ORIGINAL RESEARCH ARTICLE

Performance of a large fruit sized tomato cv. Anna F1 under different root volume restriction systems

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ABSTRACT

To increase production and improve quality of tomatoes grown under greenhouses, root zone volume restriction system is one method that could be adopted by farmers. However, this technique predisposes the plant to moderate water stress and water stress is associated with increased risk of physiological disorders especially blossom end rot (BER). The main objective of this study, therefore, was to evaluate performance of tomato fruits under different root volume restrictions. The experiment was carried out in JKUAT from July 2020-February 2021. Tomato cv. Anna F1 was grown in four pot volumes; 0.25L,0.5L,1L and 2L respectively in a greenhouse, fertigated using Hoagland solution under hydroponic system. Results showed that fruits had mean weight of 70g, 78.12g, 81.77g and 90.53g in the 0.25L, 0.5L, 1L and 2L pots respectively. Yield per plant (1st- 7th truss) was significantly different with the lowest in 0.25L pots (4095g) and the highest (8232g) in the 2L pot. There was a significant difference in the marketable to non-marketable fruits ratio (2.33, 2.79, 4.36 and 9.07 in 0.25l, 0.5L, 1L, and 2L pots respectively) due to BER incidence. In terms of flavor, there was no significant difference in fruits grown in the four volumes. Fruits in the 0.25L pot had the highest sugar/acid ratio of 1.89 followed by 1.09, 1.06 and 1.02 in the 0.5L, 1L and 2L pots respectively. Mean lycopene concentration was highest in the 2l pot (443. 98µg.g^{-1}) and lowest in the 0.25L pot (264. 71µg.g^{-1}) and mean beta carotene concentration was highest in the 0.25L pot (1.861mg.100g^{-1}) and lowest in the 2L pot (1.287 mg.100g^{-1}) however the differences in concentration were not significantly different at P=0.05. In conclusion, root volume restriction of between 0.25L and 2L can be recommended for quality production of tomatoes.

Keywords Tomato, quality, root volume restriction, fertigation, BER

1.0 Introduction

Crop production will become more difficult with climate change, resource scarcity (e.g. land, water, energy, and nutrients) and environmental degradation (e.g. declining soil quality, increased greenhouse gas emissions, and surface water eutrophication)(FAO, 2015). To pursue the fastest and most practical route to improved yield, the near-term strategy is application and extension of existing agricultural technologies. This would lead to substantial improvement in crop and soil

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management practices, which are currently suboptimal (Khan et al.,2021) Yield and quality of horticultural crops such as tomatoes must be sustained to meet the demands of a growing population in Kenya for food security (Van den Broeck & Maertens, 2016). Tomato *Solanum lycopersicum* L. is the second most important exotic vegetable and is widely consumed in Kenya. There is need for greater attention to be paid towards farmer training to enhance their knowledge and farming experience with regard to tomatoes (Najjuma et al., 2016). It is high in nutraceutical value and is utilized fresh in salads or cooked in many local dishes and can also be processed into a range of value-added products. Tomato accounted for 20 percent by value of the exotic vegetables in 2016 and was produced in an area of 20,011ha with an output of 341,026 tons valued at KES 13.68 billion. Tomato production has the potential for commercialization by small-holder farmers and other chain actors across gender divide (KALRO, 2017).

In tomato, salinity and water stress in the root zone are known to improve the fruit quality by influencing the content and composition of soluble sugars, organic acids, and some amino acids. Saito et al.,(2006a) reported that root zone restriction with a polyester sheet improve TSS and acid content with a decrease of fruit yield. Yamasaki (1999) also reported that restricting the root volume of tomatoes, using non-woven fabric, simplified the management of water in the root zone, thus improving the fruit quality. The use of root-volume restriction can improve the quality of tomato fruit produced using drip fertigation (Saito et al., 2008). However, there is the challenge of physiological disorders under this system as a result of the moderate water stress.

It is well known that water stress is associated with the increased risk of Blossom end-rot (BER) (Adams and Ho, 1992; Taylor and Locascio, 2004), one of the major physiological disorders in tomato that reduces both yield and quality and has been documented as a major challenge in tomato production in Kenya (Indeche et al, 2020). Water stress restricts water uptake which is the solvent for Ca^{2+} flux, therefore depressing Ca translocation along vascular vessels and then causing a lack of calcium in fruit required for cell structure maintenance. It further increases the risk of BER development by restricting Ca^{2+} uptake and/or reducing transpiration rate which is known as driving force of transport of Ca^{2+} together with water flow to fruit (Adams and Ho, 1993; De Freitas et al., 2011; Taylor and Locascio, 2004).

Mineral imbalance has also been reported to pose a risk to BER development in tomato. Studies have shown that high level of nitrogen in soil or hydroponic solution may stimulate root growth or favor vegetative growth which can enhance the competition for Ca^{2+} intake due to higher transpiration rate compared to fruit. Besides, high nitrogen may promote fruit growth and its enlargement may dilute fruit calcium content and therefore increasing the risk to BER development (Saure 2001; Ho and White 2005). Further, application of NH_4^+-N fertilizers or higher NH_4^+/NO_3^- ratios in soil or hydroponic solution were reported to increase the rate and severity of BER occurrence probably due to interfering with root Ca^{2+} uptake. This implies that the presence of antagonistic ions may not only restrict root calcium intake but also likely result in stimulation of fruit growth which had been associated with development of BER. For a proper mineral balance in

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optimizing the mineral composition of the solution, avoiding high salinity (i.e. <5 $dS.m^{-1}$) or excessive NH_4^+ (i.e. <10% total N, $K^{+,}$ and Mg^{2+}) concentrations, whilst maintaining adequate Ca^{2+} concentration have been suggested for adequate root Ca^{2+} uptake (Ho and White, 2005).

Studies have shown that large-fruit tomato cultivars are more susceptible to BER (Vinh, et al., 2018; Indeche et al., 2020). Rapid fruit expansion is believed to be a dominant factor to dilute fruit Ca concentration and increasing fruit susceptibility to BER during the fruit enlarging period in these cultivars (De Freitas and Mitcham, 2012; Dekock et al., 1982; Ikeda et al., 2017; Ooyama et al., 2016; Wui and Takano, 1995; Vinh et al, 2018; Indeche et al, 2020) and defoliation increases calcium concentration in these cultivars under root volume restriction (Indeche et al, 2020). However, limited studies have determined performance especially yield and quality of large fruit cultivars of tomatoes under root restriction, under Kenyan conditions. Yield and quality are key parameters in production both for farmers and consumers and large fruit cultivars are preferred by most consumers. This study, therefore, seeks to evaluate the performance of a popular large-fruit Tomato cultivar 'Anna F1'under different root volume restrictions.

2.0 Methodology

2.1 Experimental layout

The experiment was carried out in JKUAT from July 2020- February 2021. Tomato cv. Anna F1 was grown in four pot volumes; 0.25L, 0.5L, 1L and 2L respectively in a greenhouse, fertigated using Hoagland solution under hydroponic system. The different pot volumes (treatments) were arranged in a completely randomized design replicated three times with 15 growing pots per treatment. The pots were laid out in an automated drip irrigation system. Automation was achieved through the use of sensors (moisture, temperature, and humidity sensors). The capacitive moisture sensors were first calibrated using peat moss media of different moisture content to set the action threshold. The sensors were then connected to the system control panel using electric wire cables. The control panel was then connected to the electric valves and the pump so as to facilitate automatic irrigation depending on the conditions detected by the moisture sensors.

Peat moss media was used as the substrate to provide support for the growing tomato plants. The media was first soaked in clean tap water overnight to ensure it was uniformly wetted. The tomato seedlings were then transplanted into each treatment. Cultural practices such as trellising, pest management, pruning, and defoliation of old leaves were done in all the treatments.

2.2 Fruit Sampling and analysis

In this study, sampling of the fruits was done by harvesting two mature fruits each from the 1^{st} - 7^{th} truss of each tomato plant. The weight of each fruit was obtained and recorded. Other data collected included measurement of $brix^0$ using a handheld refractometer, moisture content of the fruits, acidity, calcium, lycopene and beta carotene. The lycopene and beta carotene test involved three main procedures: Separation of the pigment; running the samples in the HPLC machine; data

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interpretation and analysis. The extraction, storage, handling, and analysis of lycopene were carried out under controlled environment to minimize losses through oxidation or isomerization.

2.2.1 Determination of calcium in tomato fruit

2g of tomato pulp was weighed in a crucible and heated at 350 degrees on a heating plate under a fume chamber until the sample was completely charred. The sample was then introduced into a muffle furnace and heated further at 550 degrees for six hours. The sample was left to cool in a desiccator. The sample ash was dissolved in 0.5 molar nitric acid, made to 100 milliliters total volume in a volumetric flask and filtered into a polyethylene bottle. A series of concentration for calcium standard was prepared using the 0.5 M nitric acid and lanthanum chloride added to the sample in the ratio 1:1. Atomic absorption spectrophotometer *Shimadzu AA-7000 series* with a hollow cathode lamp for calcium installed was used to generate a straight line calibration graph using the series of concentrations of calcium standards which subsequently were used to calculate the concentration of calcium in the sample using the absorbance value measured (Okalebo et al., 2002) Total calcium concentration in the fruit was expressed in mg^{-1}.

2.2.2 Extraction and determination of beta carotene and lycopene in tomato fruits (HPLC method)

Beta carotene and lycopene were extracted from tomato pulp sample using hexane/acetone/ethanol (50:25:25 v/v/v), centrifuged and evaporated in a vacuum rotary evaporator. The resulting dry extract was dissolved in methanol/acetonitrile (90:10), passed through 0.45 µm filter into a vial and injected on a C18 column with methanol/acetonitrile (90:10 v/v) as mobile phase at 1 ml/min flow rate. Photodiode array detector was used and the wavelengths 470 nm and 503 nm were set for beta carotene and lycopene respectively. Acquisition time was ten minutes per sample and the column oven set at 30 degrees. Beta carotene and lycopene standards were prepared using the mobile phase and a straight-line calibration graph obtained was used to calculate the concentration of the carotenoids ($\mu g.g^{-1}$) in the sample using the peak area measured. Equipment details-High Performance Liquid Chromatography (HPLC) *Shimadzu LC20AD, SPDM20A, CT-10 VP.*

2.3 Data analysis

Data were subjected to two-way analysis of variance (ANOVA) using Genstat statistical package, 15th edition and means found to be significantly different at $p \leq 0.05$ were separated using Tukey's HSD test.

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3.0 Results

3.1 Environmental conditions

Table 1: Mean environmental conditions in the greenhouse from anthesis to sampling

Environmental condition	Mean
Temperature	25.9^{0}C
Relative humidity	67%
Media moisture	80-97%.

3.2 Nutrient solution supply and drainage

Table 2: Mean amount (ml) of nutrient solution supplied, drained, and absorbed by individual Tomato plants cv. Anna F1 daily under different root volume restriction system

Root volume (L)	Supply (ml)	Drainage (ml)	Absorbed (ml)
0.25	390a	158a	232a
0.5	504b	252b	277b
1	601b	265bc	324c
2	872c	277c	607d

Means followed by the same letter in the column are not significantly different at P<0.05

Plants in 2L pots absorbed approximately 70% of the nutrients solution applied while those in 0.25L pots absorbed 59%.

3.3 Effect of root volume restriction on fruit weight

Fruit weight was significantly different in the different root volumes. The largest fruit weight was observed in plants with root volume restricted in 2 L pots and the least in the 0.25 L pots. However, there was no significant difference in fruit weight between plants in 0.25L and those in 0.5L. Similarly, there was no difference in fruit weight between plants in 1L and 2L pots respectively. As shown in Figure 1, fruit weight increased with an increase in pot size.

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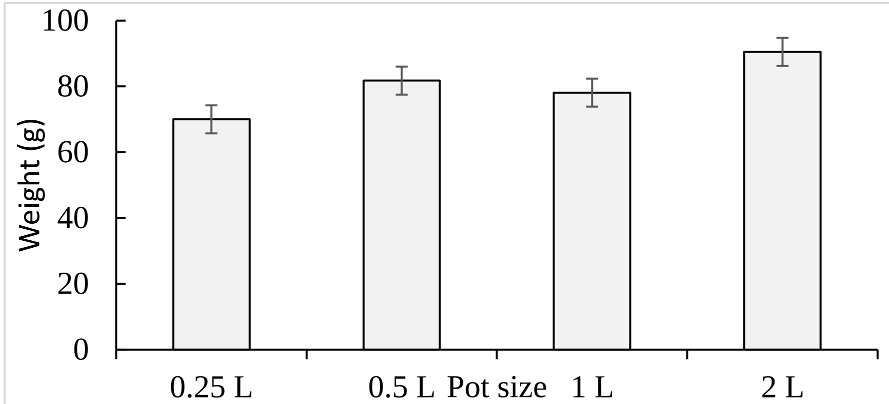

Figure 1: Mean weight of tomato fruit cv. Anna F1 under different root volume restriction system

3.4 Effect of root volume restriction on Yield

There was a significant difference in the number of fruits per truss between plants with roots restricted in 0.25L volume pots and 2L but no difference between 0.5L and 1L. Yield per plant (1st-7th truss) was significantly different in the different pot sizes. The lowest yield was observed in 0.25L pots at 4095g and the highest in the 2L pot at 8232g, respectively. However, there was no significant difference in yield between plants in pot sizes 0.5L and 1L as shown in Figure 2.

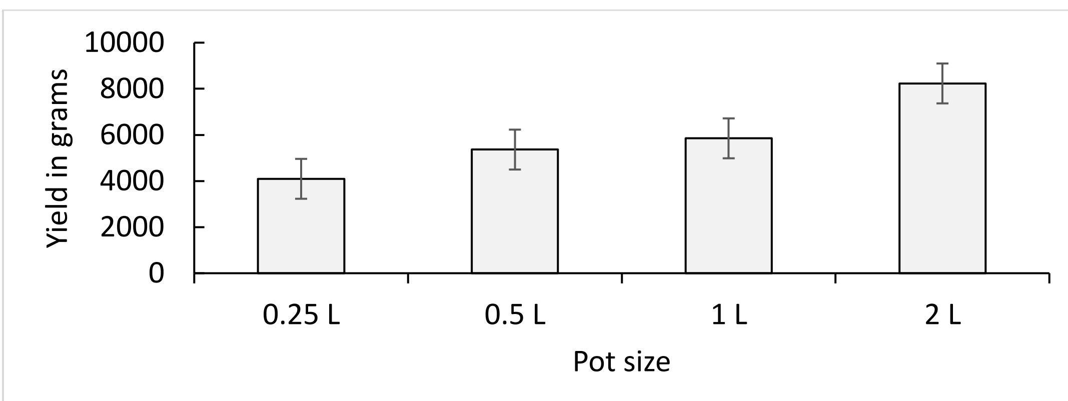

Fig 2: Mean total weight (fruits from 1st to 7th truss) per tomato plant cv. Anna F1 grown under different root volume restriction system

3.5 Effect of root volume restriction on BER incidence

There was a significant difference in the marketable to non-marketable fruits ratio due to BER incidence. The ratio of marketable to non-marketable fruits increased with increase in pot size. There was no significant difference in BER incidence between plants with roots restricted in 0. 25L and 0.5L with ratios of 2.33 and 2.79, respectively. The ratio of marketable to non-marketable fruits due to BER incidence was significantly different in the 1L and 2L pot at 4.36 and 9.07, respectively.

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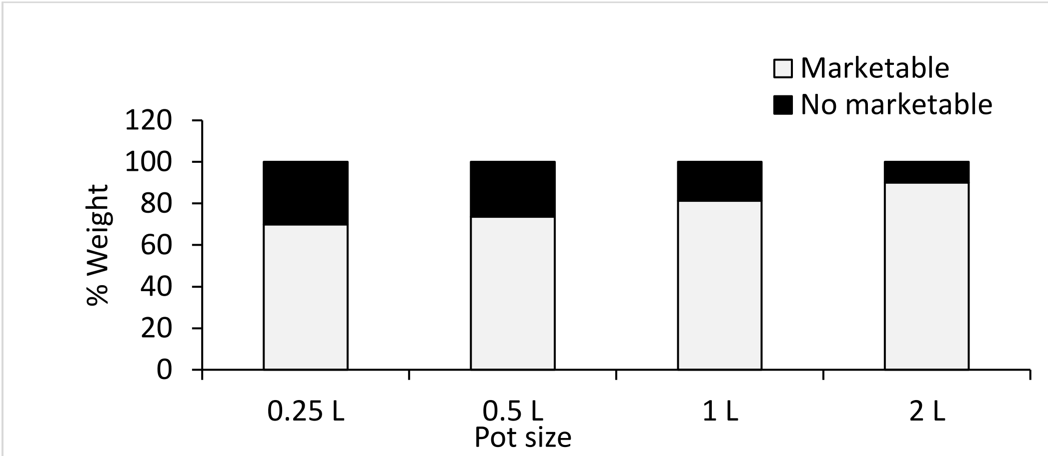

Figure 3: Ratio of marketable to non-marketable tomato fruits grown under different root volume restriction systems

3.6 Effect of root volume on the quality of tomato fruit under different root volume restriction systems

3.6.1 Total Ca (mg) translocated into fruit

The total amount of Ca in the fruit increased significantly with increase in pot size (Figure 4). The difference was observed between the 0.25L and the 2L pot. However, there was no significant difference between Ca content in the fruit in 2L pot and that in the 1L and 0.5L pots, respectively.

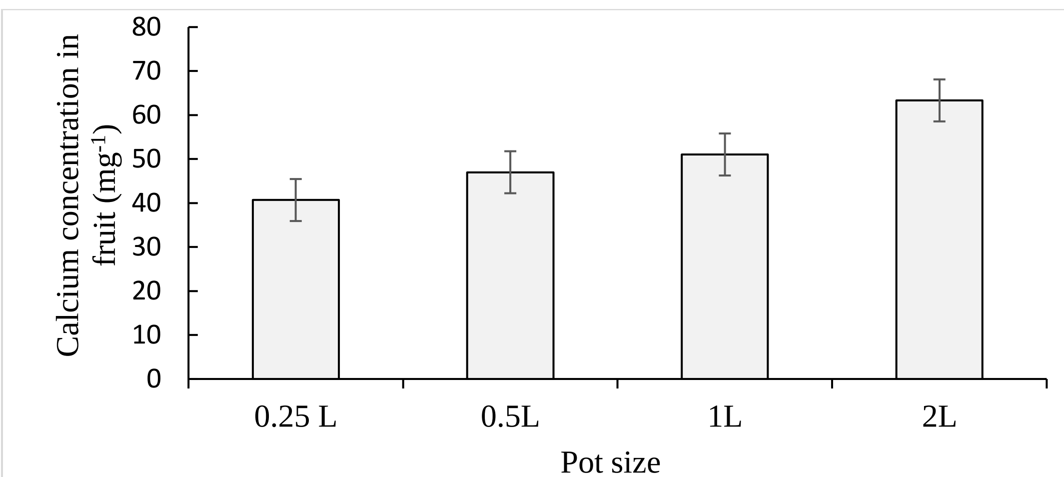

Figure 4: Total calcium concentration in tomato fruit under different root volumes

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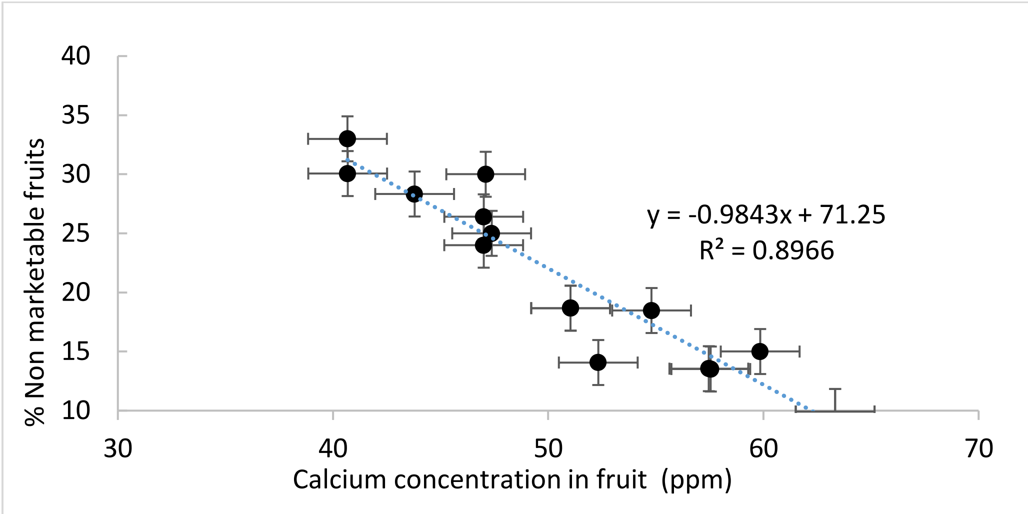

Figure 5: Relationship between Calcium in fruit and Non-marketable fruits due to BER

There was a significant relationship between calcium in fruit and non-marketable fruits due to BER as shown in the Figure 5. As calcium concentration increased in the fruit, BER incidence in the fruit decreased.

3.6.2 Sugar/acid ratio

In terms of sugar/acid ratio, there was no significant difference in fruits grown in the four volumes. However, the ratio decreased with increase in pot size. The ratio was 1.89, 1.09, 1.06 and 1.02 in the 0.25L, 0.5L, 1L and 2L pots, respectively.

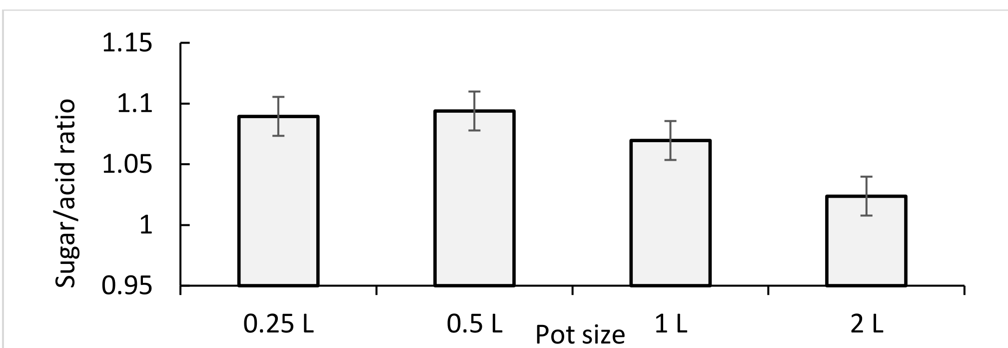

Figure 6: Sugar/acid ratio in tomato fruit cv. Anna F1 as influenced by different root volume restriction

3.6.3 Lycopene content

Results showed that there was a significant difference in lycopene concentration in the fruits at different root restriction volumes. The mean lycopene concentration in the fruit increased with an increase in pot size. However, there was no significant difference in lycopene content between

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fruits in the 0.25L and 0.5L (264.71 and 283.84 μg.g^{-1}, respectively) and between 1L and 2L (437.9 and 443.98 μg.g^{-1}, respectively).

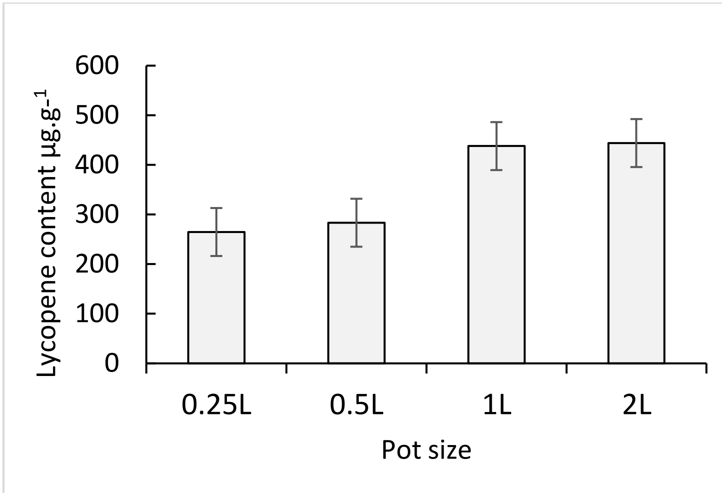

Fig 7: Lycopene content in tomato fruit cv. Anna F1 under different root volume restriction system

3.6.4 Beta Carotene

Root restriction did not have any significant effect on β-carotene in the fruit. However, the amount decreased with an increase in pot size (Fig 8). The mean β-carotene content was highest in the 0.25L pot (1.861μg.g^{-1}) and lowest in the 2L pot (1.15 μg.g^{-1}).

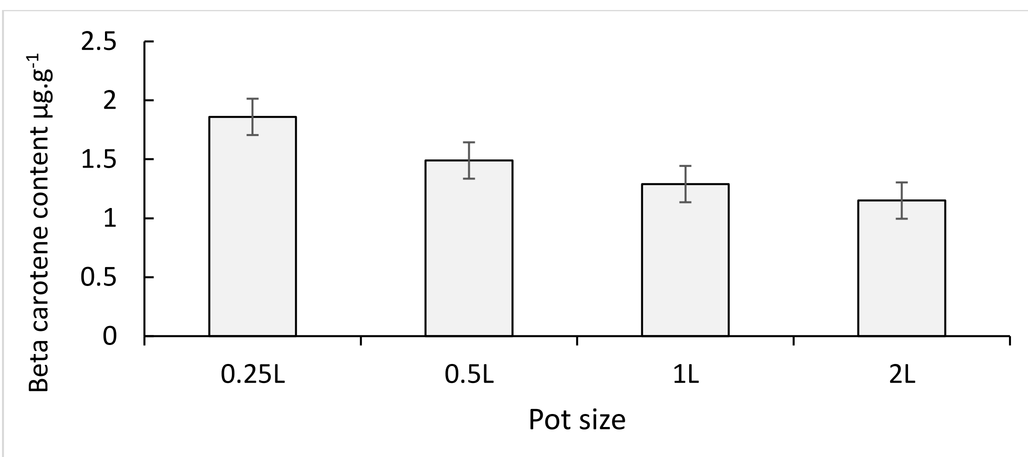

Fig 8: Beta carotene content in tomato fruit cv. Anna F1 under different root volume restriction system

4.0 Discussion

The study revealed that the root restriction system had an effect on the amount of nutrient solution supplied to the plants. The smaller pots utilized less nutrient solution compared to the

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larger pots. Plants in the larger pots absorbed significantly higher amounts of nutrient solution. This could be attributed to the volume of roots restricted in each pot size.

The tomato cultivar 'Anna F1' performed comparatively well under root volume restriction. In this study yield of up to 8 kg per plant from a harvesting period of 1 and a half months was realized. Conventionally, yields of 6.6 kg per plant have been reported for the same harvesting period. This increase in yield could be attributed to the efficient use of nutrients through the automation of the fertigation system.

In regard to BER incidence in relation to the amount of calcium in fruit, Ho and White, (2005) noted that the complex interactive effects between calcium and mineral ions may influence calcium uptake and partially define fruit calcium concentration intake, therefore, affecting the probability of BER development due to promotion or reduction of Ca^{2+} uptake. Results of this study indicated that the number of fruits with BER hence non-marketable were more in the smaller (0.25L) pots than in the larger (2L) pots (Fig. 3). This was probably due to the low Ca in fruits in the small pots (Fig 4). BER is associated with Ca deficiency. In plants, Ca has irreplaceable functions such as the construction of cell walls and signal transduction involving responses to external or internal signals (White and Broadley, 2003; Hocking et al., 2016). Studies have shown that systemic or localized Ca deficiency in plants causes various physiological disorders leading to substantial yield and quality losses (Tonetto de Freitas and Mitcham, 2012; Vinh et al., 2018; Indeche et al., 2020). However, the development of Ca deficiency symptoms is determined by a number of internal and external factors including the transport of Ca to fruit, Ca allocation, and subcellular distribution (Bangerth, 1979; Ho and White, 2005; Tonetto de Freitas et al., 2014; Hocking et al., 2016). In this study there was a significant relationship between Ca in fruit and the development of BER (Fig.5). This study, therefore, supports the assertion that Ca deficiency in fruit is highly associated with the development of BER.

Traditionally, the concept of quality in vegetables has been related with their external appearance. However, sugars and organic acids are among the key components impacting tomato quality and customer preferences. Sugar, acids and sugar/acid ratio are good indicators of tomato flavor. Several studies have shown that they account for over 60% of the dry matter, and contribute to soluble solid content (SSC) and also are essential to the flavor intensity (Davies et al., 1981; Goff and Klee, 2006; Baldwin et al., 2008; Kader, 2008; Bastias et al., 2011). Carli et al (2011) reported that environmental effect on the sensory profile (sugar and acid concentration) of tomatoes is highly dependent on the genotype. In this study, root restriction had a significant effect on the sweetness and taste intensity within the genotype evaluated. Fruits on plants in the small pots had a higher sugar/acid ratio (Fig.6). This implies that moderate stress improved tomato flavor.

In ripe tomato fruits, lycopene is the main carotenoid that can be found and it causes its red coloration. The contents of carotenoids, as well as other chemoprotective substances are highly conditioned by the genotype and environmental conditions (Tiwari and Cummins, 2013). Further,

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they reported that, considering this variability, lycopene concentrations from standard tomato cultivars range from 7.8 to 18.1 mg 100 g^{-1} fresh weight (fw). The second main colored carotenoid present in tomatoes is β-carotene, responsible for orangey colors. Its concentration is much lower, up to 1.2 mg 100 g^{-1} fw. In this study, a similar trend was observed (Fig 7 and Fig 8).

Evidence of genotype and environmental effect on the accumulation of these bioactive compounds has been reported. Besides their functions as pigments and nutrients, carotenoids are also the precursors of many important volatile flavor compounds in plants, conferring the sensory attribute that can be detected by consumers (Vogel et al., 2010). Carotenoids in plants produce a range of compounds named apocarotenoids under oxidative cleavage, giving rise to volatile compounds that constitute the aromatic components of flowers, fruits, and leaves, as well as the well-known phytohormones such as abscisic acid (ABA) and strigolactones, upon abiotic stress (Rolland et al., 2012). It has been reported that among the environmental factors that influence the metabolism of carotenoid, moderate stress is especially effective without inducing senescence or necrosis (Poiroux-Gonord et al., 2010). The difference in the contents of carotenoids in the different root volume restrictions could be due to the effect of abiotic stress conferred on the plants. In a previous study, Indeche et al., (2020) revealed that root volume restriction confers moderate water stress on tomato plants.

5.0 Conclusion and recommendations

Results of this study show that tomatoes can be grown under root restriction, moisture mediated fertigated system without compromising yield and quality. Yield increased with increase in pot size. Small pot size increased development of BER, however, sensory attributes improved with reduced pot size. It's recommended that trials on substrate amendment for increased performance and water saving in tomato production under 0.5L and 1L root volumes be done. Performance of other high value crops such as sweet pepper and cucumber under root volume restriction system could be evaluated. Full automation for critical environmental conditions within the greenhouse for optimum tomato production under root volume restriction system is key.

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6.2 General acknowledgement

None

6.3 Declaration of interest

None

6.4 Conflict of interest

None

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