academicJournals

Vol. 10(12), pp. 1392-1400, 19 March, 2015
DOI: 10.5897/AJAR2015.9491
Article Number: AFD771351798
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Influence of soil moisture levels and packaging on postharvest qualities of tomato (*Solanum lycopersicum*)

Caroline Imani Sibomana[1], Arnold Mathew Opiyo[2]* and Joseph Nyamori Aguyoh[3]

[1]Faculty of Agriculture and Environment, Université Evangélique en Afrique (UEA), P. O. Box 3323 Bukavu, Democratic Republic of Congo (DRC).
[2]Department of Crops, Horticulture and Soils, Egerton University, P. O. Box 536 Egerton, Kenya.
[3]Department of Agriculture and Environmental Sciences Rongo University College, P. O. Box 103-40404 Rongo, Kenya.

Received 8 January, 2015; Accepted 11 March, 2015

Preharvest factors influence postharvest quality of tomatoes. Whereas water stress improves fruit total soluble solids; and polyethylene is used for packaging of fresh horticultural produce, little is known about their combined effects on quality and shelf life of tomatoes. The objective of this study was to investigate the independent and interactive effects of deficit irrigation and packaging on postharvest quality and shelf life of tomatoes. The experiment was a split plot arranged in a Randomized Complete Block Design with three replicates. Packaging was the main treatment and water levels the sub treatments. Water treatments were 20, 40, 60, 80 and 100% of pot capacity (PC). Packaging treatments were perforated, non-perforated and non-packaged (control). Fruits harvested at breaker stage were stored at 21±2ºC. Quality parameters assessed were fruit weight loss, colour change, firmness, total soluble solids, titratable acidity and shelf life. Polyethylene bags commonly used in the market (22 x 6.37 cm of size; 0.02 mm of thickness) were used as packaging material. At 16 days storage, unpackaged fruit had lost 34.23% of initial weight compared to 9.06% in perforated and 4.43% in non-perforated packaging. At 8 days of storage, 20% PC fruits were firmer than 80% PC fruits. At 10 days storage, 20% PC fruits were firmer compared to those from 40 and 80% PC. Total Soluble Solids (TSS) increased with decrease in moisture level. At 10 DAH, the lowest TSS was recorded in fruits subjected to 100% PC and highest in 40% PC. Deficit Irrigation effectively regulates tomato fruit quality; and combining it with packaging can enhance shelf life of tomato fruits.

Key words: Water stress, packaging, fruit firmness, total soluble solids (TSS).

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is one of the most popular fruit vegetables worldwide and plays a vital role in providing substantial quantities of vitamins C and A in human diet. The fruits are eaten either raw or cooked. Being a climacteric and perishable vegetable, tomatoes have a very short lifespan, usually 2 to 3

*Corresponding author. E-mail: aopiyo@hotmail.com

weeks. Deterioration of tomato is brought about by several factors such as the harvesting stage, postharvest handling including packaging material (Mathooko, 2003). Tomato is sensitive to many environmental stresses, including extreme temperature, drought, salinity and inadequate moisture (Nahar et al., 2011). Water plays an important role in plant life; and is the major limiting factor in agricultural production. According to Nahar et al. (2011), since water is essential for plant growth, it is axiomatic that water stress will affect plant growth, yield and quality of yield. The degree to which they will be affected will depend on the severity and duration of the water stress. Judicious use of water in agriculture is a priority and adoption of irrigation strategies which use less water while maintaining satisfactory yields, thus improving water use efficiency may play a key role in preservation of this scarce resource (Patanè et al., 2011). Deficit irrigation (DI) is a water saving strategy whereby crops are subjected to a level of water stress either during a particular period or throughout the entire growing season.

Adequate soil moisture during preharvest periods is essential for the maintenance of postharvest quality. During the growing season, water stress can affect the size of the harvested plant organ, and lead to soft or dehydrated fruit that is more prone to damage and decay during storage (Shewfelt and Prussia, 1993). Postharvest qualities of tomatoes partly depend upon preharvest factors such as cultural practices, genetic and environmental conditions (Meaza et al., 2007). Although growth can be adversely affected due to water stress, fruit quality parameters such as total soluble solids usually improve (Birhanu and Tilahun, 2010). Birhanu and Tilahun (2010) found that total and marketable yield of tomato was lowest in the most stressed treatment (75% water deficit); but fruit soluble solid content increased with increase in water stress. In their study, Nahar et al. (2011) observed that water deficit stress did not cause physical and internal tissue damages in fruits; but instead improved the quality of fruits by increasing different solutes and organic acids.

Packaging of fresh horticultural produce is carried out to prevent kinds of degradation that might render it unsuitable for consumption. According to Kader and Rolle (2004), the principal purpose of packaging is to reduce damage during transport. As a feature of proper packaging in a sealed package, a fresh product will create a modified atmosphere by respiration and gas permeation through the packaging material (Sammi and Masud, 2009). Packaging has been reported to significantly reduce fruit weight loss (Sammi and Masud, 2009); and that tomatoes sealed in plastic films have an extended marketable life. Polyethylene is the most commonly used polymer film used for packaging of fresh horticultural products. Its advantages are that it is inert, permeable to gases and impermeable to water vapour. Consumers are interested in produce having long shelf life with minimal change in quality attributes during storage. An increase in the storage life and superior fruit quality is therefore desirable to the consumer (Sammi and Masud, 2009). Important tomato quality criteria to both traders and consumers are appearance, firmness, ripening behaviour and shelf life. In the developing countries, consumers are rarely concerned with the flavour and nutritive value.

Water deficit during production and packaging are important factors which have been found to influence the postharvest quality and shelf life of tomatoes. Few studies if any, have evaluated the combined effect of deficit irrigation and packaging on the quality and shelf life of tomatoes. The present study was therefore undertaken with the objective of investigating the independent and interactive effects of deficit irrigation and packaging on postharvest quality and shelf life of tomatoes.

MATERIALS AND METHODS

Field experiment

Tomato seeds (cv. 'Moneymaker') were sown in plastic pots in polythene covered greenhouse at the Horticulture Research and Demonstration Field, in Egerton University (Kenya). The plants were subjected to five different soil moisture levels (20, 40, 60, 80 and 100% of the pot capacity) until harvesting. Each water treatment had 6 plants and was replicated 4 times. Each plastic pot (20.32 x 35.56 cm in size) contained 10 kg of air dried soil (a mixture of sand, top soil and manure at the ratio of 1:2:0.5) and were arranged in a randomized complete block design (RCBD) (Appendix Figure 1). The top of the containers were covered with black plastic to prevent evaporation and were put on top of a plastic paper to avoid direct contact with the soil surface. The amount of water to be applied for each treatment was determined on the basis of the percentage of pot water capacity.

Laboratory experiment

Tomato fruits were harvested at the breaker stage from the field trial and stored in a temperature controlled chamber at 21±2ºC. The laboratory experiment was a split plot arranged in a Randomized Complete Block Design (RCBD) (Appendix Figure 2); with packaging as the main treatment and water levels being the sub treatments. The water treatments comprised of 5 levels (WS1: 100% of PC, WS2: 80% of PC, WS3: 60% of PC, WS4: 40 % of PC and WS5: 20% of PC) whereas packaging had 3 levels [Perforated (P), Non-Perforated (NP) and Non-Packaged or control (C)] and were replicated three times. Two trials were conducted, with the first trial running from June to July 2010, and the second trial from August to October 2010. Five fruits were used for each of the treatments. The quality parameters assessed during storage were fruit weight loss, colour change, firmness, total soluble solids (TSS), titratable acidity (TA) and fruit shelf life. The type of packaging used was the polyethylene bags, commonly used in the market - high density polyethylene bag - (HDPE: 22 x 6.37 cm of size; 0.02 mm of thickness). The bags were perforated with a punch (Model: Kangaroo Punch DP 520-8 cm of 2.5 mm punching probe).

Fruits were harvested at the breaker stage; and colour change determined on two fruits per treatment per replicate by use of a tomato colour chart according to Abdullah et al., (2004). Fruit firmness was analysed by a destructive procedure on 2 fruits per treatment per replication using a handheld penetrometer [Fruit

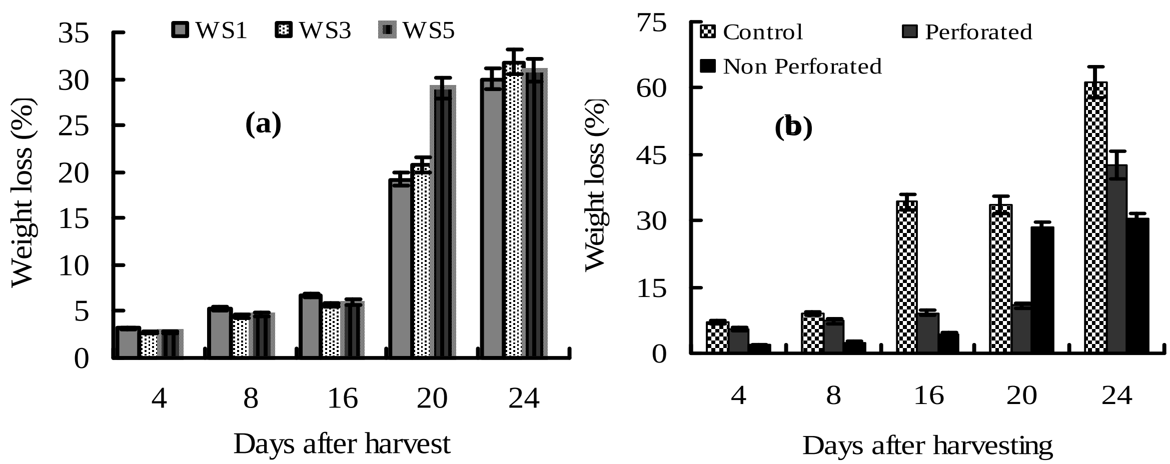

Figure 1. Effect of (a) Water stress and (b) Packaging on weight loss of harvested tomato (WS1 = 100% of PC; WS3 = 60% of PC; WS5 = 20% of PC).

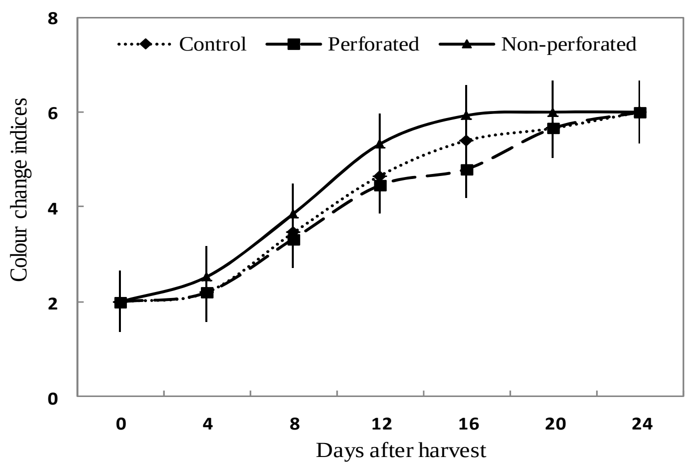

Figure 2. Influence of packaging on tomato fruit colour change.

pressure tester, Model: *FT 327* (1-12 kg), with 0.7 x 0.92 mm of probe size] and was recorded at the equatorial surface for each individual fruit. The firmness and colour readings were taken at harvest (day 0) and thereafter at 2-day intervals until termination of the experiment.

Total soluble solids (TSS) were determined on two fruits per treatment per replicate using a hand-held refractometer [Model SKU: MT- 032 (^{o}Brix, 0-32%)]. Determination was done by calculating the average TSS for the 2 fruits per treatment for each replicate. The final value was obtained by determining the average of the replicate for each treatment.

Fruit juice (5 ml) from 2 fruits per treatment per replicate was titrated with 0.1 N NaOH to pH 8.1 using phenolphthalein as an indicator and the percentage titratable acidity (TA) was calculated using the following formula by Monash Scientific (2003):

TA (g/l) = T x M x 0.75/ V x 10 x 0.1

Where,
M= Molarity (M) of 0.1 M NaOH
V= Volume (ml) of sample
T= Titre (ml) of 0.1 M NaOH

The fruit shelf life was considered to have elapsed when the fruits lost 75% of their initial weight (Marcos et al., 2005) and/or started showing signs of shrivelling and decay.

Data collected were subjected to Analysis of Variance (ANOVA) using SAS version 9.2 and mean separations were done using Duncan Multiple Range Test (DMRT) at 5% level of significance.

RESULTS

Fruit weight loss

Soil moisture levels had significant effects on the fruit weight. At harvest, fruit weight increased with increasing moisture levels. The highest fruit weight was recorded in fruits harvested from plants subjected to 100% Pot Capacity (PC); while those with the lowest weight were from plants which received 20% PC. All treatments were significantly different at harvest up to 16 days of storage or days after harvest (DAH). However, at 20 and 24 DAH, there was no significant difference in weight between fruits subjected to 80 and 100% PC. The differences in weight loss between all other treatments were significant (Figure 1a).

During the first 12 days of storage, packaging did not significantly influence fruit weight. Weight loss for fruits in non-perforated package was significantly lower compared to the control (non-packaged fruits) at 16 and 24 DAH (Figure 1b). Differences between perforated and non-perforated packaged fruits were not significant.

Colour change

Packaging had a significant effect on fruit colour change. Fruits packaged in non-perforated bags developed colour

Table 1. Effect of moisture levels on fruit firmness (Kgf).

Water stress (Pot capacity)	Days after harvest					
	0	2	4	6	8	10
WS_1	5.53[a*]	4.60[ab]	4.04[bc]	4.23[a]	4.69[ab]	3.88[ab]
WS_2	6.03[a]	3.98[b]	3.23[c]	4.30[a]	3.47[b]	3.24[b]
WS_3	5.94[a]	5.50[a]	4.90[ab]	4.69[a]	4.36[ab]	4.40[ab]
WS_4	5.30[a]	5.32[a]	5.46[a]	4.40[a]	4.29[ab]	3.71[b]
WS_5	5.52[a]	4.57[ab]	4.72[ab]	4.34[a]	5.12[a]	5.22[a]

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05.

Table 2. Effect of packaging on tomato fruit firmness (Kgf).

Packaging	Days after harvest					
	0	2	4	6	8	10
Control	5.61[a*]	5.39[a]	4.63[a]	5.03[a]	4.63[a]	3.43[b]
Perforated	5.86[a]	3.84[b]	4.33[a]	4.25[b]	4.71[a]	4.86[a]
Non-perforated	5.53[a]	5.15[a]	4.45[a]	4.45[b]	3.81[a]	3.98[ab]

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05

faster than those in perforated packages and the control (Figure 2). From 4 to 16 DAH, significant differences were observed between the perforated and non-perforated packaging. At 16 DAH, significant differences were observed between all treatments with the colour index being highest in fruits packaged in non-perforated bags.

The interaction between water levels and packaging treatments was significant. At 12 DAH, non-perforated packaged fruits from 40% PC had a significantly higher fruit colour development than control (unpackaged) fruits from 60% PC. The colour change in fruits from 100% PC in perforated bags was significantly slower compared to all other treatments in control and non-perforated packages and fruits from the 80 and 60% in the perforated bags at 16 DAH.

Fruit firmness

Fruit firmness was significantly influenced by soil moisture levels. At 2 days of storage, fruits from 80% PC were less firm compared to those from 60 and 40% PC. 4 days after storage, fruits from 80% PC were significantly softer compared to all other treatments except 100% PC; while at 8 days of storage, 20% PC fruits were firmer than 80% PC fruits; and at 10 days storage they (20% PC) were firmer compared to those from 40 and 80% PC (Table 1).

After 2 days storage, fruits in perforated packages were softer than those in non-perforated packages and control (unpackaged). After 6 days storage, control fruits were firmer than those packaged (perforated and non-perforated). At 10 days storage, fruits in perforated packages were firmer than the control fruits (Table 2).

Fruit total soluble solids (TSS)

Fruit Total Soluble Solids (TSS) increased with decrease in moisture level (% PC). At the time of harvest, fruits from plants subjected to 20% PC had significantly higher TSS compared to all other treatments; while those subjected to 40 and 60% PC had higher TSS compared to 80 and 100% PC fruits. A similar trend was observed throughout the storage period (Table 3). At 10 DAH, the lowest TSS was recorded in fruits subjected to 100% PC and the highest in 40% PC. However, the differences in TSS between the 20, 40 and 60% PC fruits at 10 DAH were not significant. TSS generally increased with increase in storage time. Packaging had no significant influence on the fruit TSS. Significant effects on TSS were observed due to the interaction between water and packaging treatments. After 2 days storage, fruits from 20% PC plants in perforated packaging had significantly higher TSS than 100% PC perforated and non-perforated packaged fruits (Table 4). After 6 days of storage fruits subjected to 20% PC in non-perforated packaging had higher TSS compared to those from 100% PC in non-perforated packaging and unpackaged. At the end of the storage period (10 DAH), unpackaged 100% PC fruits had significantly lower TSS than unpackaged 80, 60, 40 and 20%; perforated 20 and 40% and 60 and 40% PC non-perforated packaged fruits (Table 4).

Fruit titratable acidity (TA)

Fruits from 20% PC exhibited the lowest TA while those

Table 3. Effect of moisture levels on tomato fruit TSS (^{o} Brix).

Water stress	Days after harvest					
	0	2	4	6	8	10
WS_1	4.06^{c*}	4.46^{c}	4.37^{d}	4.28^{c}	4.71^{c}	4.28^{d}
WS_2	4.42^{c}	4.71^{bc}	4.94^{c}	5.03^{b}	5.15^{b}	5.16^{c}
WS_3	4.93^{b}	5.12^{ab}	5.68^{ab}	5.33^{ab}	5.31^{b}	5.43^{bc}
WS_4	5.38^{b}	5.43^{a}	5.52^{b}	5.28^{b}	5.78^{a}	5.82^{a}
WS_5	5.90^{a}	5.52^{a}	6.08^{a}	5.79^{a}	5.81^{a}	5.63^{ab}

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05.

Table 4. Interactive effects of water and packing on the TSS (^{o} Brix) of tomato fruits.

WS	DAH packaging								
	2			6			10		
	C	P	NP	C	P	NP	C	P	NP
WS_1	5.0^{a}	4.1^{b}	4.3^{b}	4.0^{c}	4.5^{abc}	4.4^{bc}	4.2^{d}	4.2^{d}	4.5^{cd}
WS_2	4.6^{ab}	4.6^{ab}	4.9^{ab}	5.3^{abc}	4.7^{abc}	5.1^{abc}	5.5^{abc}	4.9^{bcd}	5.1^{abcd}
WS_3	5.3^{ab}	5.1^{ab}	5.0^{ab}	5.9^{ab}	5.1^{abc}	5.0^{abc}	5.6^{abc}	5.0^{bcd}	5.7^{abc}
WS_4	5.5^{ab}	5.4^{ab}	5.4^{ab}	4.9^{abc}	5.4^{abc}	5.6^{ab}	5.7^{abc}	5.5^{abc}	6.3^{a}
WS_5	4.9^{ab}	6.2^{a}	5.4^{ab}	5.7^{ab}	5.7^{ab}	6.0^{a}	6.0^{ab}	5.6^{abc}	5.3^{abcd}

Table 5. Effect of moisture levels on tomato fruit titratable acidity (%).

Water stress	Days after harvest					
	0	2	4	6	8	10
WS_1	7.90^{a*}	9.80^{b}	10.14^{ab}	10.82^{b}	11.08^{a}	11.07^{ab}
WS_2	6.36^{ab}	13.23^{a}	12.79^{a}	14.34^{a}	10.99^{a}	12.62^{a}
WS_3	5.06^{b}	8.49^{bc}	8.38^{b}	10.24^{bc}	12.70^{a}	9.74^{abc}
WS_4	5.65^{b}	8.17^{bc}	7.84^{b}	10.74^{bc}	7.32^{b}	8.96^{bc}
WS_5	5.57^{b}	6.41^{c}	8.42^{b}	7.44^{c}	8.69^{b}	7.24^{c}

*Means with the same letter(s) within a column are not significantly different at P ≤ 0.05.

from 80% PC had the highest TA (Table 5). At the start of storage, although TA tended to increase with increasing moisture levels, the differences between 20, 40, 60 and 80% PC were not significant; neither was the difference between 80 and 100% PC. At 2 and 6 DAH, fruits from plants subjected to 80% PC had the highest TA; while those from 100% PC had a significantly higher TA compared to 20% PC. No significant differences in TA were observed between fruits subjected to 100, 80 and 60% PC after 8 days storage. Likewise there was no significant difference between fruits subjected to 40 and 20% PC. In all treatments, TA tended to increase with storage time.

With respect to packaging, at 2 days storage, fruits in non-perforated packaging had lower TA compared to those in perforated packaging and control (Table 6). At 6 days storage, fruits in non-perforated packaging exhibited lower TA than the control. There were no significant differences between treatments after 8 days storage; however, after 10 days storage, fruits in non-perforated packaging had significantly lower TA compared to those in perforated packaging.

DISCUSSION

Weight loss

Most fresh fruits and vegetables contain so much water (80 to 90%), thus their quality suffer very quickly from water loss; including loss of saleable weight. Tomato quality changes continuously after harvesting. Fruit weight loss is normally due to senescence or desiccation of tomato fruits (Batu and Thompson, 1998). In this study,

Table 6. Effect of packaging on tomato fruit titratable acidity (%).

Packing	Days after harvest					
	0	2	4	6	8	10
Control	5.34[a]*	10.63[a]	10.40[a]	12.09[a]	10.82[a]	9.76[ab]
Perforated	6.94[a]	10.08[a]	9.83[a]	11.18[ab]	9.69[a]	11.55[a]
Non-perforated	6.04[a]	6.95[b]	8.31[a]	8.87[b]	9.96[a]	8.47[b]

as would be expected, fruit size and weight increased with increasing water levels. These observations are similar to those of Birhanu and Tilahun (2010) who reported that fruit size was reduced with reduction in the amount of irrigation water applied. According to Zegbe et al. (2006), reduction in fruit size is mainly due to reduced fruit water content. Larger fruit size can be the result of cell expansion or a larger number of cells and positive effect of water availability on cell division (Proietti and Antognozzi, 1996). Increase in fruit size due to higher irrigation has also been reported by Ehret et al. (2012). Since water stress results in lower fruit water content, the higher weight in well irrigated fruits is most likely due to the high fruit water content.

Plastic packaging for fresh fruits and vegetables has been in commercial use for decades. Respiring fresh fruits and vegetables sealed in plastic films will cause the surrounding atmosphere to change; in particular O_2 levels will be depleted and CO_2 levels increased. We observed that weight loss for fruits in non-perforated package was significantly lower compared to the control. According to Abdullah et al. (2004), packaging restricts the air movement around the produce, hence minimising fruit weight loss. This may be the reason why the highest percentage in fruit weight loss was observed in unpackaged fruits. MAP creates a water saturated or near saturated atmosphere around the fruit which lowers fruit transpiration rate; hence reducing water loss and shrinkage. Loss of moisture results in a reduction in fresh weight of harvested produce. This explains why unpackaged fruits lost more weight compared to fruits in non-perforated bags. Similar observations were made by Mathooko (2003), who reported that MAP reduced water loss in bell pepper by 40 to 50%. Weight loss in tomato fruits is primarily a result of water loss. According to Nyalala and Wainwright (1998), the rate of the water loss is a function of surface area and temperature; as they (surface area and temperature) increase, water loss also increases. The two authors further attribute water loss to polygalacturonase activity, which increases cell wall permeability, which results in increased transpiration.

Colour change

The influence of irrigation levels on fruit colour development did not give a very clear trend; though it (colour development) appeared to be higher at lower moisture levels. As ripening proceeds in tomato fruits, the colour changes from green to red. This, according to Li et al. (2015), is mainly due to increased lycopene and decreased chlorophyll content in fruit tissues. It has been reported that controlled or modified atmospheres delay fruit ripening at 12.8°C and that modified atmospheres resulting from the enclosure of mature green tomatoes in polyethylene or other forms of plastic packaging may also delay fruit ripening (Harold et al., 2007). According to Batu and Thompson (1998), tomato fruits sealed in plastic films change colour more slowly compared to those unwrapped. In contrast, we observed that colour change was fast in packaged fruits (especially in the non-perforated package). This variance could be due to stage of harvesting (breaker stage) and storage temperature (21±2°C). Another factor could be the package plastic type and thickness, which influences its permeability to gases (oxygen, carbon dioxide and ethylene). Similar findings that polythene packaging results in early ripening and better colour development in mature green tomatoes as well as better maintenance of the best physicochemical quality of fruit during storage to marketing was also reported by Moneruzzaman et al. (2009).

Fruit firmness

Our observations of fruit firmness decreasing with increasing moisture levels are similar to those of Proietti and Antognozzi (1996) who reported a slight decrease in firmness of irrigated olive fruits; and Ehret et al. (2012) who found that higher irrigation volumes reduced fruit firmness in blueberry. In well watered plants, (without stress), the water concentration in the fruits increase and tend to make the fruits softer during the period of storage. This might explain the higher levels of firmness that we observed in fruits from water stressed plants. Crookes and Grierson (1983) reported that as ripening progresses, the cell wall becomes increasingly hydrated and pectin in the middle lamella is modified and partially hydrolysed. The change in cohesion of the pectin gel governs the ease with which one cell can be separated from another, which in turn affects the final texture of the ripe fruit. This process occurs early at ripening stage in soft fruit such as tomato. According to Li et al. (2015), tomato fruit hardness gradually decreased due to multiple coordinated processes, including the disassembly of polysaccharides in the primary cell wall and middle lamella and transpirational water/turgor loss. Packaged fruits were firmer than those unpackaged because MAP inhibits the synthesis and accumulation of cell wall degrading enzymes by slowing down their activities that cause fruit tissue softening. Low oxygen levels in modified or controlled atmospheres inhibit polygalacturonase activity, thus reducing the rate of fruit softening (Kapotis et al., 2004). Our findings that fruits in perforated packages were firmer than the control fruits corroborates observations by Batu and Thompson (1998) of softening of tomato fruits sealed in plastic film being significantly slower compared to those stored unwrapped.

Fruit total soluble solids (TSS)

This increased with decrease in moisture level (% PC). Similar observations were made by Birhanu and Tilahun (2010), Ehret et al. (2012). Water stress enhances sweetness of tomatoes by increasing their glucose, fructose and sucrose contents (Nahar et al., 2011). The increase in TSS with decreasing moisture level according to Patanè et al. (2011) is because water deficit induces a higher starch accumulation during the first stage of fruit growth, followed by conversion of starch into sugars during maturation. Decreased irrigation will induce greater TS and TSS contents because of a decrease in water accumulation by the fruit without any significant modification in the quantity of accumulated sugars (Patanè et al. 2011). It has been widely shown that reduced soil moisture and salt stress increase sugar content in tomatoes (Obreza et al., 2001; Hanson and May, 2003; Birhanu and Tilahun, 2010). Although water stress results in decreased yield in tomatoes, it increases brix values (Shinohara et al., 1995). The lowest TSS observed in fruits from the well and moderate water stressed plants (100, 80 and 60% PC) can be attributed to the higher water uptake by the plants which leads to the dilution of the concentration of TSS. Packaging had no significant influence on the fruit TSS. Similar observations have previously been reported. According to Mathooko (2003), MAP had no significant effect on TSS content in tomato fruit treated at the breaker stage of ripeness due to the inhibitory effect by MAP on respiration; since TSS has been reported to be closely related to the rate of respiration.

Fruit titratable acidity (TA)

Although TA tended to increase with increasing moisture levels, the differences between 20, 40, 60 and 80% PC were not significant; which was contrary to previous reports. Water stress has been reported to increase the synthesis of malic acid and increase citric acid content in tomatoes (Nahar et al., 2011). Patanè et al. (2011) found that deficit irrigation enhanced TA compared to full irrigation treatment. Fruits in non-perforated packaging exhibited lower TA than the control and perforated packaging. The relative humidity found under MAP is high; and according to Mathooko (2003), the low TA in fruits observed under such conditions is due to their higher retention of water.

Conclusion

Water levels and packaging independently and together significantly influenced the postharvest qualities of tomato. Moisture stress increased fruit total soluble solids (TSS) and preserving its firmness. In this study, the higher the water content, the faster the fruit lost its firmness. Packaging reduced loss in weight and firmness, and extended fruit shelf life. In light of the above, it can be concluded that deficit irrigation effectively regulates tomato fruit quality, and combining it with packaging, it can enhance the shelf life of tomato fruits.

ACKNOWLEDGEMENTS

Authors wish to thank RUFORUM and SCARDA-ECA for supporting this work financially and Egerton University (Kenya) for facilitating the experimental procedures.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Abdullah AA, Abdullah AM, Mahmoud AO (2004). Effect of Plastic and Paper Packaging on Tomato Fruits Stored at Different Temperatures and High Relative Humidity. Paper Presentation: International Symposium on Greenhouses, Environmental Controls and In-house Mechanization for Crop Production in the Tropics and Sub-Tropics, Pahang, Malaysia.

Batu A, Thompson AK (1998). Effects of modified atmosphere packaging on postharvest qualities of pink tomatoes. Tr. J. Agric. For. 22:365-372.

Birhanu K, Tilahun K (2010). Fruit yield and quality of dripped-irrigated tomato under deficit irrigation. Afr. J. Food, Agric. Nutr. Develop. 10(2):2139-2151.

Crookes PR, Grierson D (1983). Ultrastructure of tomato fruit ripening and the role of polygalacturonase isozymes in cell wall degradation. Plant Physiol. 72:1088–1093.

Ehret DL, Frey B, Forge T, Holmer T, Bryla DR (2012). Effects of drip irrigation configuration and rate on yield and fruit quality of young highbush blueberry Plants. HortSci. 47:3414-421.

Hanson B, May D (2003). Drip irrigation increases tomato yields in salt-affected soil of San Joaquin Valley. California Agriculture, 57(4):132-137. http://dx.doi.org/10.3733/ca.v057n04p132

Harold CP, Karapanos IC, Bebeli PJ, Savvas D (2007). A review of recent research on tomato nutrition, Breeding and Postharvest Technology with reference to fruit quality. Eur. J. Plant Sci. Biotechnol. 1(1):1-21.

Kader AA, Rolle RS (2004). The role of postharvest management in assuring the quality and safety of horticultural produce, FAO, Rome.
Kapotis G, Passam HC, Akoumianakis K, Olympios CM (2004). Storage of tomatoes in low oxygen atmospheres inhibits ethylene action and polygalacturonase activity. Russian. J. Plant Physiol. 51:112-115.
Li L, LVK, Wang Y, Zhao B, Yang Z (2015). Multi-scale engineering properties of tomato fruits related to harvesting, simulation and textural evaluation. LWT - Food Sci. Technol. 61:444-451.
Marcos DF, André TOF, Ricardo FK, Antonio COF, Sylvio LH, Marcelo T (2005). Post-harvest quality of fresh-marketed tomatoes as a function of harvest periods. Sci. Agric. 62(5):446-451.
Mathooko FM (2003). A comparison of modified atmosphere packaging under ambient conditions and low temperatures storage on quality of tomato fruit. Afr. J. Food, Agric. Nutr. Develop. 3(2).
Meaza M, Seyoum T, Woldetsadik k (2007). Effects of preharvest treatments on yield and chemical composition of tomato. Afr. Crop Sci. J. 15(3):149-159.
Moneruzzaman KM, Hossain ABMS, Sani W, Saifuddin M, Alezani M (2009). Effect of harvesting and storage condition on the Postharvest quality of tomato (Lycopersicon esculentum Mill cv Roma VF). Austr. J. Crop Sci. 3(2):113-121.
Nahar K, Ullah SM, Islam N (2011). Osmotic adjustment and quality response of five tomato cultivars (*Lycopersicon esculentum* Mill.) following water deficit stress under subtropical climate. Asian J. Plant Sci. 10(2):153-157. http://dx.doi.org/10.3923/ajps.2011.153.157
Nyalala SPO, Wainwright H (1998). The shelf life of tomato cultivars at different storage temperatures. Trop. Sci. 38:151-154.
Obreza TA, Pitts DJ, McGovern RJ, Spreen TH (2001). Deficit irrigation of micro-irrigated tomato affects yield, fruit quality, and disease severity. Florida Agricultural Experimental Station, University of Florida, P. 4626.
Patanè CS, Tringali, Sortino O (2011). Effects of deficit irrigation on biomass, yield, water, productivity and fruit quality of processing tomato under semi-arid and Mediterranean climate conditions. Sci. Hortic. 129:590-596.
Proietti P, Antognozzi E (1996). Effect of irrigation on fruit quality of table olives (*Olea europaea*) cultivar 'Ascolana tenera'. New Zealand J. Crop Hortic. Sci. 24:175-181.
Sammi S, Masud T (2009). Effect of different packaging systems on the quality of tomato (Lycopersicon esculentum var. Rio Grande) fruit during storage. Int. J. Food Sci. Technol. 44:918-926.
Shewfelt RL, Prussia SE (1993). Postharvest handling: a system approach, Academic Press Inc. San Diego, CA.
Shinohara Y, Akiba K, Maruo T, Ito T (1995). Effect of water stress on the fruit yield, quality and physiological condition of tomato plants using the gravel culture. Acta Hortic. 396:211-218. http://www.monashscientific.com.au/AcidCalculations.htm 6/25/2003.
Zegbe JA, Behboudian MH, Clothier BE (2006). Yield and fruit quality in processing tomato under partial rootzone drying. Eur. J. Hortic. Sci. 71(6):252-258.

APPENDIX

EXPERIMENTAL LAYOUT

BLOCK 1	WS_1	WS_3	WS_4	WS_5	WS_2
BLOCK 2	WS_5	WS_4	WS_1	WS_2	WS_3
BLOCK 3	WS_2	WS_1	WS_5	WS_3	WS_4
BLOCK 4	WS_3	WS_5	WS_2	WS_4	WS_1

Figure 1. Field Layout: R**andomized Complete Block Design (RCBD).** WS_1: 100% of PC; WS_2: 80% of PC; WS_3: 60% of PC; WS_4: 40% of PC and WS_5: 20% of PC.

WS_1 WS_2 WS_3 WS_4 WS_5 CONTROL (non-packaged)	WS_5 WS_1 WS_4 WS_2 WS_3 NON-PERFORATED	WS_3 WS_5 WS_1 WS_4 WS_2 PERFORATED
WS_2 WS_4 WS_1 WS_5 WS_3 PERFORATED	WS_3 WS_2 WS_1 WS_4 WS_5 CONTROL (non-packaged)	WS_1 WS_4 WS_5 WS_2 WS_3 NON-PERFORATED
WS_4 WS_5 WS_2 WS_3 WS_1 NON-PERFORATED	WS_2 WS_1 WS_5 WS_3 WS_4 PERFORATED	WS_5 WS_2 WS_3 WS_1 WS_4 CONTROL (non-packaged)

Figure 2. Laboratory Layout: Split-plot in a Randomized Complete Block Design (RCBD). WS_1: 100% of PC; WS_2: 80% of PC; WS_3: 60% of PC; WS_4: 40% of PC and WS_5: 20% of PC.