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Salinity and Variety Effects on Yield, Yield Attributes and Soil of Tomato under Greenhouse Conditions of Central Fiji

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ABSTRACT

Background: Tomato (*Lycopersicon esculentum* Mill) is a widely cultivated vegetable crop worldwide, including in Fiji. However, the suitability of tomato cultivation under greenhouse conditions in the central region of Fiji, which experiences salinity issues, remains unclear.

Methods: A pot experiment was conducted at the Instructional Agricultural Farm Complex of the College of Agriculture, Fisheries and Forestry, Fiji National University, Fiji, to determine the effect of different levels of salinity on the growth and yield of tomato (*Lycopersicon esculentum* Mill) varieties. The experiment included two factors: three tomato varieties (V1= Melrose; V2= Alton; V3= Alafua Large) and four levels of NaCl salinity (T_1= Control; T_2= 2 dSm^{-1}; T_3= 4 dSm^{-1} and T_4= 8 dSm^{-1}) randomized thrice in a randomized complete block design. The effects of various varieties and salinity levels on tomato yield were studied in this experiment.

Result: The results revealed that variety Alafua Large performed comparatively better in all cases. This recorded maximum fruit length (4.22 cm), fruit breadth (3.31 cm), individual fruit weight (45.60 g), number of fruits (7.83) and fruit yield (352.10 g) whereas Alton recorded the minimum of the above yield attributes. In the case of the combined effect of variety and salinity, Alafua Large showed better yield (432.17 g and 394.51 g) per plant than the other varieties when combined with the lower salinity level *i.e.*, EC 2 dSm^{-1} and 4 dSm^{-1}, respectively. The yield of tomato varieties declined with the increasing salinity level condition. The yield of Alafua Large was 194.54 g when applied with the highest level of salinity *i.e.*, EC 8 dSm^{-1} and the yield of Alton was 64.69 g which was the lowest yield among the varieties with the highest level of salinity condition. Therefore, from the results, Alafua Large is comparatively more salt tolerant than the other varieties which were studied in this experiment.

Key words: NaCl, Salinity, Tomato, Yield attributes.

INTRODUCTION

Soil salinity is one of the most significant limitations on plant growth, development and production all over the world and the harm produced by excessive salinity manifests itself as either a loss of plant productivity or plant mortality (Farooq, 2019). The buildup of various soluble salts in the root zone causes soil salinization (Farooq *et al*., 2021).

In 2021 tomatoes were planted on 163 ha with a production of 1633.05 tons. However, Fiji consumed about 3000 tons of tomatoes in the year 2020 (FAOSTAT, 2021). The crop yield is low in comparison to that of some developed nations (Chand *et al*., 2022). Due to insufficient local production, Fiji imports 300 tons of tomatoes worth $2.5 million annually.

Tomato is a salinity-sensitive crop. It is noticed that soil salinity is increasing in new regions in Fiji. Increasing salinity is caused by a) intrusion of seawater due to river draining during winter, b) cyclones in the coastal region and c) influx of salt from the ground to the surface during the dry season via capillary movement (Rahman *et al*., 2018). As a consequence of sea level rise, climate change exacerbates coastal flooding, salinization and erosion (Morgan and Lese, 2011; Stocker, 2014; Sen, 2017). Due to the Large number of Oceanians along the coasts, saline intrusion threatens Pacific cash crops. Seawater intrusion is detrimental to fertile soils because it increases the saline content of the soil, preventing optimal growth and crop yields (Freeman, 2010). In Fiji, not enough research has been conducted on the effect of salinity on growth and yield characteristics of different crops including tomatoes. Therefore, the effects of various salt concentrations on the development and yield of three tomato varieties, namely Melrose, Alton and Alafua Large, were studied and an attempt was made to identify the tomato variety with the highest salt tolerance.

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MATERIALS AND METHODS

Experiment details

In a greenhouse at the Instructional Agriculture Farm Complex, College of Agriculture, Fisheries and Forestry, Koronivia Campus, Fiji National University, Fiji, a tomato

field experiment was conducted from January to December 2022. The geographic coordinates of the studied area are 18°2′ 30″-18°3′ 36″ South, 178°31′ 17″-178°33′ 10″ East and the elevation ranges from 6 to 23 meters above mean sea level. The climate is tropical and the temperature was moderate (2°C-26°C) (Sachan *et al*., 2020). The experiment included two factors: three tomato varieties (V_1= Melrose; V_2= Alton; V_3= Alafua Large) and four salinity levels (T_1= Control with no application of saline water; T_2= 2 dSm^{-1}; T_3= 4 dSm^{-1} and T_4= 8 dSm^{-1}) which were arranged in a randomized complete block design (RCBD) comprising three replications. The entire experiment was divided into three replications and each replication comprised of twelve plastic containers. Each of the 36 plastic containers in the experiment contained a single plant. Data on fruit length, fruit breadth, individual fruit weight, fruit numbers and fruit yield were collected. Pre- and post-harvest soil samples were collected and analyzed at the Fiji Agricultural Chemistry Laboratory, Koronivia Research Station, Fiji. Various soil attributes such as pH, electrical conductivity (EC), organic carbon (OC) and primary and secondary plant nutrients (total nitrogen, available phosphorus, available potassium, sodium, calcium and magnesium) were measured using standard analytical techniques (Sachan and Krishna, 2018).

Preparation and application of salt solution

NaCl concentrations of 0 dSm^{-1}, 2 dSm^{-1}, 4 dSm^{-1} and 8 dSm^{-1} were used as treatment levels. Sodium chloride (MERCK chemicals, AR grade) was measured in 0, 1.28, 2.56 and 5.12 g/L of water using an electric balance. A one-liter-capacity watering cane was used to irrigate the soil after the measured salt had been correctly dissolved in water to irrigate each pot. In the experiment, irrigation with saltwater was permitted every seven days. In addition, freshwater was irrigated during the initial stage at a one-day interval.

Crop management

Selected tomato varieties seeds which are commonly grown around different parts of Fiji namely Alton, Alafua Large and Melrose were obtained from the Sigatoka Research Station, Ministry of Agriculture, Fiji. Tomato Seedlings were transferred to the pots once they were 2 weeks old, reaching 2 and 3 leaf stages. Fertilizers and manures were mixed as required in each pot. 1.0 g NPK (13:13:21), 0.5 g Urea and 270 g poultry manure (NPK at 200 kg/ha, Urea at 100 kg/ha and poultry manure at 12 t/ha) were applied basally to each pot (MoA, 2014). Urea was applied as the top dressing at the branching and flowering stages. 28-day-old healthy seedlings were uprooted and one seedling was transplanted into each pot. After planting, the seedlings were immediately watered. Plant protection measures were taken to prevent infestation of insects, weeds and diseases.

Data recording and data analysis

Data on yield and yield attributes of tomatoes *i.e*., fruit length (cm), fruit breadth (cm), individual fruit weight (g), number of fruits $plant^{-1}$ and fruit yield $plant^{-1}$ (g) were recorded. Soil pH, organic matter (%), total nitrogen (%), available phosphorus (mg/kg), potassium (meq/100 g), calcium (meq/100 g) and sodium (meq/100 g) content in soil was also recorded after post-harvest soil sample analysis. The collected data were statistically analyzed to ascertain the statistical significance of the experimental results. After determining the means for each treatment, the F test was used to conduct analyses of variance for each character. Using the LSD test with a probability level of 5%.

RESULTS AND DISCUSSION

Yield attributes

All the tomato yield attributes varied significantly with increased salinity except fruit length and width.

Fruit length and breadth

A significant effect of variety on the fruit length was recorded. A maximum of 4.22 cm of fruit length was recorded in Alafua Large followed by Melrose, however, the minimum 3.31 cm fruit length was recorded in Alton (Table 2). The minimum fruit length in Alton may be due to their genetic characteristics. The effect of salinity on the fruit length was non-significant. A maximum of 4.25 cm fruit length was observed from the application of the concentration of saltwater at EC 4 dSm^{-1} however, a minimum of 3.55 cm was recorded from the application of the concentration of saltwater at EC 8 dSm^{-1}. Salinity stress reduced marketable yield by reducing fruit size (Zhang *et al*., 2022). Ahmed *et al*. (2017) also supported the results and reported that plants irrigated with fresh water gave the tallest fruit followed by treatment (Freshwater) whereas the shortest fruit followed by treatment (10 dSm^{-1}). The combined effect of variety and salinity on the fruit length was statistically significant. A maximum of 4.41 cm fruit length was observed from the combination of Alafua Large and the application of the concentration of saltwater at EC 4 dSm^{-1} and a minimum of 2.49 cm was observed from the combination of Alton and the application of the concentration of saltwater at EC 8 dSm^{-1} (Table 2).

A significant effect of variety on the fruit breadth of tomatoes at harvest was recorded. The maximum 4.50 cm fruit breadth was recorded in Alafua Large whereas the minimum 2.89 cm was produced in Alton. Whereas the salinity effect on the fruit breadth of tomatoes at harvest was recorded as non-significant (Table 2). The minimum 3.39 cm fruit breadth was recorded from the application of the concentration of saltwater at EC 8 dSm^{-1} whereas the maximum 4.12 cm fruit breadth was recorded from the application of the concentration of saltwater at EC 4 dSm^{-1}. The maximum 4.84 cm fruit breadth was recorded in combination with Alafua Large and the application of the concentration of saltwater at EC 4 dSm^{-1} while the minimum 2.17 cm fruit breadth was recorded from the combination of Alton and the application of the concentration of saltwater at EC 8 dSm^{-1} (Table 2).

Individual fruit weight

The effect of variety, salinity and their combinations was significant on individual fruit weight. The minimum 21.27 individual fruit weight was recorded in Alton whereas the maximum 45.60 g individual fruit weight was recorded in the Alafua Large (Table 2). The highest 40.24 g fruit weight was recorded from the application of the concentration of saltwater at EC 4 dSm^{-1} and the lowest 30.14 g from the application of the concentration of saltwater at EC 8 dSm^{-1}. This might have been due to higher levels of salinity providing the plants with insufficient foods with decreased cell division, which contributed to the minimum fruit weight Ahmed *et al*. (2017). The maximum 56.21 g individual fruit weight was recorded from the Alafua Large and application of the concentration of saltwater at EC 4 dSm^{-1} and the lowest 14.29 g was observed from the combination of Alton and the application of concentration of saltwater at EC 8 dSm^{-1} (Table 2).

Number of fruits

A significant variation between variety, salinity and their interaction in terms of the number of fruits per plant was recorded. The highest 7.83 fruits were produced by Alafua Large, whereas the lowest 5.41 fruits were by Alton (Table 2). The highest number of 9.11 fruits was obtained from the no saltwater application (Control), whereas the lowest 4.22 fruits were recorded from the application of concentration of saltwater at EC 8 dSm^{-1}. A maximum of 10.33 fruits per plant was recorded from Alafua Large and the application of saltwater concentration at EC 8 dSm^{-1}) while the minimum of 3.00 fruits from the combination of Alafua Large and application of saltwater concentration at EC 2 dSm^{-1}

Table 1: Some characteristics of potting soil used in the experiment.

Characteristics	Value
pH	6.2
Organic carbon (%)	1.87
Organic matter (%)	3.74
Total nitrogen (%)	0.86
Available phosphorus (mg/kg)	269.20
Exchangeable potassium (meq./100 g soil)	2.62
Exchangeable calcium (meq./100 g soil)	33.45
Exchangeable sodium (meq./100 g soil)	1.11

Table 2: Yield attributes and yield of tomato crop as affected by variety, salinity and their combinations.

Treatments	Fruit length (cm)	Fruit breadth (cm)	Individual fruit weight (g)	Number of fruits $plant^{-1}$	Fruit $yield^{-1}$ (g)
Variety					
V_1	4.21a	3.92a	36.39b	7.41a	275.93b
V_2	3.31b	2.89b	21.27c	5.41b	140.41c
V_3	4.22a	4.50a	45.60a	7.83a	352.05a
$LSD_{0.05}$	0.84	0.76	8.19	1.53	71.35
Salinity					
T_1	4.09a	4.00a	34.44ab	9.11a	323.52a
T_2	3.78a	3.60a	32.86ab	7.44ab	279.25a
T_3	4.25a	4.12a	40.24a	6.78b	276.16a
T_4	3.55a	3.39a	30.14b	4.22c	145.59b
$LSD_{0.05}$	0.96	0.87	9.46	1.77	82.39
Treatments					
$V_1 \times T_1$	4.29a	3.97a	36.61bc	9.00abc	334.06abc
$V_1 \times T_2$	4.23a	3.89ab	36.84bc	8.33abc	308.49abcd
$V_1 \times T_3$	4.33a	4.03a	38.34bc	7.33abcde	283.63bcde
$V_1 \times T_4$	4.01ab	3.82ab	33.77bcd	5.00def	177.54def
$V_2 \times T_1$	3.95ab	3.48abc	25.27cde	8.00abcd	204.32cdef
$V_2 \times T_2$	2.79ab	2.45bc	19.33de	4.67ef	134.75f
$V_2 \times T_3$	4.02ab	3.48abc	26.18bcde	6.00cdef	157.87ef
$V_2 \times T_4$	2.49b	2.17c	14.29e	3.00f	64.69f
$V_3 \times T_1$	4.05ab	4.54a	41.45abc	10.33a	432.17a
$V_3 \times T_2$	4.28a	4.46a	42.40ab	9.33ab	394.51ab
$V_3 \times T_3$	4.41a	4.84a	56.21a	7.00bcde	386.99ab
$V_3 \times T_4$	4.15ab	4.18a	42.35ab	4.66ef	194.54cdef
$LSD0_{.05}$	1.69	1.51	16.38	3.07	69.14
CV (%)	25.48	23.73	28.11	26.50	33.06

V_1= Melrose; V_2= Alton; V_3= Alafua Large; T_1= Control; T_2= EC 2 dSm^{-1}; T_3= EC 4 dSm^{-1}; T4= EC 8 dSm^{-1}; Values with the same letters in the same column are statistically identical whereas values that have different letters are statistically different. dSm^{-1}= Decisiemens per metre.

(Table 2). A reduction in fruit number of 2.0% was reported with an increase of 1 dSm^{-1} beyond the threshold value of 4.4 dSm^{-1} (Magan *et al*., 2008). Ahmed *et al* (2017) also supported this finding and reported the highest number of mature fruits per plant was produced by the T1 treatment (Irrigation with fresh water) and then decreased gradually.

Fruit yield

Fruit yield differed significantly between variety and salinity. The highest 352.10 g fruit yield per plant was recorded in Alafua Large and the lowest 140.41 g was recorded in Alton (Table 2). The fruit yield decreased as the salinity level increased. The highest 323.52 g fruit yield was recorded from the no saltwater application (Control) followed by the application of the concentration of saltwater at EC 2 dSm^{-1} and the lowest 145.59 g was recorded from the application of the concentration of saltwater at EC 8 dSm^{-1} (Table 1). A reduction in fruit yield was noticed with the increasing salinity. This result agreed with the findings of Mou (2021); El-mogy *et al*. (2018), Islam *et al*. (2011) and Mazumder (2016 a and b). Zhang *et al*. (2022) discovered that the overall yield of tomatoes was remarkably decreased at the salinity of 5 dSm^{-1} and above. The highest fruit yield of 432.17 g was observed from Alafua Large and no saltwater application (Control) and the lowest 64.69 g was recorded from Alton and the application of the concentration of saltwater at EC 8 dSm^{-1} (Table 2). Salinity may cause a significant decrease in photosynthesis and an increase in transpiration rate, resulting in a deficiency of assimilation to the developing organs and consequently delaying or halting growth (El-Hendaway *et al*., 2005). In addition, the application of NaCl solution to planting soil could have detrimental effects on the soil's physicochemical properties (Fontes and Ronchi, 2002). Salinity negatively affects the yield of crop plants by reducing the availability of soil moisture and due to the toxicity effects of sodium and chloride ions at high concentrations in the plant (Mallick *et al*., 2020).

Soil properties

The addition of NaCl solution to planting soil could have detrimental effects on the soil's physicochemical properties (Fontes and Ronchi, 2002). Therefore, the post-harvest

Table 3: Soil pH, organic matter, total nitrogen, available phosphorus, potassium, calcium and sodium content in the soil as affected by variety, salinity their combinations.

Treatment	Soil pH	Organic matter (%)	Total nitrogen (%)	Available phosphorus (mg/kg)	Potassium (meq/100 g)	Calcium (meq/100 g)	Sodium (meq/100 g)
Variety							
V_1	6.91b	1.73a	0.41ab	165.25a	1.86a	33.93a	1.66a
V_2	7.03ab	1.75a	0.37b	185.83a	1.73a	31.53a	1.15a
V_3	7.10a	1.98a	0.46a	181.08a	2.00a	29.70a	1.61a
$LSD_{0.05}$	0.17	0.31	0.07	22.04	0.45	5.80	0.78
Salinity							
T_1	6.84b	1.96a	0.43a	192.78a	1.86a	31.68a	0.65b
T_2	7.03ab	1.73a	0.39a	160.33 b	2.06a	33.65a	0.97bc
T_3	7.01ab	1.78a	0.41a	171.11ab	1.75a	30.38a	1.78ab
T_4	7.15a	1.82a	0.42a	185.33ab	1.79a	31.17a	2.47a
$LSD_{0.05}$	0.19	0.36	0.09	25.45	0.52	6.70	0.91
Treatments							
$V_1 \times T_1$	6.77c	2.00ab	0.43ab	168.00b	1.97a	31.98ab	0.27d
$V_1 \times T_2$	6.90bc	1.43b	0.37ab	159.33b	1.94a	28.17ab	0.78cd
$V_1 \times T_3$	6.97abc	1.62ab	0.44ab	168.00b	1.81a	31.61ab	2.09abc
$V_1 \times T_4$	7.00abc	1.87ab	0.39ab	165.67b	1.71a	34.38ab	3.47a
$V_2 \times T_1$	6.83bc	1.74ab	0.37ab	214.33a	1.57a	28.64ab	0.55cd
$V_2 \times T_2$	7.10ab	1.80ab	0.33b	160.67b	2.24a	38.54a	0.55cd
$V_2 \times T_3$	6.93abc	1.84ab	0.41ab	168.00b	1.58a	26.28b	1.90bc
$V_2 \times T_4$	7.23a	1.63ab	0.37ab	200.33ab	1.53a	25.33b	1.58bcd
$V_3 \times T_1$	6.93abc	2.16a	0.49ab	196.00ab	2.04a	34.42ab	1.15bcd
$V_3 \times T_2$	7.10ab	1.95ab	0.48ab	161.00b	1.99a	34.24ab	1.59bcd
$V_3 \times T_3$	7.13ab	1.87ab	0.39ab	177.33ab	1.85a	33.25ab	1.35bcd
$V_3 \times T_4$	7.23a	1.94ab	0.49a	190.00ab	2.12a	33.81ab	2.36ab
$LSD_{0.05}$	0.33	0.63	0.15	44.08	0.91	11.61	1.57
CV (%)	2.79	20.56	22.56	14.67	28.77	21.63	63.00

V_1= Melrose; V_2= Alton; V_3= Alafua Large; T_1= Control; T_2= EC 2 dSm^{-1}; T_3= EC 4 dSm^{-1}; T4= EC 8 dSm^{-1}; Values with the same letters in the same column are statistically identical whereas values that have different letters are statistically different. dSm^{-1}= Decisiemens per metre.

plant soil's physicochemical properties, including pH, OM, Na, K, Ca, P and total N, were investigated. The results of potting soil after NaCl salinity (2, 4 and 8 dSm^{-1}) irrigation are shown in Table 3. The maximum 7.15 soil pH was recorded from the application of the concentration of saltwater at EC 8 dSm^{-1}, while the minimum 6.84 soil pH was recorded from no saltwater application (Control). The soil pH increased with the application of saline water to the pot plants. The initial pH of the potting soil was 6.2 and after increasing salinity, the maximum pH reached a value of 7.15 (8 dSm^{-1}). For tomato cultivation, the optimum soil pH range lies between 6.00 to 6.8, so the application of moderate levels of salinity maintains soil pH within the tolerable range. Similar results were reported by Rahman *et al*. (2018). The organic matter decreased with the addition of NaCl-solution to the soil, from 1.96% in the control to 1.82% in T_4 (8 dSm^{-1}). A maximum of 0.43% total nitrogen was recorded from the no saltwater application (Control), while a minimum of 0.39% was recorded from the application of the concentration of saltwater at EC 2 dSm^{-1}. A decrease in total nitrogen was recorded due to the application of NaCl to irrigation water (Fontes and Ronchi, 2002 and Rahman *et al*., 2018). The maximum 192.78 mg/kg available phosphorus was recorded from no saltwater application (Control), while the minimum 160.33 mg/kg was recorded from the application of the concentration of saltwater at EC 2 dSm^{-1}. The addition of NaCl reduced the amount of available phosphorus in the soil. A maximum of 2.06 meq/100 g potassium was recorded from the application of the concentration of saltwater at EC 2 dS^{-1}, while a minimum of 1.75 meq/100 g was recorded from the application of the concentration of saltwater at EC 4 dSm^{-1}. The addition of NaCl reduced the amount of potassium in the soil. A maximum of 33.65 meq/100 g of Calcium was recorded from the application of the concentration of saltwater at EC 2 dSm^{-1}, while a minimum of 30.38 meq/100 g was recorded from the application of the concentration of saltwater at EC 4 dSm^{-1}. The addition of NaCl solution reduced the concentration of Ca. The maximum of 2.47 meq/100 g sodium was recorded from the application of the concentration of saltwater at EC 8 dSm^{-1}, while the minimum of 0.65 meq/100 g was recorded from the control with no saltwater application (Control). The Na concentration eventually increased from 1.11 meq/100 g to 2.47 meq/100 g (8 dSm^{-1}) in treated soil. In response to the application of NaCl solution to the pot, almost every studied parameter (OM, Total N, K, Ca and Available P) decreased with salinity, except pH and Na (Table 3). The decrease in these could be the cause of the decrease in tomato plant growth and development. Thus, it is observed that as soil salinity increases, growth-influencing parameters change and reduce yields.

CONCLUSION

The tomato growth and yield varied with the varieties and salinity levels. Alafua Large performed better than all other varieties and recorded higher yields at higher salinity levels. In combined effect of variety and the salt concentration Alafua Large showed a better yield performance than other varieties when combined with the lower salinity levels. In response to the application of NaCl solution to the pot, studied parameters (pH, Total nitrogen and Na) increased with salinity, whereas OM, P, K and Ca recorded reduction. Hence, from the results, Alafua Large is comparatively more salt tolerant than the other varieties. However, further studies can be conducted in field or pot conditions with more tomato varieties using more salt concentrations to identify any suitable varieties to cultivate under the saline-prone areas of Fiji.

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Conflict of interest

All authors declare that they have no conflict of interest.

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