits at maturity stage.

A field experiment was conducted by Jiang *et al.* (2013) to study the effects of deficit irrigation with saline water on spring wheat growth and yield in an arid region of Northwest China. They applied nine treatments included three salinity levels S1, S2 and S3 (0.65, 3.2, and 6.1 dSm-1) in combination with three water levels W1, W2 and W3 (375, 300, and 225 mm). For most treatments, deficit irrigation showed adverse effects on wheat growth; meanwhile, the effect of saline irrigation was not apparent. At 3.2 and 6.1 dS/m, the highest yield was obtained by W1 treatments, however, the weight of 1,000 grains and wheat yield both followed the order W2> W1 > W3. They showed that, spring wheat was sensitive to water deficit, especially at the booting to grain-filling stages, but was not significantly affected by saline irrigation and the combination of the two factors. The results demonstrated that 300 mm irrigation water with a salinity of less than 3.2 dS/m is suitable for wheat fields in the study area.

A pot experiment was conducted to study the effect of different salinity levels, i.e. EC= 3 dS/m (control), 8, 12 and 16 dS/m on four wheat grain yield, yield components and leaf ion uptake. Result revealed that higher grain yield production, higher leaf K+ concentration, K+:Na+ ratio and lower leaf Na+ and Cl− concentration were observed in Kouhdasht, followed by Attrak, Rasoul and Tajan, respectively (Asgari *et al*., 2012).

Kumar *et al.* (2012) conducted an experiment on eight genotypes of wheat with varying in their salt tolerance level, to evaluate effect of salinity on germination, growth, and yield related parameters. Lower salinity (3dS/m) did not affect the germination, growth and yield attributing parameters. Higher salinity levels reduced germination, growth and yield attributing parameters. Genotypes K9644 and K9465 showed maximum reduction in all these regards. Genotypes K9006, K8434, KRL1-4, K88 and HD2733 showed hardness against higher levels of salinity.

An experiment has been carried out by Akbari ghogdi *et al*. (2012) on four cultivars of wheat (Neishabor and Sistani as salt tolerant and Bahar and Tajan as salt sensitive) were exposed to four salinity levels (1.3 dS/m as control, 5, 10, 15 dS/m) via calcium chloride and sodium chloride with 1:10 (Ca^{2+}:Na^{+} ratio). Chlorophyll content (CHL), Leaf relative water content (RWC), sodium and potassium contents, and also K^{+}/Na^{+} ratio were measured at tillering and flowering stages, Total grain yield and yield components were determined. Salinity stress decreased relative water content (RWC), K^{+} content, K^{+}/Na^{+} ratio and grain yield; however Na^{+} content in all the genotypes and in both stages were increased. CHL content increased at tillering stage while it is decreased at flowering stage. Sistani and Neishabour cultivars had more amounts of K^{+} content, K^{+}/Na^{+} ratio and RWC under salt conditions, at tillering stage Bahar and Tajan cultivars recorded higher CHL and sodium content at both stages. Results showed that the salinity tolerance in tolerant cultivars as

manifested by lower decrease in grain yield is associated with the lower sodium accumulation and higher K^+/Na^+ compared to the sensitive cultivars.

A pot experiment was carried out by Al-Musa *et al.* (2012) to study the performance of some BARI wheat varieties under the coastal area of Patuakhali. Four wheat varieties viz. BARI Gom 23, BARI Gom 24, BARI Gom 25 and BARI Gom 26 were planted in the field to evaluate their comparative performance in respect of germination percentage, growth, yield and yield attributing characters. Among the four varieties, BARI Gom 26 showed superior performance irrespective of all parameters studied except total dry matter content (TDM) and yield reduction percentage. Among the BARI varieties, BARI Gom 26 produced greater germination (61.00%) at 13 days judge against to other varieties. The taller plant (47.91 cm), higher LAI (1.84), maximum TDM (17.37 g $plant^{-1}$) and effective tillers $hill^{-1}$ (18.08) were also obtained with the similar variety. BARI Gom 26 was also most effective to produce the maximum grains $spike^{-1}$ (38.52), higher weight of 1000-grains (49.38 g), higher grain (3.35 t ha^{-1}) and straw (8.50 g $plant^{-1}$) yield and greater HI (4.03%).

Sadat Noori *et al.* (2010) conducted an experiment to examine the morpho-physiological effects of eight wheat genotype (Cajema × Sette Cerros, Cajema × HO2 and Cajema × Lermaroja as hybrid; Sette Cerros, HO2, Lermaroja, Cajema as parent and Axona as a control) with the application of four saline solutions (0, 150, 200 and 250 mM NaCl) As salinity levels increased, yield and 1000 grain weight and K+ concentration declined. Based on Na/K ratio, the best physiological characteristic for recognizing sensitive and tolerant genotypes, Cajema was the most tolerant genotype. Hybrids produced in this study weren't good for salinity condition and the hybrids didn't show more feature than their parents.

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, fertilizer application, uprooting of seedlings, intercultural operations, data collection and statistical analysis.

3.1 Location

The experiment was conducted at the experimental net house of the Department of Agronomy, Sher-e-Bangla Agricultural University, Dhaka (90°77' E longitude and 23°77' N latitude) during the period from November, 2017 to March, 2018. The location of the experimental site has been shown in Appendix I.

3.2 Climate

The experimental area was under the subtropical climate and was characterized by high temperature, high humidity and heavy precipitation with occasional gusty winds during the period from April to September, but scanty rainfall associated with moderately low temperature prevailed during the period from October to March. The detailed meteorological data in respect of air temperature, relative humidity, rainfall and sunshine hour recorded by the meteorology center, Dhaka for the period of experimentation have been presented in Appendix II.

3.3 Soil

The soil of the experimental area belonged to the Modhupur tract (AEZ No. 28). It was a medium high land with non-calcarious dark grey soil. The pH value of the soil was 5.6. The physical and chemical properties of the experimental soil have been shown in Appendix III.

3.4 Plant materials

Seeds of two quinoa varieties namely Titicaca and Vikinga were collected from personal contact of Wageningen University, Denmark. Before sowing, the first experiment was conducted at laboratory where the seeds were tested for germination and the percentage of germination was found to be over 80% for the two varieties.

3.5 Germination test

Germination test was done before sowing the seeds in the field. Filter paper was placed on petridishes and the papers were soaked with water. Seeds were distributed at random in petridishes. Data on sprouted seeds were collected and converted to percentage basis by using the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Number of seeds set for germination}} \times 100$$

The details of second experiment was as below:

3.6 Experimental treatments

The experimental treatments were as follows:

Factor A: Variety - 2

1. Titicaca
2. Vikinga

Factor B: Salinity levels - 7

1. Control (no salinity)
2. EC 5 dS/m
3. EC 10 dS/m
4. EC 15 dS/m

5. EC 20 dS/m
6. EC 25 dS/m
7. EC 30 dS/m

3.7 Experimental design and layout:

Both the experiments were laid out in a Randomized Complete Block Design (RCBD) (factorial) with three replications. Factorial arrangements of treatments were made at random. The experimental design has been shown in Appendix IV.

3.8 Pot preparation

Empty earthen pots with 18 inch depth were used for the experiment. The collected soil was sun dried, crushed and sieved. The soil and fertilizers were mixed well before placing the soils in the pots. Each pot was filled up with 12 kg soil. Pots were placed at the net house of Sher-e Bangla Agricultural University. The pots were pre-labeled for each variety and treatment. Finally, water was added to bring soil water level to field capacity.

3.9 Fertilizer and manure application

The experimental plots were fertilized with a recommended dose of 100-90-60 kg ha^{-1} of N, P_2O_5 and K_2O respectively from their sources of Urea, TSP and MoP. The pot was filled with 6-4-3g of N, P_2O_5 and K_2O respectively from their sources of Urea, TSP, MoP. The half of urea and the whole amount of other fertilizers applied as basal during final pot preparation and the rest urea as top dressing before flowering.

3.10 Salinity treatment

The salinity treatments were started at 30 DAS. Total six doses were given. Subsequent doses were given at six days interval. There were seven salinity levels including control where salinity developed by adding respected amount of commercial NaCl salt to the soil/pot as water dissolved solution. In order to spread homogenously in each pot the salts were dissolved in water and were

added to pots for proper salinity imposition. For the preparation of 5, 10, 15, 20, 25 and 30 dS/m salt solution, 9g, 18g, 27g, 36g, 45g and 54g of NaCl salt was dissolved respectively in 3000ml of normal water by using the formula:

Mass = Concentration × Volume × Molar weight

1M = 58.5g of NaCl and 1 mmol/L = EC (dS/m) × 10

3.11 Sowing of seeds

Seeds were sown on 10th November, 2017. Four healthy seeds of each variety were sown in each pot. After germination one plant were allowed to grow in each pot.

3.12 Intercultural operations

3.12.1 Gap filling and thinning

After sowing seeds continuous observation was kept. It was observed that no single seed failed to germinate. So, there was no need of gap filling. Keen observation was made for thinning to maintain 1 seedling per pot.

3.12.2 Weeding and watering

Sometimes there were some weeds observed in pots which were uprooted manually. First weeding was done at 30 DAS. Watering was given frequently when needed and after salt treatment to maintain field capacity moisture level.

3.12.3 Plant protection measure

There was aphid attack in the early vegetative stage. Ripcord 1ml/L was sprayed. There was also cutworm attack appeared in both vegetative and reproductive stages. Cut worms were removed manually. After 1 rain in this period, damping off occurred. Necessary measures had been taken to protect the plants. At the end, rats attack occurred. Pesticide mixed with dried fish was applied at the corner of the pots. Moreover, the pots were protected by netting to prevent birds or animals.

3.13 Harvesting and Processing

The experimental crop was harvested at maturity when 80% of the inflorescence turned reddish yellow in colour. Harvesting was done in the morning to avoid shattering. The crop was sun dried properly by spreading them over floor and seeds were separated from the inflorescence by beating the bundles with the help of bamboo sticks. The seeds thus collected were dried in the sun for reducing the moisture in the seed to about 9% level. The husk and straws were also dried in the sun and weight was recorded. The biological yield was calculated as the sum of the seed yield and husk and straw yield.

3.14 Sampling and data collection

The following data were collected during the study:

1. Germination test (%)
2. Plant height (cm)
3. Number of branches plant $^{-1}$
4. Number of leaves plant^{-1}
5. Number of inflorescence plant^{-1}
6. Length of inflorescence plant^{-1} (cm)
7. 1000-seed weight (g)
8. Yield plant^{-1} (g)
9. Husk weight plant^{-1} (g)
10. Straw weight plant^{-1} (g)
11. Biological yield plant^{-1} (g)
12. Harvest index (%)

3.15 Procedure of recording data

3.15.1 Plant height (cm)

The height was measured from ground level (stem base) to the tip of the plant from each replication. Mean plant height was calculated and expressed in cm.

3.15.2 Number of branches per plant

The number of branches was counted and recorded from each plant of each pot. Average value was recorded as number of branches per plant.

3.15.2 Number of leaves plant^{-1}

Total leaves from each plant of each replication was counted and average was recorded as number of leaves per plant

3.15.3 Number of inflorescence plant^{-1}

Number of inflorescence of each plant from each pot was counted and average was recorded as Number of inflorescence plant^{-1}.

3.15.4 Length of inflorescence plant^{-1} (cm)

The inflorescence length was measured from base to tip of the inflorescence from each plant of each replication. Mean was calculated and expressed in cm.

3.15.5 Weight of 1000-seeds (g)

One hundred clean sun dried grains were counted from the seed stock obtained from the sample plants and weighed by using an electronic balance. Then it was converted into thousand grain weight.

3.15.6 Yield plant^{-1} (g)

The seeds were separated by threshing per plant and then sun dried and weighed.

3.15.7 Husk weight plant^{-1} (g)

The husks were separated by threshing per plant and weighed.

3.15.8 Straw weight plant^{-1} (g)

The straw were separated by threshing per plant and weighed.

3.15.9 Biological yield plant^{-1} (g)

Biological yield was calculated by using the following formula:

Biological yield= Grain yield + straw and husk yield

3.15.10 Harvest index (%)

It denotes the ratio of economic yield to biological yield and was calculated following the formula of Gardner *et al*. (1985). It was calculated by using the following formula:

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

3.16 Statistical analysis

The data obtained for different parameters were statistically analyzed following computer based software STATISTICS 10 and mean differences among treatments were tested with Duncan's Multiple Range Test at 5% level of probability.

CHAPTER IV

RESULTS AND DISCUSSION

Variety and salinity effect on seed germination, growth and yield of quinoa (*Chenopodium quinoa*) have been presented and discussed in this chapter. The analysis of variance of data on different characteristics of quinoa plants obtained from the present investigations has been presented in Appendix V-X. The results and possible interpretations of the results have been given under the following headlines for easy of discussion, comprehension and understanding.

4.1 Germination rate under salinity levels

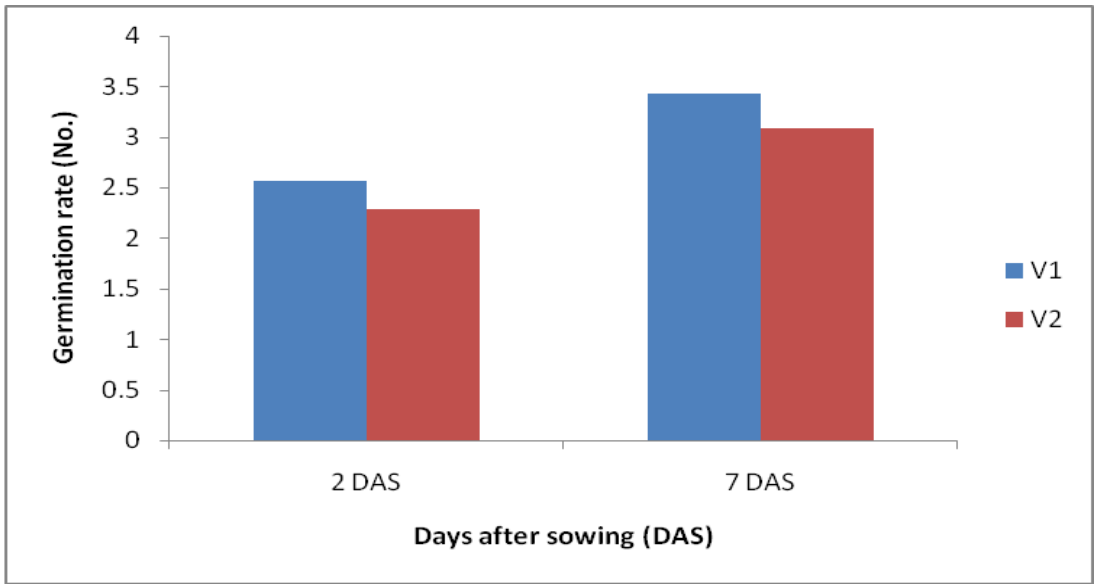
Effect of variety

Varity had no significant effect on germination rate (Fig. 1 and Appendix V). However, the higher germination rate (2.57 and 3.43 out of 4 seeds at 2 and 7 DAS, respectively) was found from the variety V_1 (Titicaca) and the lower germination rate (2.28 and 3.09 out of 4 seeds at 2 and 7 DAS, respectively) was found from the variety V_2 (Vikinga). The germination percentage of Titicaca was 64.25 and 85.75 at 2 and 7 DAS respectively whereas it was 57.0 and 77.25 at 2 and 7 DAS respectively for the other variety Vikinga.

Effect of salinity

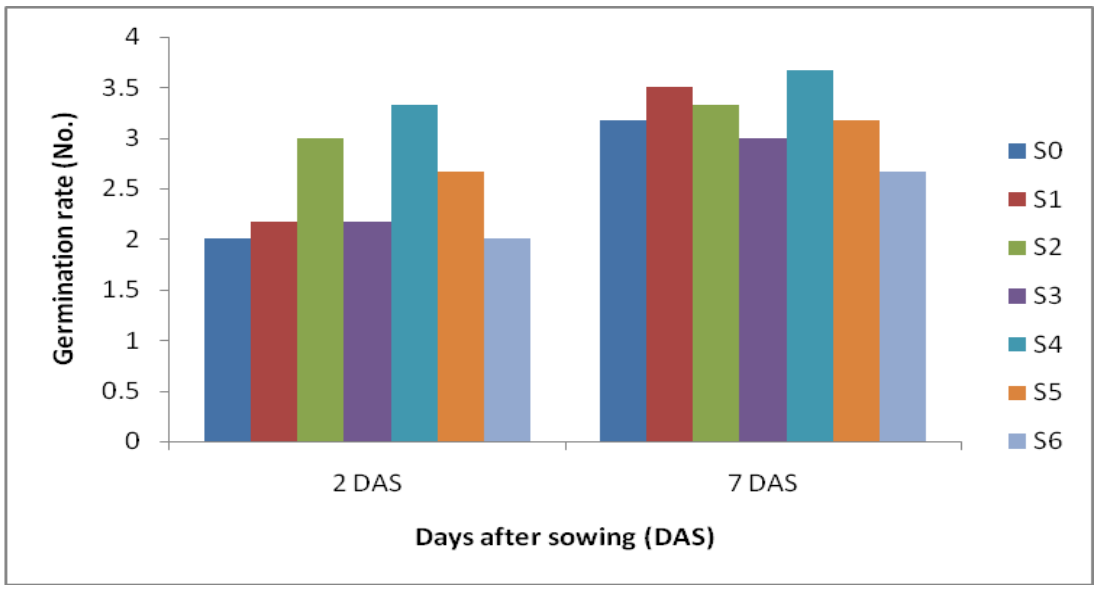
Germination rate was significantly affected by different salinity levels (Fig. 2 and Appendix V). Results showed that the highest germination rate (3.33 (83.25%) and 3.67 (91.75%) out of 4 seeds at 2 and 7 DAS, respectively) was found from the salinity level S_4 (EC 20 dS/m) and the lowest germination rate (2.00 (50.0%) and 2.67 (66.75%) at 2 and 7 DAS, respectively) was found from the salinity level S_6 (EC 30 dS/m). Finally, at 7 DAS, the treatment S_4 (EC 20 dS/m) gave the highest germination rate (3.67 (91.75%) out of 4 seeds) which was statistically similar with S_0 (control), S_1 (EC 5 dS/m), S_2 (EC 10 dS/m) and

S_5 (EC 25 dS/m) where S_6 (EC 30 dS/m) showed the lowest germination rate (2.67 (66.75%) out of 4 seeds) which was statistically similar with S_3 (EC 15 dS/m). Similar result was also observed by Gomez *et al*. (2010).



V_1 = Titicaca, V_2 = Vikinga

Fig. 1. Effect of variety on germination rate (out of 4.0) of quinoa seeds (SE± = 0.23^{NS} and 0.16^{NS} at 2 and 7 DAS, respectively)



S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

Fig. 2. Effect of salinity on germination rate (out of 4.0) of quinoa seeds (SE± = 0.89^{NS} and 0.31^{NS} at 2 and 7 DAS, respectively)

Combined effect of variety and salinity

Treatment combination of variety and salinity levels showed significant variation on germination rate (Table 1 and Appendix V). Results revealed that the highest germination rate (3.67 and 4.00 out of 4 seeds at 2 and 7 DAS, respectively) was found from the treatment combination of V_1S_4 and the lowest germination rate (1.67 and 2.67 out of 4 seeds at 2 and 7 DAS, respectively) was found from the treatment combination of V_2S_6. Results also revealed that at 7 DAS, the highest germination rate (4.00 out of 4 seeds) which was found from V_1S_4 which was statistically similar with V_1S_1 and V_2S_4 where the lowest germination rate (2.67 out of 4 seeds) was found from the treatment combination of V_2S_6 which was statistically similar with V_2S_3.

Table 1. Combined effect of variety and salinity on germination test of quinoa seeds

Treatments	Germination rate at	
	2 DAS	7 DAS
V_1S_0	2.33 bc **(58.25)**	3.33 ab **(83.25)**
V_1S_1	2.00 bc **(50.0)**	3.67 a **(91.75)**
V_1S_2	3.00 ab **(75.0)**	3.33 ab **(83.25)**
V_1S_3	2.00 bc **(50.0)**	3.33 ab **(83.25)**
V_1S_4	3.67 a **(91.75)**	4.00 a **(100.0)**
V_1S_5	2.67 abc **(66.75)**	3.33 ab **(83.25)**
V_1S_6	2.33 bc **(58.25)**	3.33 ab **(83.25)**
V_2S_0	1.67 c **(41.75)**	3.00 ab **(75.0)**
V_2S_1	2.33 bc **(58.25)**	3.33 ab **(83.25)**
V_2S_2	3.00 ab **(75.0)**	3.33 ab **(83.25)**
V_2S_3	2.33 bc **(58.25)**	2.67 b **(66.75)**
V_2S_4	2.67 abc **(66.75)**	3.67 a **(91.75)**
V_2S_5	2.33 bc **(58.25)**	3.00 ab **(75.0)**
V_2S_6	1.67 c **(41.75)**	2.67 b **(66.75)**
SE (±)	0.616	0.435
CV(%)	8.87	7.52

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m**,** bold one in parenthesis denotes percentage.

4.2 Growth parameters

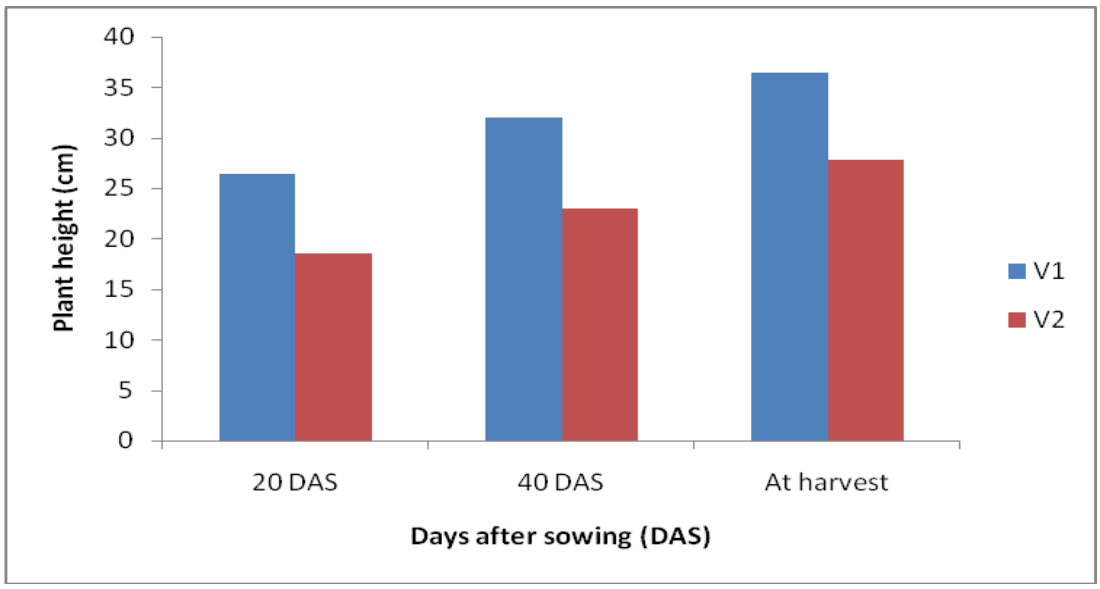
4.2.1 Plant height (cm)

Effect of variety

Plant height was significantly influenced by different variety of quinoa at different growth stages (Fig. 3 and Appendix VI). Results showed that the higher plant height (26.40, 31.95 and 36.43 cm at 20, 40 DAS and at harvest, respectively) was found from the variety V_1 (Titicaca) whereas the lower plant height (18.55, 23.01 and 27.77 cm at 20, 40 DAS and at harvest) was found from the variety V_2 (Vikinga).

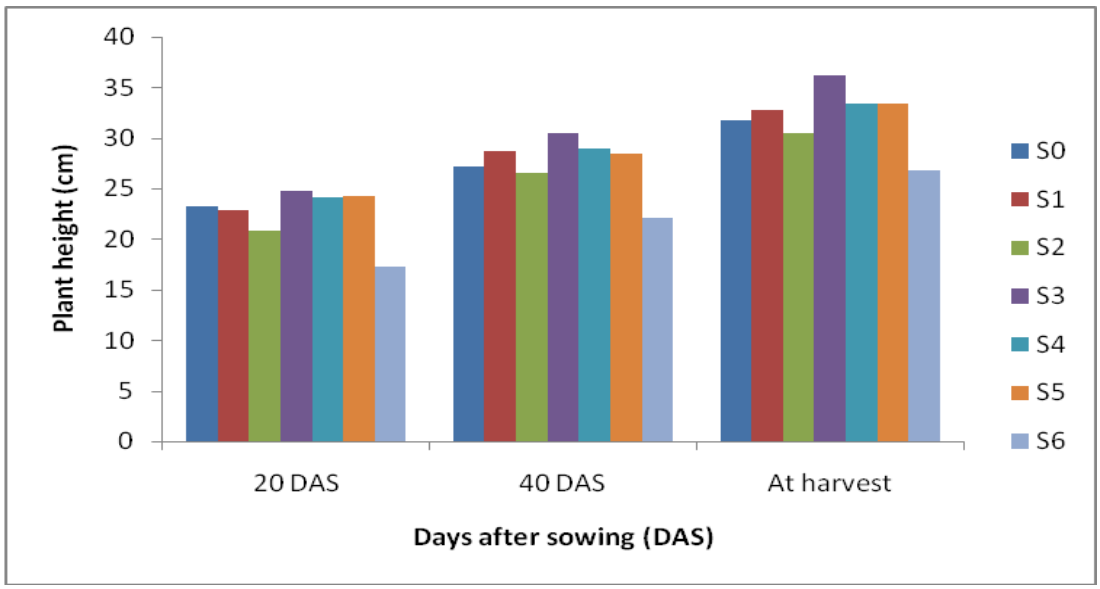
Effect of salinity

Remarkable variation was observed on plant height at different growth stages due to the effect of different salinity levels (Fig. 4 and Appendix VI). The highest plant height (24.71, 30.50 and 36.17 cm at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_3 (EC 15 dS/m) which was statistically similar with S_0 (control), S_1 (EC 5 dS/m), S_2 (EC 10 dS/m), S_4 (EC 20 dS/m) and S_5 (EC 25 dS/m) at all growth stages. The lowest plant height (17.28, 22.06 and 26.78 cm at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_6 (EC 30 dS/m). The result found from the present study was similar with findings of John and Essam Abo-Kassem (2007) who reported that leaf k^+ levels decreased by only 7% with salinity level of 19 dS/m in quinoa with higher plant height whereas the same salinity level decreased 40% k^+ level with lower plant height.



V_1 = Titicaca, V_2 = Vikinga

Fig. 3. Effect of variety on plant height of quinoa (SE± = 1.90, 3.55 and 5.02 at 20 and 40 DAS and at harvest, respectively)



S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

Fig. 4. Effect of salinity on plant height of quinoa (SE± = 1.82, 3.40 and 4.80 at 20 and 40 DAS and at harvest, respectively)

Combined effect of variety and salinity

Considerable influence was found at different growth stages on plant height persuaded by combined effect of variety and salinity levels (Table 2 and Appendix VI). The highest plant height (34.03, 39.96 and 44.60 cm at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_1S_3 which was statistically similar with V_1S_5 at the time of harvest. The lowest plant height (14.60, 20.26 and 24.06 cm at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_2S_2 at the time of harvest.

Table 2. Combined effect of variety and salinity on plant height of quinoa

Treatments	Plant height (cm) at		
	20 DAS	40 DAS	At harvest
V_1S_0	25.66 abc	29.43 bcd	33.76 bcd
V_1S_1	26.50 abc	33.66 ab	37.26 abc
V_1S_2	23.96 abcd	31.70 abc	35.36 abc
V_1S_3	34.03 a	39.96 a	44.60 a
V_1S_4	27.13 abc	31.73 abc	36.33 abc
V_1S_5	30.00 ab	33.33 abc	38.20 ab
V_1S_6	17.53 cd	23.86 bcd	29.50 bcd
V_2S_0	20.70 bcd	24.90 bcd	29.76 bcd
V_2S_1	19.33 cd	23.80 bcd	28.26 cd
V_2S_2	17.70 cd	21.43 d	25.56 d
V_2S_3	17.03 cd	21.03 d	27.73 cd
V_2S_4	21.10 bcd	26.13 bcd	30.36 bcd
V_2S_5	19.43 cd	23.53 cd	28.66 bcd
V_2S_6	14.60 d	20.26 d	24.06 d
SE	1.794	3.356	4.747
CV(%)	9.38	12.78	13.64

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

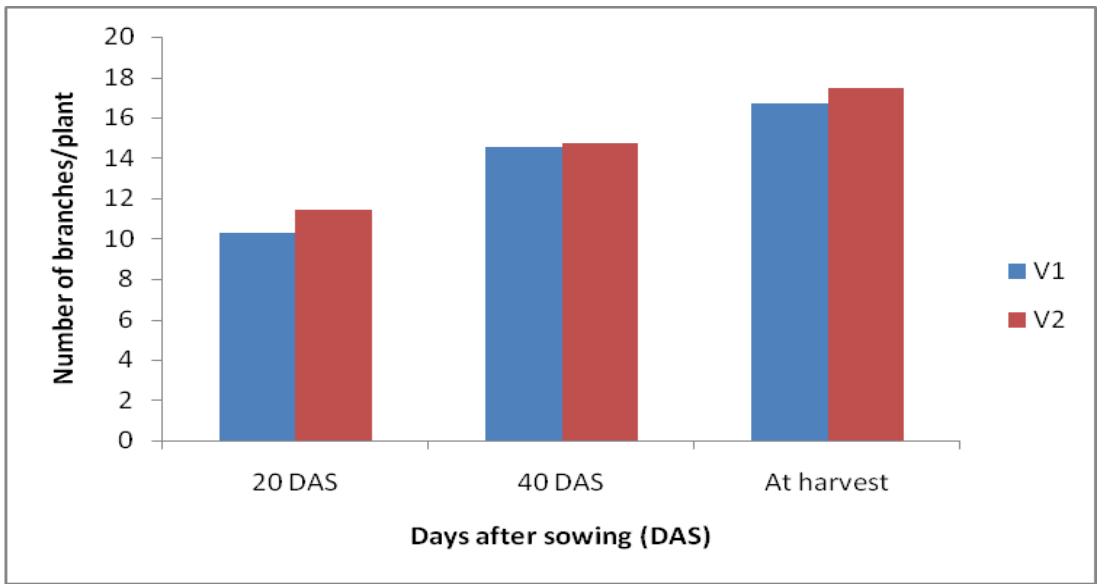
4.2.2 Number of branches plant^{-1}

Effect of variety

Significant influence was not found on number of branches plant^{-1} at different growth stages affected by different variety (Fig. 5 and Appendix VII). However, the highest number of branches plant^{-1} (11.42, 14.57 and 17.43 at 20, 40 DAS and at harvest, respectively) was found from the variety V_2 (Vikinga) and the lowest number of branches plant^{-1} (8.00, 12.50 and 15.50 at 20, 40 DAS and at harvest, respectively) was found from the variety V_1 (Titicaca).

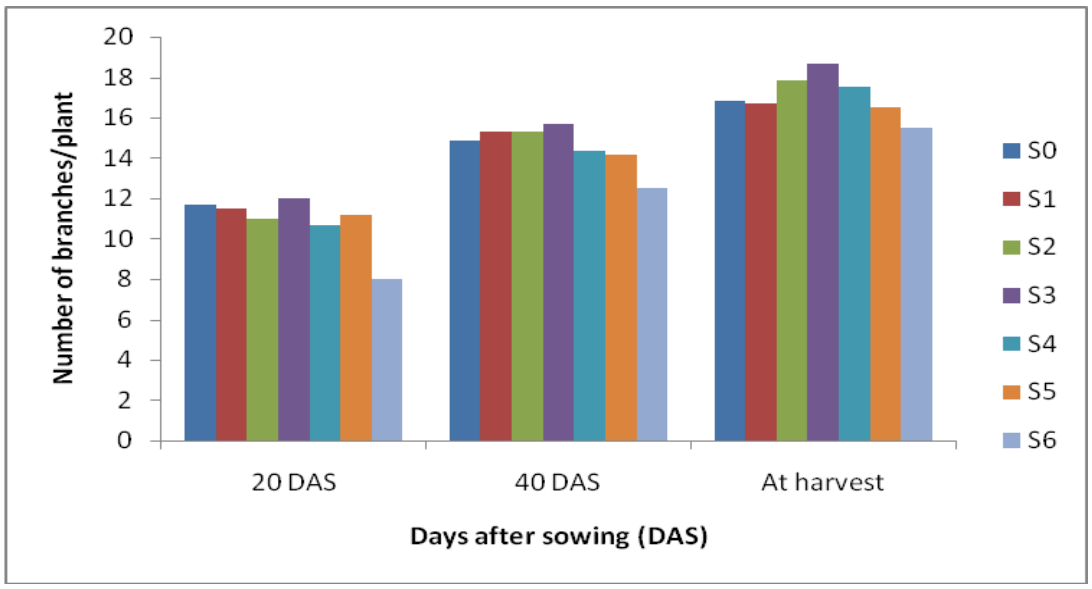
Effect of salinity

Significant variation was not found on number of branches plant^{-1} at different growth stages as influenced by different salinity levels (Fig. 6 and Appendix VII). However, the highest number of branches plant^{-1} (12.00, 15.67 and 18.67 at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_3 (EC 15 dS/m) and the lowest number of branches plant^{-1} (8.00, 12.50 and 15.50 at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_6 (EC 30 dS/m).



V_1 = Titicaca, V_2 = Vikinga

Fig. 5. Effect of variety on number of branches plant^{-1} of quinoa (SE± =1.12^{NS}, 1.13^{NS} and 1.21^{NS} at 20 and 40 DAS and at harvest, respectively)



S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

Fig. 6. Effect of salinity on number of branches plant^{-1} of quinoa (SE± =2.09^{NS}, 2.11^{NS} and 2.27^{NS} at 20 and 40 DAS and at harvest, respectively)

Combined effect of variety and salinity

Significant variation on number of branches plant^{-1} was found influenced by combined effect of variety and salinity levels at at all growth stages except 40 DAS (Table 3 and Appendix VII). The highest number of branches plant^{-1} (14.00, 17.67 and 20.67 at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_1S_3 where the lowest number of branches plant^{-1} (6.33, 12.00 and13.33 at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S

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Table 3. Combined effect of variety and salinity on number of branches plant^{-1} of quinoa

Treatments	Number of branches plant^{-1} at		
	20 DAS	40 DAS	At harvest
V_1S_0	10.00 ab	12.67	17.00 ab
V_1S_1	10.00 ab	14.00	13.67 b
V_1S_2	12.67 a	12.67	18.33 ab
V_1S_3	14.00 a	17.67	20.67 a
V_1S_4	9.33 ab	15.67	16.00 ab
V_1S_5	11.67 ab	17.00	15.00 ab
V_1S_6	6.33 b	12.00	13.33 b
V_2S_0	12.00 ab	14.00	20.33 a
V_2S_1	13.00 a	16.67	17.33 ab
V_2S_2	10.67 ab	17.33	17.33 ab
V_2S_3	10.00 ab	13.67	16.67 ab
V_2S_4	12.00 ab	16.00	19.00 ab
V_2S_5	10.66 ab	12.67	18.00 ab
V_2S_6	9.67 ab	13.00	16.33 ab
SE	2.968	NS	3.223
CV(%)	9.76	12.28	13.52

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

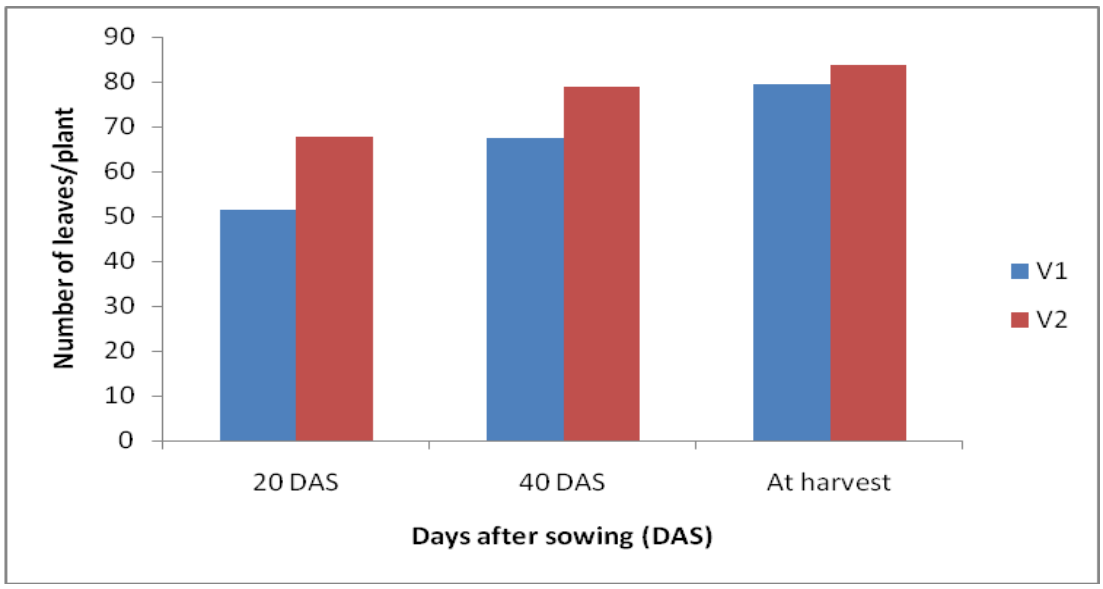
V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

4.2.3 Number of leaves plant^{-1}

Effect of variety

Number of leaves plant^{-1} at different growth stages varied significantly due to different varieties of quinoa (Fig. 7 and Appendix VIII). The higher number of leaves plant^{-1} (67.67, 78.76 and 83.81 at 20, 40 DAS and at harvest, respectively) was found from the variety V_2 (Vikinga) the lower number of leaves plant^{-1} (51.43, 67.48 and 79.48 at 20, 40 DAS and at harvest, respectively) was found from the variety V_1 (Titicaca).

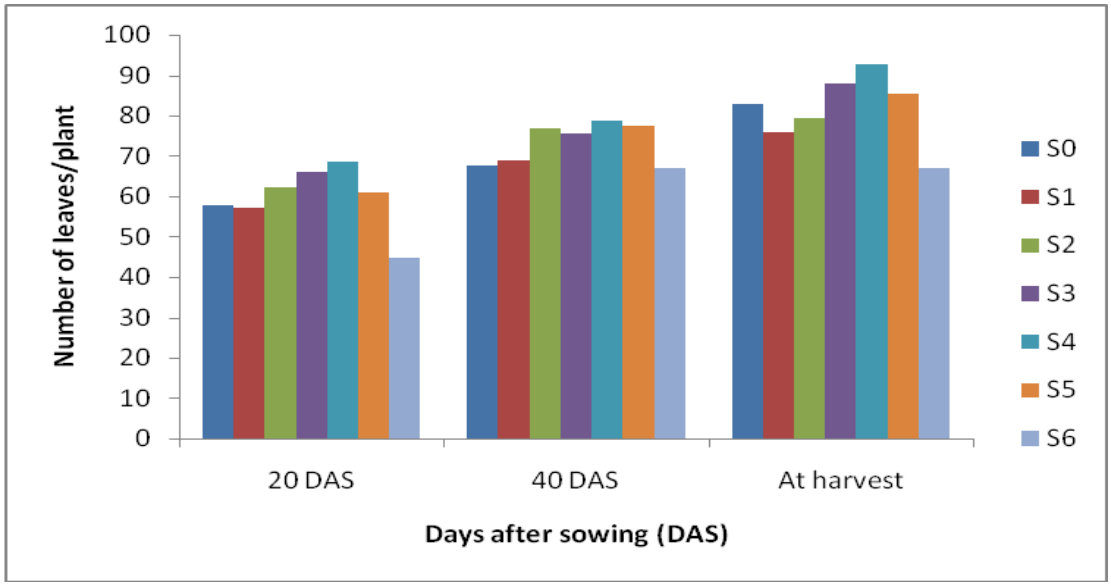


V_1 = Titicaca, V_2 = Vikinga

Fig. 7. Effect of variety on number of leaves plant^{-1} of quinoa (SE± = 4.69, 4.04 and 4.55 at 20 and 40 DAS and at harvest, respectively)

Effect of salinity

Variation on number of leaves plant^{-1} was affected significantly by different salinity levels (Fig. 8 and Appendix VIII). The highest number of leaves plant^{-1} (68.67, 78.67 and 92.83 at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_4 (EC 20 dS/m) which was statistically similar with S_3 (EC 15 dS/m) at the time of harvest. The lowest number of leaves plant^{-1} (44.67, 67.00 and 67.00 at 20, 40 DAS and at harvest, respectively) was found from the salinity level S_6 (EC 30 dS/m) which was significantly different from all other treatments followed by S_1 (EC 5 dS/m). Sanchez *et al.* (2006) also reported better absolute and relative growth rate of quinoa with higher salinity levels.



S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

Fig. 8. Effect of salinity on number of leaves plant^{-1} of quinoa (SE± = 8.77, 7.09 and 12.27 at 20 and 40 DAS and at harvest, respectively)

Combined effect of variety and salinity

The recorded data on number of leaves plant^{-1} was significantly influence by combined effect of variety and salinity levels (Table 4 and Appendix VIII). Results revealed that the highest number of leaves plant^{-1} (75.33, 91.67 and109.00 at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_2S_4 whereas the the lowest number of leaves plant^{-1} (33.33, 55.33 and 60.33 at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_1S_6.

Table 4. Combined effect of variety and salinity on number of leaves plant^{-1} of quinoa

Treatments	Number of leaves plant^{-1} at		
	20 DAS	40 DAS	At harvest
V_1S_0	46.33 bc	62.67 ab	69.00 bc
V_1S_1	50.67 abc	64.00 ab	70.33 bc
V_1S_2	55.00 abc	73.33 ab	83.33 abc
V_1S_3	61.67 ab	77.00 ab	96.33 ab
V_1S_4	51.00 abc	61.00 ab	76.67 abc
V_1S_5	62.00 ab	79.00 ab	87.00 abc
V_1S_6	33.33 c	55.33 b	60.33 c
V_2S_0	69.33 ab	78.67 ab	96.67 ab
V_2S_1	63.67 ab	73.67 ab	81.33 abc
V_2S_2	69.33 ab	80.33 ab	75.67 abc
V_2S_3	70.33 ab	74.33 ab	79.67 abc
V_2S_4	75.33 a	93.67 a	109.00 a
V_2S_5	70.67 ab	78.33 ab	84.00 abc
V_2S_6	55.00 abc	72.33 ab	73.67 abc
SE	12.40	15.99	17.335
CV(%)	13.63	11.92	14.38

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

4.3 Yield contributing parameters and yield

4.3.1 Number of inflorescence plant^{-1}

Effect of variety

Significant influence was noted on number of inflorescence plant^{-1} affected by different variety (Table 5 and Appendix IX). However, the higher number of inflorescence plant^{-1} (8.33) was found from the variety V_1 (Titicaca) and the lower number of inflorescence plant^{-1} (7.95) was found from the variety V_2 (Vikinga).

Effect of salinity

Number of inflorescence plant^{-1} varied significantly due to different salinity levels (Table 5 and Appendix IX). It was found that the highest number of inflorescence plant^{-1} (12.0) was found from the salinity level S_4 (EC 20 dS/m) which was significantly different from all other treatments followed by S_2 (EC 10 dS/m) and S_3 (EC 15 dS/m). The lowest number of inflorescence plant^{-1} (5.67) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_5 (EC 25 dS/m).

Combined effect of variety and salinity

Significant variation was remarked on number of inflorescence plant^{-1} as influenced by combined effect of variety and salinity levels (Table 5 and Appendix IX). The highest number of inflorescence plant^{-1} (12.3) was found from the treatment combination of V_1S_4 which was statistically similar with the treatment combination of V_2S_4. The lowest number of inflorescence plant^{-1} (5.33) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_6.

4.3.2 Length of inflorescence plant^{-1} (cm)

Effect of variety

Length of inflorescence plant^{-1} was not found significantly affected by different variety (Table 5 and Appendix IX). However, the higher length of inflorescence plant^{-1} (8.24cm) was found from the variety V_1 (Titicaca) and the lower length of inflorescence plant^{-1} (8.07cm) was found from the variety V_2 (Vikinga).

Effect of salinity

Variation on length of inflorescence plant^{-1} was significantly influenced by different salinity levels (Table 5 and Appendix IX). Results indicated that the highest length of inflorescence plant^{-1} (11.92cm) was found from the salinity level S_4 (EC 20 dS/m) which was significantly different from all other treatments followed by S_3 (EC 15 dS/m). The lowest length of inflorescence plant^{-1} (4.25cm) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_5 (EC 25 dS/m).

Combined effect of variety and salinity

Length of inflorescence plant^{-1} of quinoa was significantly affected by combined effect of variety and salinity levels (Table 5 and Appendix IX). The highest length of inflorescence plant^{-1} (12.67cm) was found from the treatment combination of V_1S_4 which was statistically similar with the treatment combination of V_2S_4. The lowest length of inflorescence plant^{-1} (4.00cm) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_5 and V_1S_6.

Table 5. Effect of variety and salinity and their combination on inflorescence number and length of quinoa

Treatments	Inflorescence number and length	
	Number of inflorescence plant^{-1}	Length of inflorescence plant^{-1} (cm)
Effect of variety		
V_1	8.33	8.24
V_2	7.95	8.07
SE	NS	NS
Effect of salinity		
S_0	7.00 c	6.92 d
S_1	7.50 c	8.59 c
S_2	8.84 b	9.50 bc
S_3	9.34 b	10.25 b
S_4	12.0 a	11.92 a
S_5	6.67 cd	5.67 de
S_6	5.67 d	4.25 e
SE	1.07	1.445
Combined effect of variety and salinity		
V_1S_0	7.00 cd	6.00 f
V_1S_1	7.67 c	8.67 de
V_1S_2	9.00 b	10.0 bcd
V_1S_3	9.67 b	10.5 bc
V_1S_4	12.3 a	12.67 a
V_1S_5	6.67 cd	5.33 fg
V_1S_6	6.00 de	4.50 fg
V_2S_0	7.00 cd	7.83 e
V_2S_1	7.33 c	8.50 de
V_2S_2	8.67 b	9.00 cde
V_2S_3	9.00 b	10.0 bcd
V_2S_4	11.6z a	11.17 ab
V_2S_5	6.67 cd	6.00 f
V_2S_6	5.33 e	4.00 g
SE	0.92	1.59
CV(%)	11.32	13.57

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

4.3.3 Weight of 1000 seeds (g)

Effect of variety

Significant influence was not found for 1000-seed weight affected by different variety (Table 6 and Appendix X). However, the higher 1000-seed weight (2.28 g) was found from the variety V_1 (Titicaca) and the lower 1000-seed weight (2.25 g) was found from the variety V_2 (Vikinga).

Effect of salinity

Significant influence was found on 1000-seed weight affected by different salinity levels (Table 6 and Appendix X). The highest 1000-seed weight (2.57 g) was found from the salinity level S_4 (EC 20 dS/m) which was statistically similar with S_3 (EC 15 dS/m). The lowest 1000-seed weight (2.03 g) was found from the salinity level S_6 (EC 30 dS/m) that similar to S_0 (control) and S_5 (EC 25 dS/m).

Combined effect of variety and salinity

Significant variation was remarked on 1000-seed weight as influenced by combined effect of variety and salinity levels (Table 6 and Appendix X). The highest 1000-seed weight (2.61 g) was found from the treatment combination of V_1S_4 which was statistically similar with V_2S_4 and statistically similar with V_1S_3 and V_2S_3. The lowest 1000-seed weight (2.00 g) was found from the treatment combination of V_2S_6 which was statistically similar with V_1S_5, V_1S_6 and V_2S_5.

4.3.4 Yield plant^{-1} (g)

Effect of variety

Yield plant^{-1} was not found significant with influenced by variety (Table 6 and Appendix X). However, the higher yield plant^{-1} (1.45 g) was found from the variety V_1 (Titicaca) and the lower yield plant^{-1} (1.43 g) was found from the variety V_2 (Vikinga).

Effect of salinity

Variation on yield plant^{-1} was found influenced by different salinity levels (Table 6 and Appendix X). The highest yield plant^{-1} (1.69 g) was found from the salinity level S_4 (EC 20 dS/m) which was statistically similar with S_2 (EC 10 dS/m) and S_3 (EC 15 dS/m) and also statistically similar with S_1 (EC 5 dS/m). The lowest yield plant^{-1} (1.25 g) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_5 (EC 25 dS/m). The result found from the present study was similar with findings of Anwar *et al.* (2018). They found that salinity stress increases quinoa drought tolerance in terms of yield and biomass production. Ruffino *et al.* (2010) mentioned that high adaptability of quinoa to soil salinity due to improved metabolic control based on ion absorption, osmolyte accumulation and osmotic adjustment.

Combined effect of variety and salinity

Yield plant^{-1} of quinoa was significantly affected by combined effect of variety and salinity levels (Table 6 and Appendix X). The highest yield plant^{-1} (1.71 g) was found from the treatment combination of V_1S_4 which was statistically similar with the treatment combination of V_1S_3 and V_2S_4. The lowest yield plant^{-1} (1.12 g) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_6 and statistically similar with the treatment combination of V_1S_5.

4.3.5 Husk weight plant^{-1} (g)

Effect of variety

The recorded data on highest husk weight plant^{-1} was not influenced significantly by different salinity levels (Table 6 and Appendix X). However, the higher husk weight plant^{-1} (0.78 g) was found from the variety V_1 (Titicaca) and the lower husk weight plant^{-1} (0.74 g) was found from the variety V_2 (Vikinga).

Effect of salinity

Considerable influence was observed on highest husk weight plant^{-1} persuaded by different salinity levels (Table 6 and Appendix X). The highest husk weight plant^{-1} (0.91 g) was found from the salinity level S_4 (EC 20 dS/m) which was statistically similar with S_1 (EC 5 dS/m), S_2 (EC 10 dS/m) and S_3 (EC 15 dS/m). The lowest husk weight plant^{-1} (0.57 g) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_0 (control) and S_5 (EC 25 dS/m).

Combined effect of variety and salinity

Remarkable variation was identified on husk weight plant^{-1} due to the combined effect of variety and salinity levels (Table 6 and Appendix X). The highest husk weight plant^{-1} (0.95 g) was found from the treatment combination of V_1S_4 which was statistically similar with the treatment combination of V_1S_2, V_1S_3, V_2S_3 and V_2S_4. The lowest husk weight plant^{-1} (0.52 g) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_6

4.3.6 Straw weight plant^{-1} (g)

Effect of variety

Significant influence was not observed on straw weight plant^{-1} affected by different variety (Table 6 and Appendix X). However, the higher straw weight plant^{-1} (1.66 g) was found from the variety V_1 (Titicaca) and the lower straw weight plant^{-1} (1.55 g) was found from the variety V_2 (Vikinga).

Effect of salinity

Straw weight plant^{-1} varied significantly due to different salinity levels (Table 6 and Appendix X). The highest straw weight plant^{-1} (2.44 g) was found from the salinity level S_4 (EC 15 dS/m) which was statistically similar with S_3 (EC 15 dS/m). The lowest straw weight plant^{-1} (0.95 g) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_0 (control) and S_5 (EC 25 dS/m). The result found from the present study was similar with findings of Anwar *et al.* (2018). They found that salinity stress increases quinoa drought tolerance in terms of biomass production. Hariadi et al. (2011) found maximum shoot biomass of quinoa at 100 mM NaCl treatment. Even at 500 mM salinity level a minor (below 20%) reduction in shoot weight was observed.

Combined effect of variety and salinity

Significant variation was remarked on straw weight plant^{-1} as influenced by combined effect of variety and salinity levels (Table 6 and Appendix X). The highest straw weight plant^{-1} (2.66 g) was found from the treatment combination of V_1S_4 which was significantly different from all other treatment combinations followed by V_1S_3 and V_2S_4. The lowest straw weight plant^{-1} (0.83 g) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_5 and V_1S_6.

4.3.7 Biological yield plant^{-1} (g)

Effect of variety

Biological yield plant^{-1} was not found significant influenced different variety (Table 6 and Appendix X)**.** However, the higher biological yield plant^{-1} (3.87 g) was found from the variety V_1 (Titicaca) and the lower biological yield plant^{-1} (3.75 g) was found from the variety V_2 (Vikinga).

Effect of salinity

Variation on biological yield plant^{-1} was noted significant as influenced by different salinity levels (Table 6 and Appendix X). The highest biological yield plant^{-1} (4.99 g) was found from the salinity level S_4 (EC 20 dS/m) which was significantly different from all other treatments followed by S_3 (EC 15 dS/m). The lowest biological yield plant^{-1} (3.08 g) was found from the salinity level S_6 (EC 30 dS/m) which was statistically similar with S_5 (EC 25 dS/m) and statistically similar with S_0 (control) and S_1 (EC 5 dS/m).

Combined effect of variety and salinity

Biological yield plant^{-1} of quinoa was significantly affected by combined effect of variety and salinity levels (Table 6 and Appendix X)**.** The highest biological yield plant^{-1} (5.12 g) was found from the treatment combination of V_1S_4 which was statistically similar with the treatment combination of V_2S_4. The lowest biological yield plant^{-1} (3.04 g) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_1S_5 and V_2S_5.

Table 6. Effect of variety and salinity and their combination on yield contributing parameters and yield of quinoa

Treatment	Yield contributing parameters and yield					
	1000 seed weight (g)	Yield plant^{-1} (g)	Husk weight plant^{-1} (g)	Straw weight plant^{-1} (g)	Biological yield plant^{-1} (g)	Harvest index (%)
Effect of variety						
V_1	2.28	1.45	0.78	1.66	3.87	37.78
V_2	2.25	1.43	0.74	1.55	3.75	38.35
SE	NS	NS	NS	NS	NS	NS
Effect of salinity						
S_0	2.16 cde	1.33 bc	0.73 bc	1.36 cd	3.45 cd	38.61 b
S_1	2.24 cd	1.50 ab	0.77 ab	1.56 c	3.61 cd	41.47 a
S_2	2.33 bc	1.58 a	0.81 ab	1.65 bc	3.82 c	41.38 a
S_3	2.47 ab	1.63 a	0.84 ab	2.06 ab	4.46 b	36.58 c
S_4	2.57 a	1.69 a	0.91 a	2.44 a	4.99 a	33.78 d
S_5	2.08 de	1.22 c	0.68 bc	1.22 cd	3.26 d	37.42 bc
S_6	2.03 e	1.25 c	0.57 c	0.95 d	3.08 d	37.23 bc
SE	0.1806	0.202	0.1564	0.4236	0.511	1.675
Combined effect						
V_1S_0	2.13 efg	1.31 de	0.72 bc	1.33 de	3.43 ef	38.19 bc
V_1S_1	2.29 de	1.51 c	0.79 bc	1.59 d	3.63 e	41.60 a
V_1S_2	2.36 bcd	1.60 abc	0.81 ab	1.66 cd	3.92 d	40.82 a
V_1S_3	2.48 ab	1.66 ab	0.84 ab	2.17 b	4.64 b	35.78 de
V_1S_4	2.61 a	1.71 a	0.98 a	2.66 a	5.12 a	33.40 f
V_1S_5	2.06 fg	1.20 ef	0.67 bcd	1.14 ef	3.24 fg	37.04 cd
V_1S_6	2.05 fg	1.17 f	0.62 cd	1.06 ef	3.11 g	37.62 bcd
V_2S_0	2.18 ef	1.35 d	0.74 bc	1.38 de	3.46 ef	39.02 b
V_2S_1	2.19 ef	1.48 c	0.75 bc	1.53 d	3.58 e	41.34 a
V_2S_2	2.30 cde	1.56 bc	0.80 bc	1.63 cd	3.72 de	41.94 a
V_2S_3	2.46 abc	1.60 abc	0.84 ab	1.95 bc	4.28 c	37.38 bcd
V_2S_4	2.53 a	1.66 ab	0.84 ab	2.21 b	4.86 ab	34.16 ef
V_2S_5	2.09 fg	1.24 def	0.68 bcd	1.29 de	3.28 fg	37.80 bc
V_2S_6	2.00 g	1.12 f	0.52 d	0.83 f	3.04 g	36.84 cd
SE	0.156	0.1277	0.1564	0.325	0.271	1.675
CV(%)	9.53	6.38	5.74	8.11	10.78	11.64

In a column figure having similar letter(s) do not differ significantly at 5% level whereas figures with dissimilar letter(s) differ significantly as per DMRT

V_1 = Titicaca, V_2 = Vikinga

S_0 = Control (no salinity), S_1 = EC 5 dS/m, S_2= EC 10 dS/m, S_3 = EC 15 dS/m, S_4 = EC 20 dS/m, S_5 = EC 25 dS/m, S_6 = EC 30 dS/m

4.3.8 Harvest index (%)

Effect of variety

The recorded data on harvest index was not significantly influence by different variety (Table 6 and Appendix X). However, the higher harvest index (38.34%) was found from the variety V_2 (Vikinga) and the lower harvest index (37.78%) was found from the variety V_1 (Titicaca).

Effect of salinity

Considerable influence was observed on harvest index persuaded by different salinity levels (Table 6 and Appendix X). The highest harvest index (41.47%) was found from the salinity level S_1 (EC 5 dS/m) which was statistically similar with S_2 (EC 10 dS/m). The lowest harvest index (33.78%) was found from the salinity level S_4 (EC 20 dS/m) which was significantly different from all other treatments followed by S_3 (EC 15 dS/m).

Combined effect of variety and salinity

Remarkable variation was identified on harvest index due to the combined effect of variety and salinity levels (Table 6 and Appendix X). The highest harvest index (41.94%) was found from the treatment combination of V_2S_1 which was statistically similar with the treatment combination of V_1S_1, V_1S_2 and V_2S_1. The lowest harvest index (33.40%) was found from the treatment combination of V_2S_6 which was statistically similar with the treatment combination of V_2S_4.

CHAPTER V

SUMMARY AND CONCLUSION

Pot experiment was carried out at the Agronomy net house of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2017 to March 2018 to evaluate the influence of salinity levels on seed germination, growth and yield of quinoa (*Chenopodium quinoa*). The experiment involved two factors such as two varieties of quinoa *viz*. V_1 (Titicaca) and V_2 (Vikinga) and seven levels of salinity *viz*. S_0 (control), S_1 (EC 5 dS/m), S_2 (EC 10 dS/m), S_3 (EC 15 dS/m), S_4 (EC 20 dS/m), S_5 (EC 25 dS/m) and S_6 (EC 30 dS/m). The experiment consisting of 14 treatment combinations that was laid out in RCBD (factorial) design with three replications. Data on different growth parameters, yield components and yield of plants were recorded. The collected data were statistically analyzed and the differences among the means were evaluated by LSD at 5% level of significance.

Different parameters of quinoa were influenced by variety. Results showed that Variety had significant effect on plant height and number of leaves plant^{-1} at different growth stages but number of branches plant^{-1}, number of inflorescence plant^{-1}, length of inflorescence plant^{-1}, germination rate, 1000-seed weight, yield plant^{-1}, husk weight plant^{-1}, straw weight plant^{-1}, biological yield plant^{-1} and harvest index were not significantly affected by variety. It was found that the higher plant height (26.40, 31.95 and 36.43 cm at 20, 40 DAS and at harvest, respectively) was found from the variety V_1 (Titicaca) and the higher number of leaves plant^{-1} (67.67, 78.76 and 83.81 cm at 20, 40 DAS and at harvest, respectively) was found from the variety V_2 (Vikinga) where the lower plant height (18.55, 23.01 and 27.77 cm at 20, 40 DAS and at harvest, respectively) was found from the variety V_2 (Vikinga) and lower number of leaves plant^{-1} (51.43, 67.48 and 79.48 at 20, 40 DAS and at harvest, respectively) was found from the variety V_1 (Titicaca).

In case of salinity levels, number of branches plant^{-1} was not significantly affected but rest of all other studied parameters was significantly influenced by different salinity levels. Results showed that the highest plant height (24.71, 30.50 and 36.17 cm at 20, 40 DAS and at harvest) was found from the salinity level S_3 (EC 15 dS/m) but the germination rate (3.33 and 3.67 out of 4 seeds at 2 and 7 DAS, respectively), number of leaves plant^{-1} (68.67, 78.67 and 92.83 at 20, 40 DAS and at harvest, respectively), number of inflorescence plant^{-1} (12.0), length of inflorescence plant^{-1} (11.92cm), 1000-seed weight (2.57 g), yield plant^{-1} (1.69 g), husk weight plant^{-1} (0.91 g), straw weight plant^{-1} (2.44 g) and biological yield plant^{-1} (4.99 g) were found from the salinity level S_4 (EC 20 dS/m) where the harvest index (41.47%) was found from the salinity level S_1 (EC 5 dS/m). Similarly, the lowest germination rate (2.00 and 2.67 at 2 and 7 DAS, respectively), plant height (17.28, 22.06 and 26.78 cm at 20, 40 DAS and at harvest, respectively), number of leaves plant^{-1} (44.67, 67.00 and 67.00 at 20, 40 DAS and at harvest, respectively), number of inflorescence plant^{-1} (5.67), length of inflorescence plant^{-1} (4.25cm), 1000-seed weight (2.03 g), yield plant^{-1} (1.25 g), husk weight plant^{-1} (0.57 g), straw weight plant^{-1} (0.95 g) and lowest biological yield plant^{-1} (3.08 g) was found from the salinity level S_6 (EC 30 dS/m) but the lowest harvest index (33.78%) was found from the salinity level S_4 (EC 20 dS/m).

Regarding combined effect of variety and salinity levels, number of branches plant^{-1} was not significant at 40 DAS. All the parameters under the present study were significantly affected by combined effect of variety and salinity levels. Results indidcated that the highest plant height (34.03, 39.96 and 44.60 cm at 20, 40 DAS and at harvest, respectively) and number of branches plant^{-1} (14.00 and 20.67 at 20, 40 DAS and at harvest, respectively) were found from the treatment combination of V_1S_3 but the highest number of leaves plant^{-1} (75.33, 91.67 and109.00 at 20, 40 DAS and at harvest, respectively) was found from the treatment combination of V_2S_4. Again, the highest germination rate

(3.67 and 4.00 out of 4 seeds at 2 and 7 DAS, respectively), number of inflorescence plant^{-1} (12.3), length of inflorescence plant^{-1} (12.67cm), 1000-seed weight (2.61 g), yield plant^{-1} (1.71 g), husk weight plant^{-1} (0.95 g), straw weight plant^{-1} (2.66 g) and biological yield plant^{-1} (5.12 g) was found from the treatment combination of V_1S_4 but the highest harvest index (41.94%) was found from the treatment combination of V_2S_1. The lowest germination rate (1.67 and 2.67 out of 4 seeds at 2 and 7 DAS, respectively), plant height (14.60, 20.26 and 24.06 cm at 20, 40 DAS and at harvest, respectively), number of branches plant^{-1} (6.33 and 13.33 at 20, 40 DAS and at harvest, respectively), number of leaves plant^{-1} (33.33, 55.33 and 60.33 at 20, 40 DAS and at harvest, respectively), number of inflorescence plant^{-1} (5.33), length of inflorescence plant^{-1} (4.00cm), 1000-seed weight (2.00 g), yield plant^{-1} (1.12 g), husk weight plant^{-1} (0.52 g), straw weight plant^{-1} (0.83 g) and biological yield plant^{-1} (3.04 g) was found from the treatment combination of V_2S_6 but the lowest harvest index (33.40%) was found from the treatment combination of V_2S_4.

Considering the above fact, it can be concluded that quinoa was possible to grow in Bangladesh weather condition. It can be also concluded that variety had no significant effect on different growth and yield parameters but in combination with salinity it showed better yield performance. It was found that the treatment combination of V_1S_4 (variety, Titicaca with salinity level, EC 20 dS/m) gave the best performance considering different growth and yield performance of quinoa. Its' salinity tolerance limit was upto 30 dS/m but yield was reduced.

From the above results the following recommendations could be made from the results of the present experiment:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional adaptability and other performance, specially in the coastal belt.
2. Another doses of salinity levels may be included in the future program;
3. Other cultivars may be included in the further program.

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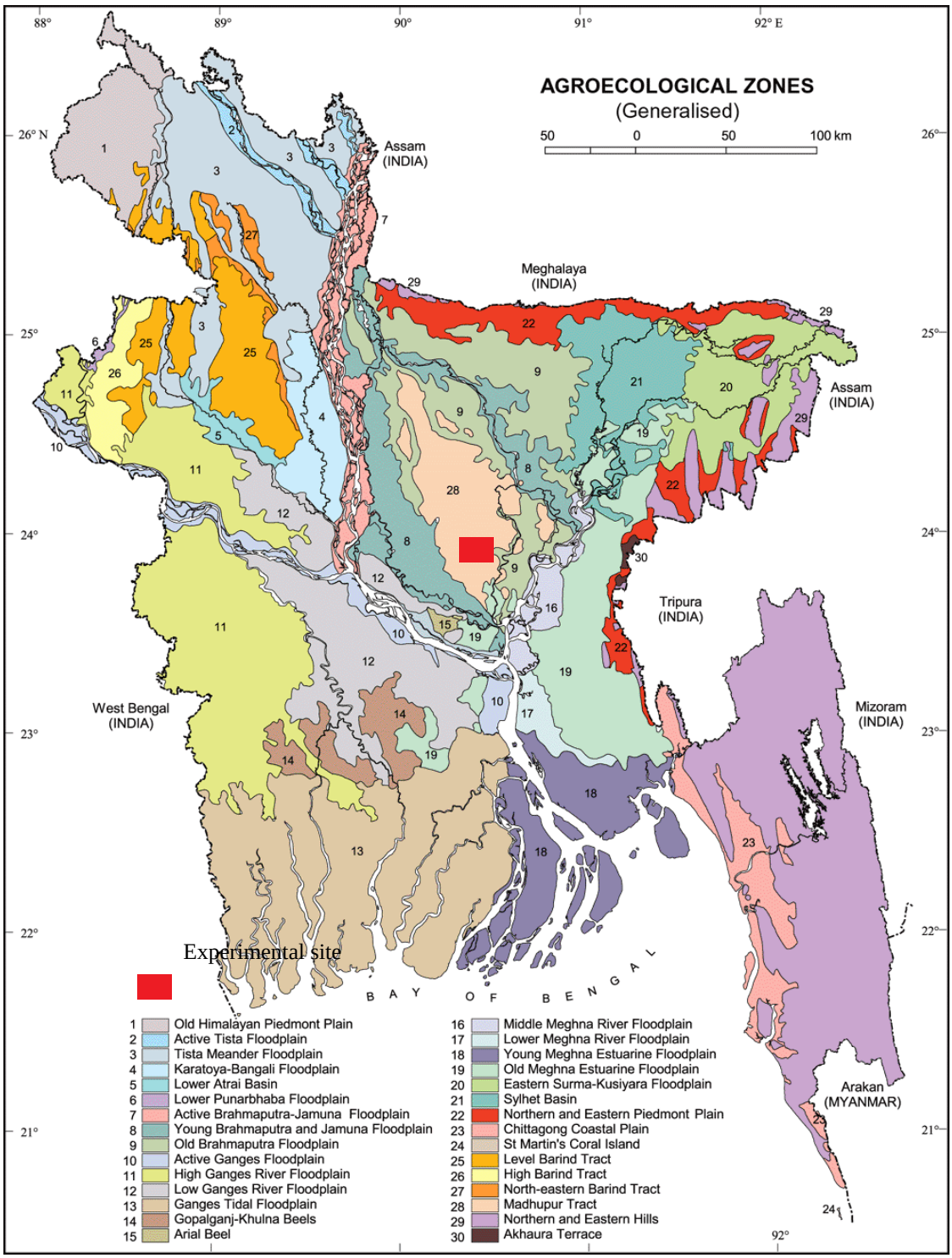
APPENDICES

Appendix I. Agro-Ecological Zone of Bangladesh showing the experimental location



Appendix II. Monthly records of air temperature, relative humidity and rainfall during the period from November 2017 to March 2018.

Year	Month	Air temperature (°C)			Relative humidity (%)	Rainfall (mm)
		Max	*Min*	*Mean*		
2017	November	28.60	8.52	18.56	56.75	14.40
2017	December	25.50	6.70	16.10	54.80	0.0
2018	January	23.80	11.70	17.75	46.20	0.0
2018	February	22.75	14.26	18.51	37.90	0.0
2018	March	35.20	21.00	28.10	52.44	20.4

Source: Bangladesh Meteorological Department (Climate division), Agargaon, Dhaka-1212.

Appendix III. Characteristics of experimental soil analyzed at Soil Resources Development Institute (SRDI), Farmgate, Dhaka.

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Agronomy Farm, SAU, Dhaka
AEZ	Modhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained
Cropping pattern	Not Applicable

Source: Soil Resource Development Institute (SRDI)

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
Partical size analysis % Sand	27
%Silt	43
% Clay	30
Textural class	Silty Clay Loam (ISSS)
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20
Exchangeable K (me/100 g soil)	0.1
Available S (ppm)	45

Source: Soil Resource Development Institute (SRDI)

Appendix IV. Layout of the experiments

R_1	R_2	R3
V_1S_0	V_2S_6	V_2S_4
V_2S_1	V_1S_1	V_1S_5
V_1S_4	V_2S_2	V_1S_6
V_2S_3	V_1S_3	V_2S_3
V_1S_2	V_2S_4	V_2S_1
V_2S_5	V_1S_5	V_1S_1
V_1S_6	V_2S_0	V_1S_2
V_2S_0	V_1S_6	V_2S_2
V_1S_5	V_2S_5	V_2S_0
V_2S_4	V_1S_4	V_1S_0
V_1S_3	V_2S_3	V_1S_3
V_2S_2	V_1S_2	V_2S_6
V_1S_1	V_2S_1	V_2S_4
V_2S_6	V_1S_0	V_2S_5

Appendix V. Effect of variety and salinity and their combination on germination test of quinoa seeds

Sources of variation	Degrees of freedom	Mean square values at	
		2 DAS	7 DAS
Replication	2	0.92	0.30
Factor A	1	NS	NS
Factor B	6	1.21*	0.38*
AB	6	0.57*	0.11*
Error	26	0.56	0.28

NS = Non-significant * = Significant at 5% level

Appendix VI. Effect of variety and salinity and their combination on plant height of quinoa

Sources of variation	Degrees of freedom	Mean square values at		
		20 DAS	40 DAS	At harvest
Replication	2	9.43	2.44	23.76
Factor A	1	646.64*	839.73*	786.93*
Factor B	6	41.45*	43.94*	51.36*
AB	6	52.54*	40.57*	27.22*
Error	26	37.76	34.70	33.80

* = Significant at 5% level

Appendix VII. Effect of variety and salinity and their combination on number of branches plant^{-1} of quinoa

Sources of variation	Degrees of freedom	Mean square values at		
		20 DAS	40 DAS	At harvest
Replication	2	0.50	1.42	2.35
Factor A	1	13.71*	0.21*	5.35*
Factor B	6	10.69*	7.52*	6.32*
AB	6	10.76*	18.49*	23.57*
Error	26	13.21	13.40	15.58

* = Significant at 5% level

Appendix VIII. Effect of variety and salinity and their combination on number of leaves plant^{-1} of quinoa

Sources of variation	Degrees of freedom	Mean square values at		
		20 DAS	40 DAS	At harvest
Replication	2	4.02	4.17	2.786
Factor A	1	NS	NS	NS
Factor B	6	NS	NS	NS
AB	6	41.71*	NS	NS
Error	26	2.64	3.01	4.734

NS = Non-significant * = Significant at 5% level

Appendix IX. Effect of variety and salinity and their combination on inflorescence number and length of quinoa

Sources of variation	Degrees of freedom	Mean square values at	
		Number of inflorescence plant^{-1}	Length of inflorescence plant^{-1}
Replication	2	2.78	7.89
Factor A	1	24.38*	135.72*
Factor B	6	10.85*	9.57*
AB	6	12.26*	13.20*
Error	26	5.55	3.05

* = Significant at 5% level

Appendix X. Effect of variety and salinity and their combination on yield contributing parameters and yield of quinoa

Sources of variation	Degrees of freedom	Mean square values at					
		1000 seed weight	Yield plant^{-1}	Husk weight plant^{-1}	Straw weight plant^{-1}	Biological yield plant^{-1}	Harvest index
Replication	2	0.054	0.013	0.004	0.07	0.115	9.49
Factor A	1	NS	NS	NS	NS	NS	NS
Factor B	6	0.133*	0.128*	0.051*	0.63*	1.081*	6.61*
AB	6	0.083*	0.094*	0.018*	0.62**	0.919**	9.00*
Error	26	0.075	0.019	0.011	0.01	0.052	6.68

NS = Non-significant * = Significant at 5% level ** = Significant at 1% level