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Vol. 12(14), pp. 1196-1203, 6 April, 2017
DOI: 10.5897/AJAR2017.12150
Article Number: 7A95F9463617
ISSN 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Maturity indices for tomato (*Solanum lycopersicum* L.), cv. Ghalia 281 in Central Uganda

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Received 13 January, 2017; Accepted 15 March, 2017

Application of maturity indices and optimal harvest time improves handling and marketing operations and minimizes pre and postharvest losses for tomato products. Growth patterns of tomato (*Solanum lycopersicum* L.), cv. Ghalia 281, were therefore analyzed to determine nondestructive maturity indices for optimal harvest regimes. Propagation experiments were run in central Uganda in 2015. A total of 216 tomato fruits were tagged and their diameter, height and color recorded daily prior to physico-chemical and nutritional analyses at Makerere University Food Science and Technology laboratory. The longest fruit (5.55 cm) was from breaker, while the shortest (4.95 cm) was in light red samples. Total soluble solids were highest at breaker (5.40 °Brix) and red (6.00 °Brix) and was lowest at turning stage (4.00 °Brix). Green tomatoes had the highest carbohydrate content of 5.99 g/100 g, followed by breaker tomatoes with 5.71 g/100 g, while the lowest CHO (4.17 g/100 g) was observed from tomatoes at turning stage. The pH decreased from 4.98 (green) to 4.60 (light red). Protein content was highest (13.05%) from red tomatoes and lowest in pink samples (10.22%). Fruit diameter was negatively correlated with fruit color (r = -0.748, *P*≤0.05) and °Brix (r = -0.787, *P*≤0.05). A highly negative correlation occurred between fruit age and pH (r = -0.949, *P*≤0.05). There was a high positive correlation between fruit diameter and total titrable acidity (r = 0.959, *P*≤0.05). Optimal harvesting should occur at breaker for distant markets and fruit with red outer colour be proposed for local consumers. Maturity indices for determining harvest time of tomato is a combination of fruit age, diameter and color, because these correlate significantly with physico-chemical and nutritional characteristics including total soluble solids (TSS), total titrable acidity (TTA) and protein content.

Key words: Color, fruit diameter, maturity index, *Solanum lycopersicum*, total soluble solids, vegetables.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the highly valuable horticultural crops in the world (Pinho et al., 2011; Caron et al., 2013; Araujo et al., 2016). According to the Food and Agricultural Organization of the United

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Nations (2014), the world production of tomato reached 161.8 million tons representing 33.7 t/ha of cultivated area in the year 2012. Tomatoes are preferred for consumption due to a low acid index, high reducing sugars content, suitable fruit flavour and great culinary versatility (Junqueira et al., 2011; Beckles, 2012). In addition, Carvalho et al. (2005) consider tomato fruit as the main source of lycopene in the human diet because of its strong antioxidant action that helps prevent degenerative and heart diseases and some types of cancer.

In Uganda, there has been a shift from production of traditional staple food crops to high value quick maturing crops like tomatoes (IPC, 2017). Tomato has highly important commercial and subsistence values in Uganda (Muzaale, 2014; YAP, 2016). However, tomato is a climacteric fruit. This implies that harvesting at an optimal stage gives the productive and commercial sectors greater flexibility for its management (Caron et al., 2013). Tomatoes develop their full characteristic flavor, taste and color during storage if picked during an optimum period. Tomatoes harvested at an early stage of maturity are susceptible to shrivelling and mechanical damage and develop poor flavor and taste, despite having long storage life (Mattheis and Fellman, 1999; Beckles, 2012). Harvesting at an advanced stage of maturity produces fruit that have good taste and flavor but have a short storage life and are not suitable for transporting for long distances (Dadzie and Orchard, 1997).

Thus, farmers ought to schedule the harvesting at optimum maturity periods to ensure quality and obtain good market price, followed by correct handling and packing of fruit (Rajkumar et al., 2012). Despite this, most farmers, especially those operating on a small scale, face challenges, among which are choice of right varieties, ineffective transport to distant markets and high perishability of tomatoes exacerbated by harvesting at improper maturity stages due to farmers' limited knowledge of maturity indicators (Kato, 2011; Muzaale, 2015).

Even then, there have been attempts (Wanitchang et al., 2011; Rajkumar et al., 2012) to examine non-destructive indices for assessing maturity of fresh fruit. Matsuda et al. (2010) studied optimal harvest time for transgenic tomatoes and Zhang and McCarthy (2012) used magnetic resonance imaging to evaluate tomato maturity. However, these methods could present high technical and financial burden to the small scale farmers in Uganda. Additionally, studies on vegetables in Uganda have focused on pests and diseases (Tushemereirwe et al., 2000, 2004) and postharvest losses. Studies on optimum harvest regimes for vegetables have not been accorded much attention. This could partly explain the increasing postharvest losses, low income and food insecurity in Uganda (IPC, 2017).

This study was therefore aimed at investigating the maturity indices for optimal harvest of one of the newly introduced but commercially viable tomato (*Solanum lycopersicum* L.) c.v. Ghalia 281 to enable small scale farmers determine harvest time based on technically and financially feasible maturity indices. The specific objectives of the study were to (i) analyze the morphological development of tomato fruit, (ii) assess the maturity and ripening stages of tomato fruit and (iii) determine the nondestructive maturity indices for optimal harvest of tomato in Central Uganda.

MATERIALS AND METHODS

Experimental site

The tomato cv. Ghalia 281, was propagated at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) which is located at 0°27'60''N, 32°36'24''E at an altitude of 1,250 to 1,320 m above mean sea level (Figure 1). The area receives an average annual precipitation of 1,218 mm and slightly drier periods in June to July and December to February (Komutunga and Musiitwa, 2001). The mean annual temperature is 21.5°C.

The Kabanyolo soils are formed on residuum and colluvium from quartzites, gneiss and basement complex rocks. Colluvium enriched with lateritic gravel is common on the side slopes of MUARIK (Yost and Eswaran, 1990). The soils are clayey, acidic (pH of 6.08 to 6.12) with low organic matter content and deficient in most minerals including P, Ca, K, Mg, Na and N. MUARIK is reported to be suitable for growing cabbage and pumpkin. However, for improved growth, yields and maturity of tomato, the Kabanyolo soils require amendments with lime (Okiror et al., 2017). In this study, the soils were not amended in order to mimic the practices of small scale farmers in Uganda (Nyombi et al., 2010).

Tomato propagation and sampling

Seedlings were produced following the methods described by Pinho et al. (2011). The soils were ploughed and loosened using hand hoes. Manual watering was done on days in which the site did receive rains as done by most small-scale farmers in Uganda (Kato, 2011). The trials were run between May and August 2015. Tomato seedlings were transplanted manually using hand hoes into pre-made holes in 3 randomized blocks on 26 May 2015. As is the case with most local small scale farmers (Muzaale, 2014, 2015; Ogundare et al., 2015), tomatoes were established in the field without application of any fertilization at transplanting. There is generally low use of chemical fertilizers by the Ugandan smallholder farmers mainly due to perceived high cost, poor availability, and lack of knowledge related to their use (Nyombi et al., 2010).

Two (2) healthy growing plants were tagged in each of the three slope points of the block (shoulder, back-slope and foot-slope) and data on leafing, root collar diameter, plant height, pest and disease incidence and weeding and pruning were recorded until flower emergence that occurred between 15-16 weeks after transplanting. After flower emergence, fruit development was monitored in all the 18 tagged plants. On the first and second branch of the tagged tomato plants, fruits were tagged and fruit diameter, height, color and pest and disease incidence were recorded daily. This was because each branch could yield 4 to 8 fruits. From the selected branches, two (2) tomato fruits were harvested from each of the 6 fruit maturity stages, that is, green, breaker, turning, pink, light red and red, and labelled and packed in a cooler box to avoid manual contact. Tomato fruit selection was based on the external colour classification for fresh tomatoes by the United States Department of Agriculture (USDA, 1991). Therefore, 216 fruits were sampled

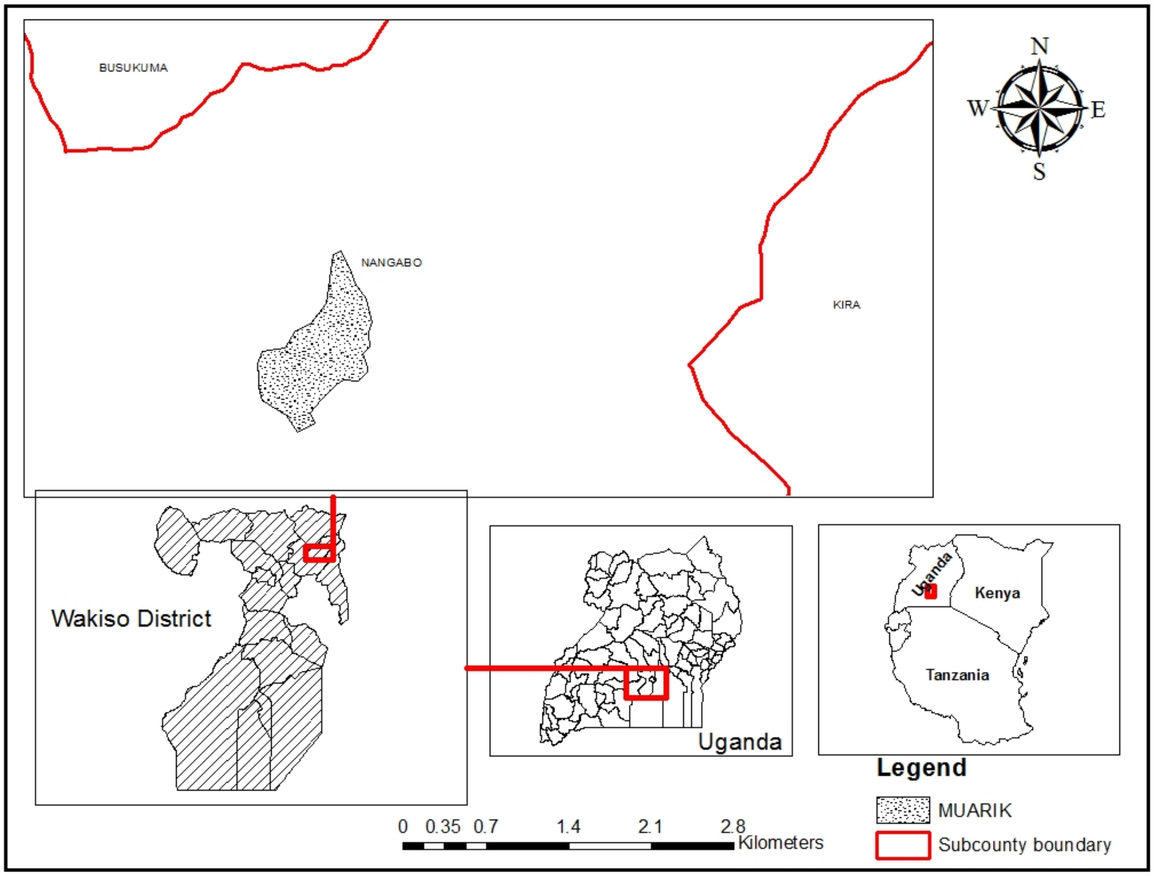

Figure 1. Map of East Africa showing the location of the study site at MUARIK, Wakiso district, Central Uganda.

representing 2 replicates of 6 maturity stages and 2 plants for 3 slope positions in 3 blocks. Fruits were sampled in the morning following the uniformity of color, size and absence of disease and injury. Samples were delivered to Makerere University Food Science and Technology laboratory for physico-chemical and nutritional analysis.

Laboratory analyses

Physico-chemical (pH, moisture and dry matter content) and nutritional (protein, total soluble solids, carbohydrates, total titrable acidity, Fe, Mn, Ca and K) composition were determined according to the methods described by AOAC (2000) and Okalebo et al. (2002).

Internal colour of tomato samples was determined using the Lovibond apparatus. The red, yellow and blue colour units were adjusted until a perfect colour match was obtained. The value of the colour with the lowest unit was subtracted from the rest of colours leaving two units which were then used to describe the colour of the sample. Colour was described using the nomenclature, notably; red, orange (combination of red and yellow), yellow, green (combination of yellow and blue), blue and violet that is derived from red and blue (Okia et al., 2013).

Data were entered in Microsoft Excel and subjected to analysis of variance (ANOVA) comparisons at 5% significance level. The Pearson's correlations (r) were run to establish the relationships between morphological, physico-chemical and nutritional maturity indices and to ascertain the optimal maturity indices.

RESULTS AND DISCUSSION

Fruit development

The fruit development curve for tomato cv. Ghalia 281 was determined (Figure 2). Following flower emergence, there was a rapid increase in fruit diameter and length in the first week, before it decreased in week 2. Further increase in fruit length occurred in week 3, reaching maximum towards the end of week 3 of fruit maturation. Diameter increased at a lower rate and plateaued within week 3 before harvest (Figure 2). Samples were harvested within 8-11 weeks after the transplanting date.

According to Wu and Kubota (2008), tomato fruit enlarge with time after anthesis during the green stage, reach maximum size at around the end of the green stage and hardly change in size after the breaker stage through the red stage as demonstrated in this study. This implies that tomato cv. Ghalia 281 can be promoted for large scale production by farmers in Uganda, thereby bridging the widening income and food security gaps in the country. Chester (2004) and Lovejoy (2016) indicated that several tomato varieties are ready for harvest between 6-11 weeks following transplanting. This study indicates that fruit development trends for cv. Ghalia are

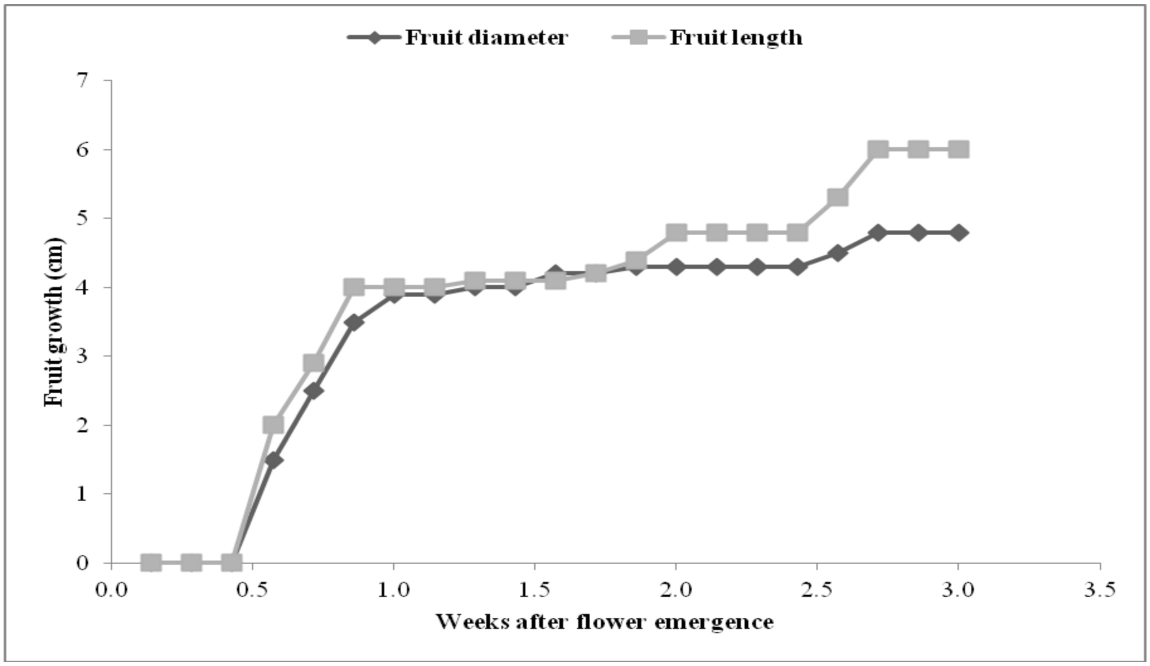

Figure 2. Fruit development of tomato, cv. Ghalia 281, in 2015.

Table 1. Maturity indices of tomato, cv. Ghalia 281, at different harvest stages[a].

Parameter	Unit	Harvest stage					
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Fruit diameter	(cm)	4.35±0.25	4.30±0.20	4.70±0.10	4.65±0.05	4.40±0.10	4.30±0.10
Fruit length	(cm)	5.30±0.20	5.55±0.25	5.15±0.05	5.15±0.05	4.95±0.15	5.10±0.10
TSS[b]	(°Brix)	5.00±0.59	5.40±0.59	4.00±0.59	5.00±0.59	5.00±0.59	6.00±0.59
MC[c]	(%)	93.72±0.22	92.73±0.03	94.44±0.02	93.95±0.08	93.79±0.12	93.40±0.43
CHO[d]	(g/100g)	5.99±0.20	5.71±0.26	4.17±0.64	4.32±0.16	4.36±0.01	5.26±0.01
Color	(Lovibond scale)	Yellow/green 4.00±0.00	Yellow/green 4.00±0.00	Yellow/green 3.35±0.35	Yellow/orange 3.07±0.09	Red/orange 4.97±0.21	Red/orange 5.47±0.24
pH	(-)	4.98±0.01	4.85±0.01	4.69±0.01	4.65±0.01	4.60±0.03	4.64±0.00
Protein	(%)	11.05±2.47	10.89±0.00	11.32±0.13	10.22±0.50	10.51±0.02	13.05±0.66
TTA[e]	(g/100 g)Citric acid	0.43±0.07	0.45±0.01	0.55±0.10	0.57±0.09	0.46±0.05	0.41±0.03
Maturity stage	Observed color[f]	Green	Breaker	Turning	Pink	Light red	Red

[a]Data means ± standard deviation; [b] TSS = total soluble solids; [c] MC = moisture content; [d] CHO = carbohydrates; [e] TTA = total titrable acidity; [f]USDA (1991)

consistent with earlier findings by Robinson (1996), Dadzie and Orchard, (1997) and Mattheis and Fellman (1999). Suryawanshi (2014), indicated tomatoes to be ready for harvest in at least 8.5 weeks following transplanting. Study samples were harvested within 8-11 weeks after transplanting pointing to the fact that cv. Ghalia 281 can be harvested within the generally acceptable time frame. The variation in times of harvest may be explained by the differences in soil, weather and pest and disease incidence across study sites. This study therefore recommends wide scale production of cv. Ghalia 281 to address the increasing demand for vegetables in Uganda (IPC, 2017).

Maturity and ripening stages

As tomato fruits progressed in maturity, they took on a bell shape with a peak at turning but at breaker and red the diameters were equal (Table 1); the second greatest diameter was observed at pink stage. Fruit length was highest in breaker, followed by green and lowest in light red stage. Mean TSS values at turning were lower than at breaker and red. Tomato moisture content was similar from breaker to pink. The highest carbohydrate content was obtained from green followed by breaker, and lowest at turning. The pH of tomato was generally acidic, decreasing from green, through light red. The highest protein content occurred at red and the lowest was from pink tomatoes. Total titrable acidity was highest in pink and red followed by turning. The morphological traits namely; color, diameter and length, and physico-chemical characteristics including pH, total soluble solids, total titrable acidity, carbohydate and protein content were best at breaker and red (Table 1). According to Zhang and McCarthy (2012), tomato maturity relates with quantifiable parameters including firmness and color which reflect the biochemical changes during ripening. In this study, breaker tomatoes had yellow green color, while the fully mature tomatoes were red. Usually, tomatoes are harvested at breaker stage for distant markets and fully ripe for local markets because the right stage of maturity influences storage life and quality and acceptance of fruit by consumers (Dadzie and Orchard, 1997).

The changes in fruit diameter and length are expected as tomatoes mature. Zhang and McCarthy (2012) stated that tomato ripening is usually associated with a number of variations: the cellular structure and internal structure of the fruit. In addition, the most significant visual changes in the morphological characteristics of the fruit during maturation occur in the size, shape, length and volume of the fruit as it advances in age (Dadzie and Orchard, 1997). This therefore means that fruit length and diameter are important indices for determining tomato maturity.

According to Gould (1974), fruit with pH values of 4.5 have appreciable aroma and taste. The optimal harvest regimes had TTA content generally decrease from turning to red samples. Titratable acidity decreases with ripening of tomato fruit (Gautier et al., 2008). Changes in pulp pH and total titratable acidity during maturation have been reported by Dadzie and Orchard (1997). However, the trend tends to vary with cultivars, in that, some cultivars are characterized by a decrease in pulp pH and increase in titratable acidity as fruits advance in age, while in some cultivars, there are no significant changes in pulp pH and titratable acidity during fruit maturation. Thus, pulp pH and titratable acidity could be used as indicators of maturity for tomato cv. Ghalia 281. The determination of pH and TTA however requires intricate and destructive laboratory procedures that may not be suitable for small scale farmers in Uganda.

The optimal harvest total soluble solids (TSS) values at breaker and red (Table 1) agree with Pinho et al. (2011) that observed between 4.0 (early harvest) to 6.00 Brix (late harvest) from tomatoes grown in both organic and conventional fields. Total soluble solids include sugars, acids, vitamin C, amino acids and some pectins (Dadzie and Orchard, 1997). These soluble compounds form the soluble solids content of the fruit. In most ripe fruits including tomato, sugar forms the main component of soluble solids. The TSS is an important postharvest quality attribute in the screening of tomato. Since the amount of TSS in fruits usually increases as they mature and ripen, the soluble solids content of the fruit can be a useful index of maturity or stage of ripeness for tomato.

This study generally revealed increasing protein values with fruit maturity which concurs with Carrari et al. (2006). More still, Faurobert et al. (2007) and Matsuda and Kubota (2010) found more total soluble protein in red stage than breaker fruit. The decreasing trend of carbohydrates with fruit maturity in this study however disagrees with Gautier et al. (2008). The variation in carbohydrates content could be attributed to differences in soil properties and agronomic practices such as fertilizer application, weeding, pruning and mulching (Fungo et al., 2011; Okiror et al., 2017).

Maturity indices

Fruit diameter was negatively associated with fruit color (r = -0.748, $P \leq 0.05$) and total soluble solids (r = -0.787, $P \leq 0.05$) (Table 2). Fruit age was negatively correlated with pH (r = -0.949, $P \leq 0.05$). There was a positive correlation between fruit diameter and TTA (r = 0.959, $P \leq 0.05$) and fruit diameter and moisture content (r = 0.817, $P \leq 0.05$). There was a moderate positive correlation between fruit color and protein content (r = 0.630, $P \leq 0.05$). A weak positive correlation occurred between fruit age and fruit diameter (r = 0.256; $P \leq 0.05$). Therefore, the maturity indices of tomato fruit are morphological features including diameter, age and color and the physico-chemical and nutritional parameters notably, pH, TSS, carbohydrate and protein content (Table 2).

There is a debate regarding effectiveness of color as a maturity index. Zhang and McCarthy (2012) recognized outer color as an index for maturity of tomato fruit, but dismissed it as unreliable. Zhang and McCarthy (2012) stated that during tomato processing, the fruit fed to the processing line are usually a mixture of tomatoes of multiple cultivars. Thus, much as colour is a significant index for cv. Ghalia 281, it may not be reliable for a mixture of cultivars. Molyneux et al. (2004) reported tomato skin color to vary between cultivars despite the cultivars falling within the same maturity stage. Dadzie and Orchard (1997) urged that because external color is noninvasive and nondestructive, it can be used to assess fruit maturity in the field or inspection points.

Previous studies including that of Carvalho et al. (2005) demonstrated that L* value decreases as tomatoes ripen and turn red because carotenoid synthesis and loss of green color reduces fruit brightness. Caron et al. (2013) describe tomato as a climacteric fruit and assert that harvesting at the light red stage would give the productive and commercial sectors greater flexibility for its management. The arguments by Carvalho et al. (2005),

Table 2. Pearson's correlation coefficients (r) and analysis of variance for maturity indices of tomato, cv. Ghalia 281, at different harvest stages.

Maturity index	Correlation coefficient (r)	Analysis of variance	
		p-value	Significance
Fruit age vs. fruit diameter	+0.256	1E-10	**
Fruit age vs. fruit color	+0.374	1E-10	**
Fruit diameter vs. fruit color	-0.748	0.44	-
Fruit length vs. fruit color	-0.327	0.021	*
Fruit age vs. fruit length	-0.829	1E-10	**
Fruit age vs. TSS	+0.173	1E-10	**
Fruit diameter vs. TSS	-0.787	0.05	*
Fruit length vs. TSS	+0.134	0.644	-
Fruit age vs. MC	+0.350	1E-06	**
Fruit diameter vs. MC	+0.817	6E-22	**
Fruit length vs. MC	-0.646	8E-22	**
Fruit age vs. pH	-0.949	1E-10	**
Fruit diameter vs. pH	-0.381	0.013	**
Fruit length vs. pH	+0.764	0.001	**
Fruit age vs. protein	+0.296	4E-10	**
Fruit diameter vs. protein	-0.389	2E-08	**
Fruit length vs. protein	-0.091	5E-08	**
Fruit color vs. protein	+ 0.630	2E-07	**
Fruit age vs. TTA	+0.194	7E-11	**
Fruit diameter vs. TTA	+0.959	2E-13	**
Fruit length vs. TTA	-0.170	1E-13	**

*, ** Significantly correlated maturity indices at 0.05 and 0.01 alpha level, respectively.

Dadzie and Orchard (1997) and Caron et al. (2013) seem valid for the case of small scale farmers in Uganda. Thus, this work retains color as an important index for maturity of tomato c.v. Ghalia 281.

The pH, TSS, TTA, carbohydate and protein contents are possible physico-chemical and nutritional maturity indices. According to Zhang and McCarthy (2012), characterization of the intricate process of maturity and ripening poses a challenge to fruit farmers and processors as well as scholars. The pH, TSS, TTA, protein and carbohydrate contents vary as fruit mature (Carrari et al., 2006; Faurobert et al., 2007; Gautier et al., 2008; Matsuda and Kubota, 2010), making these parameters indispensable maturity indices. However, determination of pH, TSS, TTA, protein and carbohydrate content requires expensive and technically intricate destructive sampling (Matsuda et al., 2010; Pinho et al., 2011). Noninvasive and nondestructive indicators which can show compositional changes or structural variations as fruit mature, is preferred (Zhang and McCarthy, 2012). It may be inevitable to undertake invasive and destructive maturity assessments especially to corroborate morphological indices and/or in determining optimal levels of carbohydrates, protein, MC, TTA and TSS required in foreign markets and in the pharmaceutical industry (Matsuda et al., 2009).

Conclusions

This study reveals that, there was a rapid increase in fruit diameter and length in the first week, before it decreased in week 2. Further increase in fruit length occurred in week 3, reaching maximum towards the end of week 3 of cv. Ghalia 281 fruit maturation.

Tomato should be harvested when the colour turns breaker and/or red. At these stages, tomato fruit would have attained acceptable physico-chemical (pH, moisture content and colour) and nutritional (TSS, TTA, protein content) qualities for distant and adjacent markets, respectively.

A combination of fruit diameter, color and age are reliable nondestructive and noninvasive indices for determining optimal time of harvest. Use of TSS, TTA and protein content are reliable indices but may not be suitable for small-scale growers because their determination requires skilled staff and expensive laboratory procedures.

It is recommended that low cost but technologically effective non-destructive tools such as colour charts, diameter tapes and Calipers be developed, in consultation with small-scale farmers, to monitor fruit maturity and determine optimal harvest times for tomato. Further studies are recommended to determine physico-chemical and nutritional values at different storage conditions such as temperature and relative humidity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

The authors acknowledge the German Federal Ministry of Education and Research and the German Federal Ministry for Economic Corporation and Development for co-funding this study through the Reduction of Post-Harvest Losses and Value Addition in East African Food Value Chains Project (RELOAD/A401UNCST2012). Support from the University of Kassel (especially Prof. Oliver Hensel and Michael Hesse), Makerere University (Dr. Susan Balaba Tumwebaze) and MUARIK (Prof. Jacob Godfrey Agea, Prof. Phinehas Tukamuhabwa and Mr. Jimmy Wesiga) is appreciated. Research assistance from Patrick Mulindwa, Jolly Joe Ochan, Esther Birungi Tendero, Harryson Lyagoba, Emmanuel Okalany and Phillip Kihumuro is also acknowledged. The anonymous reviewers are appreciated for improving the quality of this paper.

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