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RESEARCH PAPER

Effect of Electrical Conductivity on Growth, Yield and Quality of Broccoli Grown in Hydroponic System

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ABSTRACT

An experiment was conducted to identify the electrical conductivity (EC) in the nutrient solution that optimizes broccoli's growth, yield, and quality (*Brassica oleracea var. italica* L.) during cultivation. The experiment involved five EC treatments: T_1 = EC 1.5, T_2 = EC 2.0, T_3 = EC 2.5, T_4 = EC 3.0, and T_5 = EC 3.5. These treatments were implemented in a deep water culture (DWC) hydroponic production system, which is a soilless cultivation method. The study was conducted at Patuakhali Science and Technology University, Bangladesh. Parameters such as plant biomass production, yield, quality variables, and tissue mineral content were measured. The results revealed that both high (3.5 dsm^{-1}) and low (1.5 dsm^{-1}) EC treatments led to a decrease in plant biomass, yield and quality of broccoli. But at EC level 3.0 dsm^{-1} (T_4), the highest number of leaves per plant (16.3), leaf area (352.5 cm^2), shoot length (28.0 cm), root length (49.33 cm), head/curd diameter (14.67 cm), head fresh weight (257.53 g), and dry weight (29.0 g) were recorded at 60 days after transplanting (DAT). Additionally, lower levels head/curd tissue micronutrients such as manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe) content (59.63, 34.57, 29.43 and 136.67 ppm respectively) were found in lower EC level (1.5 dsm^{-1}), while higher EC level (3.5 dsm^{-1}) showed higher levels of those minerals (68.53, 45.80, 38.53 and 163.0 ppm respectively). Phosphorus (P) and Sulphur (S) content was non-significant in respect of different EC treatments. Conversely, nitrogen (N) and potassium (K) content were higher (3.16 % and 2.42 %) in lower EC treatments and lower (1.56 % and 1.64 %) in higher EC treatments. Mn, Zn, Cu, and Fe content of broccoli head/curd tissue increased progressively with higher EC treatments, while N and K content decreased. Based on this study's growth and quality criteria, the optimal EC treatment for broccoli in a deep water culture hydroponic production system was found best at EC 3.0 (T_4). It was found that both high and low EC levels induced nutrient stress, negatively affecting broccoli's quality, growth, and yield.

Key words: Broccoli, Cooper's solution, EC, Growth, Quality, Yield

Introduction

Vegetables of *Brassicaceae* family are an important food source in Asian countries such as China, Japan, India, Bangladesh, and the European Union (Cartea *et al.* 2011). Broccoli (*Brassica oleracea* var. *italica* L.), the worldwide-known immature flower vegetable of *Brassicaceae* family, is considered as an important vegetable crop due to several evidence of their health promoting effects that are associated to bioactive compounds present in the edible parts of the plants (Raiola *et al.* 2017). Numerous epidemiological studies indicate that brassicas in general, and broccoli in particular, have potential for chemoprevention of degenerative diseases and certain types of cancer since they are rich sources of glucosinolates and dietary natural antioxidants: vitamins, flavonoids and hydroxycinnamic acids (Higdon *et al.* 2007 & Moreno *et al.* 2006).

The problems in agricultural land use such as soil exhaustion, pest infestation or chemical interference are increasing greatly due to intensive cropping, injudicious application of pesticides or continuous monoculture (Asaduzzaman *et al.* 2013). Hydroponic cultivation is one of the most efficient ways to achieve maximum yield in minimum time with excellent quality. At present, farmers face difficulties in soil cultivation of horticultural crops as a result of nematodes, salinity, and environmental pollution. So, mineral and organic cultivation beds such as perlite and coco peat have received much attention. In addition, higher water and nutrition requirements in soil systems have led to an increase in soilless culture with horticultural crops in recent decades (Ramezanian *et al.* 2001).

Horticultural produce from soilless culture have better qualities such as better taste, uniformity, color, texture and higher nutritional value than those from conventional soil-based cultivation (Xu *et al.* 1995). In recent years, the use of soilless culture has increased significantly throughout the world (Grillas *et al.* 2001; Garzo *et al.* 2002). Several studies suggested soilless culture in the greenhouse as an alternative to traditional field production for high-value vegetable crops (Schroder 1999; Cantliffe *et al.* 2001; Pardossi *et al.* 2002). Over the years, hydroponics has been used sporadically throughout the world as a commercial means of growing both food and ornamental plants. Recently, it has also been used as the standard methodology for plant biological researches in different disciplines (Asao 2012).

Plant physiology, growth, and development are closely associated with the environmental conditions and nutrient supply (Savvas *et al.* 2008). Optimization of the nutrient application to plants is fundamental requirements to improve crop production (Haydon *et al.* 2015). The electrical conductivity (EC) is an index of salt concentration and an indicator of electrolyte concentration of the solution. EC of the nutrient solution is related to the amount of ions available to plants in the root zone (Nemali and Van Iersel 2004). The optimal EC is crop specific, and depends on environmental conditions (Sonneveld and Voogt 2009). In general, higher EC hinders nutrient uptake by increasing the osmotic pressure of the nutrient solution, wastes nutrients, and the increases discharged of nutrients into the environment, resulting in environmental pollution. Lower EC may severely affect plant health and yield (Signore *et al.* 2016). Therefore, changes in amount of solution, its electrical conductivity (EC), and pH should be monitored regularly for efficient use of water and nutrients.

In the global context, broccoli is estimated to be cultivated in 120.426 million ha resulting the production of 21.2668 million tons with average yield of 17.65 t/ha (FAOSTAT, 2014). There is a good scope of its cultivation in Bangladesh for increasing vegetable diversification and to meet vegetable demand of the country. Broccoli is easier to grow in hydroponics than other Brassicas (Mason 2005). Few researchers have addressed the issue of optimizing the EC for broccoli production in hydroponic culture.

In the light of above mentioned facts, the objective of this study was to assess the effect of different EC of the nutrient solution on the growth, yield, and quality in broccoli. In addition, we attempted to seek the optimal nutrient EC for both broccoli growth and quality, and the underlying mechanisms of physiological changes of plants in high or too low nutrient solution concentrations.

Materials and Methods

Experimental details

The experiment was conducted at Germplasm Center of the Department of Horticulture, Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali, Bangladesh. In this study, broccoli (F1 hybrid of Japani green broccoli) used as planting materials. The planting materials were purchased from Siddique bazar, Dhaka, Bangladesh. The experiment consisted of 5 EC levels: T_1 = EC 1.5 dSm^{-1}, T_2 = EC 2.0 dSm^{-1}, T_3 = EC 2.5 dSm^{-1}, T_4 = EC 3.0 dSm^{-1} and T_5 = EC 3.5 dSm^{-1}. The treatments were based on Cooper's (1979) hydroponic nutrients solution. The nutrient solution consisted of the nutrients concentration of 200 mgL^{-1} N, 60 mgL^{-1} P, 300 mgL^{-1} K, 170 mgL^{-1} Ca, 50 mgL^{-1} Mg, 68 mgL^{-1} S, 1 mgL^{-1} Fe, 0.1 mgL^{-1} Cu, 0.1 mgL^{-1} Zn, 2 mgL^{-1} Mn, 0.3 mgL^{-1} B, and 0.2 mgL^{-1} B. The experiment was conducted in Deep Water Culture (DWC) hydroponic production system. The factorial experimental units were distributed according to a Completely Randomized Design (CRD) with three replications.

Preparation of the nutrient solution (NS)

Fertilizers were selected that are compatible with each other. Required amount of Calcium Nitrate and EDTA Iron were mixed into a 10 liter container for the preparation of nutrient solution A and remaining nutrients were mixed into another 10 litter sized container for nutrient solution B preparation. Then the nutrients from both containers were mixed into the growth tank according to the assigned treatments.

Nutrient solution for hydroponics and its managements

All essential macro and micro nutrients based on Cooper's (1979) hydroponic nutrients solution were supplied to hydroponic plants in the form of nutrient solution, which consisted of fertilizer salts dissolved in water. The five EC treatments were assigned as follows:

T_1 (EC1.5 dSm^{-1}): NS A (187.5 mL) and NS B (187.5 mL) in 50 liters deionized water

T_2 (EC2.0 dSm^{-1}): NS A (250 mL) and NS B (250 mL) in 50 liters deionized water

T_3 (EC2.5 dSm^{-1}): NS A (312.5 mL) and NS B (312.5 mL) in 50 liters deionized water

T_4 (EC3.0 dSm^{-1}): NS A (375 mL) and NS B (375 mL) in 50 liters deionized water and

T_5 (EC3.5 dSm^{-1}): NS A (437.5 mL) and NS B (437.5 mL) in 50 liters deionized water.

Plant establishment

At first sponge foam of 30 cm × 30 cm were selected for seedling production. A square dot cut of 2.5 cm × 2.5 cm were made into sponge foam for seed sowing. Then 1 cm cut was made into the each square sized foam and seed was sown. After 3 days of seed germination 5-7 ml of nutrient solution was supplied into seedling tray. After 10 to 12 days of seed germination 10 ml of nutrient solution was supplied into seedling tray daily before transplanting of seedlings (Mallick *et al. 2018*). The pH of the solution was maintained at 6.0 by adding H_3PO_3 and lower pH levels were maintained using hydrogen phosphate (HPO_4), higher pH levels were maintained using sodium hydroxide (NaOH) throughout the experimental period. At the fourth true leaf stage of the seedlings, individual plants were transplant into a 50 liters plastic bucket. Volume of nutrient solution was maintained up to the mark by time to time addition of nutrient solution throughout the experimental period. Each plastic tank was treated with nutrient solution of each treatment and replicated for three times. EC and pH of the nutrient solution was measured and maintained by EC/TDS meter (Hanna, Japan) meter and pH meter, respectively at regular intervals. Aerator and air stone was used in each plastic tank to maintain the oxygen concentration of the nutrient solution. Broccoli plants were then grown into a well maintained glass house.

Data on different parameters were collected during the study and they are as follows:

The total number of leaves of individual plant was recorded and mean value was calculated. Leaf area was measured with a leaf area meter and was expressed in cm^2. The shoot length was measured with a meter scale from the base of the plant to the tip of the leaf of the main stem and was expressed in centimeter (cm). The root length was measured with a meter scale from the base of the plant to the end of the root and was expressed in centimeter (cm). For total number of leaves, leaf area, shoots length and root length first count was recorded at 15 days after transplanting (DAT) and second; third and fourth counts were recorded at 30, 45 and 60 DAT, respectively.

After harvesting (60 DAT), the head diameter was measured with slide calipers. The data were expressed in centimeter (cm) and mean values were calculated. Fresh weight of head was measured with an electric balance after harvesting and was expressed in gram (g). The head was cut into small pieces and oven dried at 70 ^{0}C for 7 days. The difference between fresh and dry weight was measured and mean values were calculated.

The total soluble solid (TSS) of broccoli head was determined by using a digital refractometer (BOECO, Germany). The amount of total phenolic content was determined following the established method described by Chanda and Dave (2009) with some modifications. Titratable acidity was determined according to the method by Ranganna (1977). Vitamin C (Ascorbic acid) content was determined according to the method of Ranganna (1979).

For the determination of minerals composition (macro and micro nutrients), broccoli head were chopped, air dried and kept in labeled brown paper packet. Then the samples were oven dried at 70 °C for 48 hours in a constant temperature electric oven (Heraeus, Germany) and were ground to make fine powder (20 Mesh size). One gram (1.0 g) from each of replicated broccoli samples were taken separately into a clean dry digestion flask (METTLER TOLEDO, Max. 210g and Min. 0.01g; d=0.0001g). A 10 mL of di-acid mixture (HNO_3:$HClO_4$ in the ratio of 2:1) was then added to it. After leaving for overnight, the flask was heated with a digestion chamber (BUCHI Digest System, K-437, Switzerland) at a temperature slowly raised to 180 ^{O}C (Islam *et al*., 2019). The contents of the flask were boiled until they became clean and colorless. The digest were cooled, diluted with distilled water and filtered through Whatman No. 42 filter paper. The volume was made up to 100 mL with distilled water and kept into dry plastic bottle. All of the broccoli extract were preserved at 4^{O}C until chemical analyses were done (Tandon 1995). Analytical reagent (AR) grade chemicals were of used in all cases.

Nitrogen (N) content of broccoli samples was determined by Kjeldahl method. An analysis for manganese (Mn) content of samples was carried out using a new extraction-photometric method with Toluidine Blue. Mn (VII) forms an ion-pair with triphenylmethane dye Toluidine Blue (TB). Potassium (K) content was determined using the flame emission spectrophotometer (Spectrolab, UK) by selecting appropriate filters; iron (Fe), copper (Cu) and zinc (Zn) were determined by the atomic absorption spectrophotometer (Model Varian, AAS Spectra 55B, Australia); phosphorus (P) and sulphur (S) were determined by using double beam UV-VIS spectrophotometer after necessary color development (AOAC 2000; Islam *et al*. 2019). The respective metal standard, blank, triplicate and continuing calibration verification was included in each batch throughout the elemental analysis (AOAC 2000).

Results and Discussion

Number of leaves per plant

Significant variation was found for the number of leaves per plant as affected by different EC levels (Fig. 1). Results showed that the highest number of leaves per plant (16.3 at 60 DAT) was found from T_4 (3.0 dSm^{-1}) which was significantly different from other treatments. The lowest number of leaves per plant (14.0) was found from T_1 (1.5 dSm^{-1}) at 60 DAT. Number of cauliflower (Da Costa *et al.* 2020) and tomato (Hussain *et al.* 2011; Li and Cheng 2015) leaves increased with the increase of electrical conductivity of nutrient solution up to certain level. This might be due to the fact that the number of leaves of a plant can affect the mechanism of tolerance to salt stress, which is associated with total leaf area and can compensate for losses caused by decreases in LA. It is directly related to the physical capacity of plants to compartmentalize Na^+ and Cl^- ions in the cell vacuole (Munns and Tester 2008).

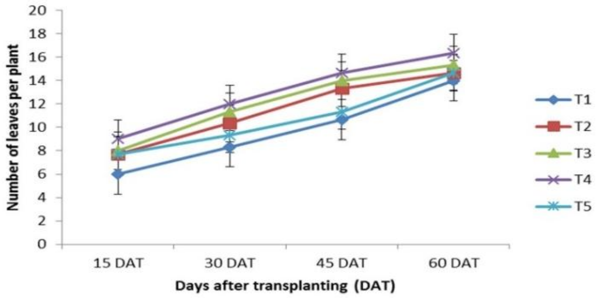

Figure 1: Number of leaves per plant of broccoli as affected by different EC Levels (T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}) at different days after transplanting (DAT)

Leaf area (cm^2)

The leaf area (cm^2) of broccoli was significantly affected by different EC levels at different growth stages (Fig. 2). The highest leaf area (352.5 cm^2 at 60 DAT) was obtained from T_4 (3.0 dSm^{-1}) which was significantly different from other treatments whereas the lowest leaf area (141.77 cm^2 at 60 DAT) was witnessed from T_1 (1.5 dSm^{-1}). Results indicated that the leaf area (LA) of the broccoli plant increased with the increase of electrical conductivity of the nutrient solution from 1.5 dSm^{-1} to 3.0 dSm^{-1}, but further decreased with the increase of EC to 3.5 dSm^{-1} (Fig. 5). Leaf area increased with the increasing of nutrient concentration (EC) to a certain amount and thereafter it was decreased in tomato (Matsuda *et al.* 2012), cucumber (Li and Cheng 2015), cabbage (Sanoubar *et al.* 2016) and rocket (Schiattone *et al.* 2017). Despite the negative effect of the EC of the nutrient solution, the relative decrease in LA was 31.5% under the highest salinity (6.7 dSm^{-1}) when compared to the control (1.4 dSm^{-1}). These results were due to decreases in plant's capacity to uptake water under salt stress, which decrease the cell division rate and, consequently, the expansion of leaves, followed by stomatal closure and decreases in photosynthesis (Rahnama et al. 2010).

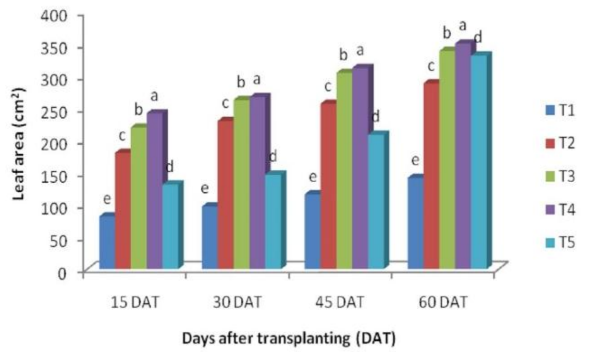

Figure 2: Leaf area of broccoli as affected by different EC Levels (T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}). Graph followed by different letters differ significantly, but with common letter (s) do not differ significantly.

Shoot length of broccoli (cm)

The highest shoot length of broccoli (28.00 cm at 60 DAT) was recorded from T_4 (3.0 dSm^{-1}) which was statistically identical with T_2 (1 dSm^{-1}), T_3 (1.5 dSm^{-1}) and T_5 (2.5 dSm^{-1}) at all growth stages. Plant height of cauliflower decreased with the magnitude of 3.48% and 3.57% respectively, per unit of EC of the nutrient solution increased (Da Costa *et al.* 2020). Decreases in plant growth can be related to accumulation of Na+ and Cl- ions in different plant tissues (Jouyban 2012); (AbdElgawad *et al.* 2016). (Giuffrida *et al.* 2018) reported the accumulation of these ions in different organs of cauliflower plants (leaves, stem, and roots) grown on nutrient solutions with electrical conductivities of 2.0 and 4.0 dS m^{-1}.

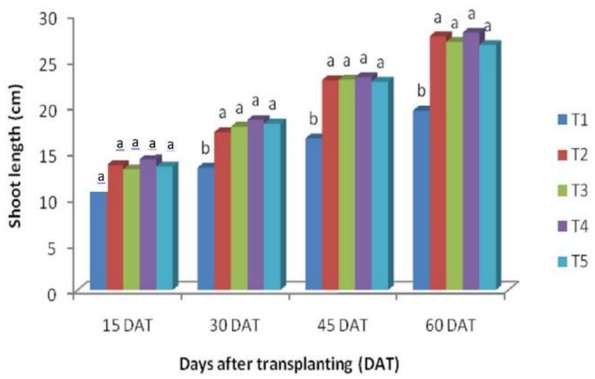

Figure 3: Shoot length of broccoli as affected by different EC Levels (T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}). Graph followed by different letters differ significantly, but with common letter (s) do not differ significantly.

Root length of broccoli (cm)

Different EC levels showed significant influence on the root length of broccoli at different growth stages (Fig. 4). The highest root length of broccoli (49.33 cm at 60 DAT) was found from T_4 (3.0 dSm^{-1}) which was significantly different from other treatments. The lowest root length of broccoli (27.00 cm at 60 DAT) was obtained from T_1 (1.5 dSm^{-1}). It was observed from the results that root length of broccoli was increased with the increase of EC levels up to certain level (3.0 dSm^{-1}) and then decreased with the further increase of EC (Fig. 5). Findings of the present study showed similarity with the result found by Matsuda *et al.* (2012). Growth of the storage roots was enhanced as the nutrient solution concentration (NSC) increased to an EC of 2.6 dS m^{-1}(Sakamoto & Suzuki 2020).

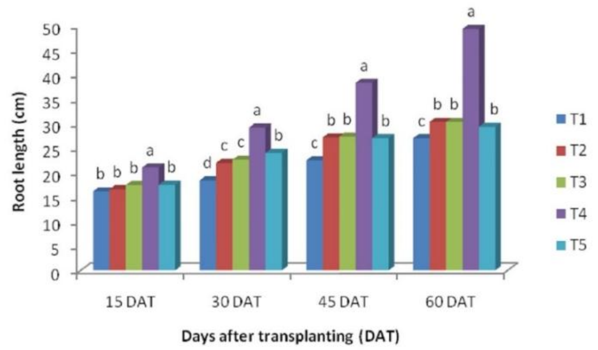

Figure 4: Root length of broccoli as affected by different EC Levels (T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}). Graph followed by different letters differ significantly, but with common letter (s) do not differ significantly by MSTAT-C package programme.

Head/curd diameter (cm)

Head diameter of broccoli was significantly affected by different EC treatments (Table 1). Results showed that the highest head diameter (14.67 cm) was recorded from the EC treatment T_4 (3.0 dSm^{-1}) which was significantly different from other treatments where the lowest head diameter (8.86 cm) was recorded from the EC treatment T_1 (Fig. 5). Despite the salt stress caused no deformity on the broccoli inflorescences, the head weight increased with the increase in EC up to 3.0 dSm^{-1} and further decreased with the increase of EC to 3.5 dSm^{-1}. This decrease is consistent with the findings of Giuffrida *et al.* (2013) for cauliflower plants grown in pots irrigated with water containing NaCl concentrations. In contrast, from a similar work with cauliflower Giuffrida *et al.* (2018) did not attribute the decreases in head diameter to the salinity of the nutrient solution.

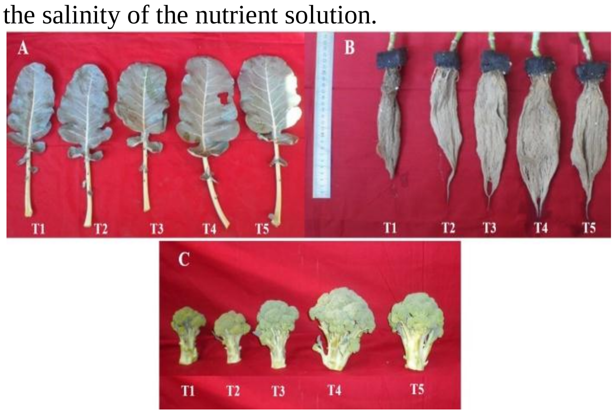

Figure 5. General aspect of the leaf (A) root (B) and head of broccoli in relation to the levels of electrical conductivity (EC) of the nutrient solution in a deep water culture (DWC) hydroponic system. T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}.

Head/curd fresh weight (g)

Significant variation was observed on head fresh weight (FW) as influenced by different EC levels (Table 1). The highest head fresh weight (257.53 g) was recorded from the EC treatment T_4 (3.0 dSm^{-1}) where the lowest head fresh weight (80.33 g) was found from the EC treatment T_1 (1.5 dSm^{-1}). The fresh weight of head gradually increased from EC 1.5 to 3.0 dSm^{-1}, but decreased as exposed to a higher salinity level (3.5 dSm^{-1}) (Table 1). Cauliflower plants grown in pots with sand and subjected to two EC solution (2 and 4 dSm^{-1}), presenting a relative decrease of 25% in the IFMY (inflorescence fresh matter yield) when using the highest salinity level (Giuffrida *et al.* 2017). Decreases in crop yield are explained by decreases in osmotic potential in the root area, which decreases water absorption and, consequently, decreases the water potential in the plant and the processes of cell division and expansion (Munns 2002). Ding *et al.* (2018) evaluated species of the *Brassicaceae* family and found that the use of high EC solution inhibits plant growth, negatively affecting the production of plants since the plants need to adjust their metabolism to attenuate the salt stress.

Head/curd dry weight (g)

Head dry weight (DW) of broccoli was significantly influenced by different EC levels (Table 1). Results indicated that the highest head dry weight (29.00 g) was recorded from the EC treatment T_4 (3.0 dSm^{-1}) which was significantly different from all other EC treatments. But, with the further increase in salinity level (3.5 dSm^{-1}) decreased the dry weight of head (16.97 g). The lowest head dry weight (10.23 g) was observed from the EC treatment T_1 (1.5 dSm^{-1}) (Table 1). It is seen from the table that head dry weight increased with the increase of nutrient solution EC up to certain level (EC 3.0 dSm^{-1}) and then decreased with the further increase in EC level (3.5 dSm^{-1}). Dry matter percentage of heads increased as the consequence of salt stress in broccoli when provided with nutrient solution (Giuffrida *et al.* 2013).

Table 1: Head/curd diameter, head/curd fresh weight and dry weight of broccoli at 60 DAT as affected by different EC Level

Treatments	Head/curd diameter (cm)	Head/curd fresh weight (g)	Head/curd dry weight (g)
T_1	8.83 d	80.33 e	10.23 c
T_2	9.63 c	102.27 d	11.70 c
T_3	11.53 b	133.23 c	15.30 b
T_4	14.67 a	257.53 a	29.00 a
T_5	11.83 b	144.10 b	16.97 b
$LSD_{0.05}$	0.61	3.17	2.14
CV (%)	3.76	7.14	5.05

Numbers in column followed by different letters differ significantly, but with common letter (s) do not differ significantly. T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}. CV= Co-efficient of variation.

Chemical constituents of broccoli head/curd

Total soluble solids (TSS), total phenol content, titratable acidity (TA), and vitamin C content of broccoli head were not significantly influenced by different EC levels (Table 2). But an increasing trend was perceived in TSS, phenols, and titratable acidity, and a decreasing trend was observed in relation to vitamin C content of broccoli head with the increasing of EC levels in the present study. Giuffrida *et al.* (2013) found that TSS content and TA increased in broccoli and cauliflower at the increase of the NaCl level in the nutrient solution. Moreno *et al.* (2006) found the highest vitamin C content in the control plants and there were non-significant difference with other salinity treatments in broccoli. Moreno *et al.* (2006) also found that the total phenol content of broccoli plant was higher in salt-induced stress plants than other treatments and untreated control.

Table 2: Chemical constituents of broccoli head/curd at 60 DAT as affected by different EC Level

Treatments	TSS (%)	Total Phenols (%)	Titratable acidity (%)	Vitamin C content (mg/100 g fresh tissue)
T_1	5.11	6.38	0.33	80.57
T_2	5.82	6.84	0.40	78.60
T_3	6.29	7.02	0.37	77.63
T_4	5.71	6.82	0.42	78.23
T_5	6.68	7.38	0.46	78.33
$LSD_{0.05}$	NS	NS	NS	NS
CV (%)	5.27	3.17	3.05	4.71

Numbers in column followed by different letters differ significantly, but with common letter (s) do not differ significantly. NS = Non-Significant. T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}. CV= Co-efficient of variation.

Minerals composition of broccoli head/curd

There was no significant influence of electrical conductivity (EC) on sulphur (S) and phosphorus (P) concentration of broccoli head (Table 3). Contrastingly, nitrogen (N) and potassium (P) content decreases with the increases of EC level. At EC level 1.5 dsm^{-1} (T_1) the nitrogen and potassium content was found the highest (3.16 % and 2.42 %), while the lowest nitrogen and potassium content was recorded in EC level 3.5 dsm^{-1} (T_5). An increasing trend of manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe) of broccoli head/curd tissue were observed. However, the concentration of manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe) were significantly higher at the highest EC level (3.5 dSm^{-1}) i.e. in treatment T_5 (68.53, 45.80, 38.53 and 163.0 ppm respectively) and the lowest in EC level (1.5 dSm^{-1}) i.e. in treatment T_1 (59.63, 34.57, 29.43 and 136.67 ppm respectively). Concentration of S, Na, Cl, Fe and Mn increased with increasing salinity in cauliflower (De Pascale *et al.* 2005; Giuffrida *et al.* 2013). De Pascale *et al.* (2005) observed that N concentration in broccoli head decreased with the increase of salinity. In our experiment the K concentration in broccoli decreased in high EC (3.5 dSm^{-1}). Salinity was found to increase Mn concentration in sugar beet shoot (Khattak and Jarrell 1989). Zinc concentration in shoot tissue was found to decrease with increasing soil salinity (Mehrotra *et al.* 1986; Shukla and Mukhi 1985). Similarly, plant Cu concentration was found to decrease in salt-stressed maize grown in both soil (Rahman *et al.* 1993) and nutrient solutions (Izzo *et al.* 1991). Rao *et al.* (2016) reported that salinity increased the shoot Fe concentration in both cauliflower and broccoli.

Table 3: Minerals composition of broccoli head/curd at 60 DAT as affected by different EC Level

Treatments	Minerals composition of broccoli head/curd							
	Macronutrients (%)				Micronutrients (ppm)			
	N	P	K	S	Mn	Zn	Cu	Fe
T_1	3.16 a	0.32	2.42 a	0.79	59.63 d	34.57 e	29.43 d	144.00 d
T_2	2.90 b	0.29	2.06 b	0.82	61.63 c	37.63 d	32.13 c	136.67 e
T_3	1.84 c	0.29	1.92 c	0.96	67.43 a	43.50 b	36.40 b	150.33 c
T_4	1.87 c	0.28	1.86 c	0.89	65.60 b	41.43 c	35.57 b	156.33 b
T_5	1.56 d	0.25	1.64 d	1.11	68.53 a	45.80 a	38.53 a	163.00 a
$LSD_{0.05}$	0.37	NS	0.20	NS	0.60	1.04	1.21	2.71
CV (%)	4.11	3.20	5.17	4.04	6.35	5.24	4.28	6.37

Numbers in column followed by different letters differ significantly, but with common letter (s) do not differ significantly. T_1 = 1.5 dSm^{-1}, T_2 = 2.0 dSm^{-1}, T_3 = 2.5 dSm^{-1}, T_4 = 3.0 dSm^{-1} and T_5 = 3.5 dSm^{-1}. NS=Non-Significant. CV= Co-efficient of variation.

Conclusion

Five different EC treatments were examined in this research. On the basis of growth characteristics, yield and head mineral composition, broccoli plants grow better in 3.0 dSm^{-1} EC level (T_4). Lower EC (1.5 dSm^{-1}) in the nutrient solution limit the plant growth due to nutrient deficiency, while higher EC (3.5 dSm^{-1}) inhibited plant growth due to salinity stress, as plants have to enhance activities to adapt to the stress conditions. The findings of this study improved our understanding of the effects of different EC levels of nutrient solutions on broccoli plants and are useful for the optimization of nutrient solutions to improve production and quality in hydroponic culture.

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