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**CHARACTERIZATION OF POSTHARVEST PHYSIOLOGY ATTRIBUTES
OF SIX COMMERCIALY GROWN TOMATO VARIETIES IN KENYA**

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ABSTRACT

Tomato (*Lycopersicon esculentum* Mill) is the leading vegetable in terms of production in Kenya. The Kenyan local market has a wide variety of tomato cultivars with a wide range of morphological and sensorial characteristics. However, information on the nutritional and postharvest quality of these varieties is lacking. The aim of this research was to investigate and identify tomato varieties of superior postharvest quality and recommend them to small and medium scale farmers. In this study, six tomato varieties were grown in a greenhouse and analyzed at three maturity stages (mature green, turning and red ripe). The tomatoes were analyzed at specific days after harvest and storage at room temperature (25° C). Percentage weight loss, color, respiration and ethylene production rates were analyzed to assess the postharvest quality of the tomatoes. The color was measured using a Minolta Chromameter while the respiration rate and ethylene production rates were determined using the static system approach. Color, weight loss, respiration and ethylene production rates were positively affected by storage time when harvested at the three maturity stages. The percentage weight loss of the tomato fruits was higher in the determinate varieties, and at the turning stage of maturity (3.8 %). Minor color changes were observed after storage of the tomatoes harvested at red stage for six days. Both rates of respiration and ethylene production were low, with the respiration rate ranging between 56-10 ml CO₂ Kg⁻¹h⁻¹. The Chonto F1 variety had the highest rate of ethylene production (5.4 µL C₂H₄ Kg⁻¹h⁻¹) on the 4th day of storage after harvest at the red ripe stage. Overall, the indeterminate tomato varieties displayed better postharvest quality that can prolong the fruits shelf life for marketing. In turn, the turning stage of maturity proved to be a better stage to harvest tomatoes as the color development was more uniform.

Key words: Tomato, varieties, postharvest quality, respiration rate, ethylene, color

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is among the most promising commodities for horticultural expansion and development in Kenya, accounting for 14% of the total vegetable produce and 6.72% of the horticultural crops [1]. In Africa, Kenya is the sixth tomato producing country with a production of 397 000 Metric tonnes in 2012 [2]. The tomato produced is locally marketed within Kenya and around East African countries [3].

Quality of harvested tomato fruits is of major concern to growers because traders grade them according to physical properties like color, size, shape and skin defects or internal characteristics like taste and texture [4, 5]. Tomato varieties can be broadly classified as determinate and indeterminate. Indeterminate varieties are usually trellised and pruned to 2-3 shoots per plant to achieve better plant health and quality while the determinate varieties are mostly left untrellised [6]. Indeterminate varieties are mainly for long harvest period and require staking while determinate varieties normally stop growing after flowering and require no support or staking.

The local Kenyan market has a variety of tomato cultivars with a wide range of morphological and sensorial characteristics. These cultivars are mainly imported hybrid varieties which are preferred to indigenous varieties by farmers because they have better growth characteristics such as in high yields, efficient water utilization, high fruit quality, prolonged production, shortened maturity period, low pest and disease incidences and reduced use of land to achieve the same results [7]. However, information on the postharvest characteristics of these varieties is lacking. This lack of knowledge contributes to seasonal postharvest losses during periods of glut on one hand and insufficient supply in the other hand during low season. Tomato fruit should be ideally produced for a specific market, that is, either for fresh consumption or processing.

Tomato fruits undergo an orderly series of physiological and morphological changes as they progress in development from mature green to red ripe fruit after harvest. These changes include the development of red color (lycopene synthesis), loss of chlorophyll, softening, weight loss, increased respiration and increased production of the plant hormone ethylene [8-11]. Respiration, transpiration and ethylene production are three main factors that contribute to deterioration of fruit and vegetable quality after harvest [12, 13]. Tomato is a climacteric fruit and its ripening is therefore accompanied by a peak in respiration and a concomitant burst in ethylene. There exists an inverse relationship between respiration rate and shelf life of fresh fruit and therefore respiration is important in determining the shelf life [14]. Respiration continues after harvest and this leads to major deterioration in both quality and quantity. For extension of the postharvest life of perishables, it is desirable that the commodity has a lower respiration rate.

The tomato fruit may suffer damage of varying degrees during harvest, classification, packaging, transportation, loading and unloading and storage which in turn leads to the change in respiration and ethylene production rates, decline in quality and decrease in the storage time. Therefore, studying and forecasting the fruits respiration rate and

ethylene production is not only essential for the fruit storage and preservation but also has direct significance to the fruit packaging design [15].

The main purpose of this study was to evaluate and characterize the postharvest harvest quality of commercially grown tomatoes for the local Kenyan market at different maturity stages: three indeterminate-Anna F1, Bravo F1, Chonto F1, and three determinate - Eden F1, Nuru F1, and Rambo F1 for the local Kenyan market. The information could be part of recommendations to farmers on minimizing postharvest loss based on varietal differences and the appropriate stage of harvesting.

MATERIALS AND METHODS

Plant Material

Six commercial tomato varieties - three indeterminate (Anna F1, Bravo F1, Chonto F1) and three determinate (Eden F1, Nuru F1, and Rambo F1) widely cultivated in Kenya were grown under greenhouse at Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya. Tomatoes were hand harvested at three maturity stages: mature green, turning and red ripe based on the “Color Classification Requirement in United States Standards for Grades of Fresh Tomatoes” chart, published by USDA [16]. The experimental design was carried out in replicate twice. Twenty fruits at each maturity stage were picked randomly from the twenty plants of each of the six varieties. Six tomatoes for each stage were then selected for analysis based on lack of defects, uniform size and shape within each variety. The fruits were then washed in distilled water, dried thoroughly with a cloth to remove surface moisture and stored in plastic crates separately according to variety and stage at room temperature (25° C). Analysis for each parameter was done on day zero, two, four and six.

Physical properties

Color

Tomato fruit color was measured using Minolta Chromameter (Minolta, model CR-200 R Japan/75043055) which provided CIE L*, a* and b* (CIELAB) values. A chromameter describes color in three coordinates: L*, lightness from 0 (black) to 100 (white); a*, from -60 (green) to +60 (red) and b*, from -60 (blue) to +60 (yellow). Color readings were taken from four points of the fruit (2 readings from equatorial region and 2 readings from the blossom end of the fruit). The L*, a* and b* readings were transformed to hue angle values using the equation below;

$$\text{Hue angle } (^{\circ}) = \tan^{-1}(b^*/a^*) \quad \text{Equation 1}$$

Weight loss

The tomato fruits were weighed using Shimadzu weighing machine (Shimadzu, model Libror AEG 220). Weight loss was presented as percentage of weight loss compared to initial weights.

Physiological properties

Ethylene production and respiration rate

The respiration rate and ethylene production rates were determined using a closed system method according to Singh with some modifications [17, 18]. Six fruits were randomly sampled from each treatment, numbered and initial weight taken. The fruits were incubated in air tight containers fitted with self-sealing rubber septa. Gas samples were taken from the headspace and injected into gas chromatographs (Models GC-8A and GC-9A, Shimadzu Corp., Kyoto, Japan) for measurement of respiration and ethylene production rates, respectively. The carbon dioxide determination gas chromatograph was fitted with a thermal conductivity detector (150 °C) and a Poropak N column while that for ethylene determination was fitted with an activated alumina column and a flame ionization detector (220 °C). The rate of carbon dioxide production (used to estimate respiration rate) was expressed as ml per Kg per hour at standard atmospheric pressure while ethylene production was expressed as µl per Kg per hour. The rates were calculated using the equation below:

$$\text{Rate of gas evolution} = f \times (V - v) \times (1/W) \times (1/T) \quad \text{Equation 2}$$

Where f is the sample concentration from the standard curve (µL/ml), V is the volume of the incubation container (ml), v is the volume of the fruits (ml), W is the weight of the fruits (g) and T is the incubation time (hours).

STATISTICAL ANALYSIS

For each analysis, six tomatoes were used. The results are expressed as mean values \pm SD. The results were analyzed using one-way analysis of variance (ANOVA) followed by Duncan multiple range test of significance at $\alpha = 0.05$. This treatment was carried out using Genstat software.

RESULTS

The hue angles and standard deviations at the three stage of maturity are shown in Tables 1-3.

From the data all the varieties had significant change ($p < 0.05$) in color as the storage period increased. A greater change in color was observed after storage in the Anna F1 (75.6 ° to 47.7 °), Rambo F1 (70.1 ° to 43.6 °) and Bravo F1 (45.5 ° to 39.9 °) at the mature green, turning and red ripe stages, respectively. Low changes were observed in Bravo F1 (74.7 ° to 61.3 °), Bravo F1 (53.8 ° to 50.2 °) Rambo F1 (46.2 ° to 44.8 °) in the mature green, turning and red ripe tomatoes, respectively. The fruits harvested at the red ripe stage of maturity showed overall higher visual quality. Fruits harvested at the mature green stage tended to be less red than the fruits harvested at the red ripe stage by the 6th day. The Anna F1 variety achieved the lowest hue angle value of 36.9 ° by the 6th day when harvested at the red ripe stage while the Bravo F1 variety had the highest value of 61.3 ° on day six.

There was a significant difference ($p < 0.05$) in the percentage weight loss by the end of the storage period between the determinate and indeterminate tomato varieties with the determinate exhibiting higher percentage weight loss. The indeterminate varieties are mainly for long harvest period while determinate varieties normally stop growing after flowering. Percentage weight loss of tomatoes at the red ripe stage was significantly higher than at the turning and mature green stage as shown in Figures 1-3. At the mature green stage, the Eden F1 variety had the highest percentage weight loss (3.33%), while the Anna F1 variety had the lowest percentage weight loss (0.16%). At the turning stage, the Nuru F1 variety had the highest % weight loss (3.80%), while the Chonto F1 variety had the lowest percentage weight loss (0.93%). At the red ripe stage, the Eden variety had the highest % weight loss (2.73%), while the Chonto F1 variety had the lowest percentage weight loss (1.34%). It is clear from the graphs of percentage weight loss that the weight loss was increasing with the advancement of storage time and maturity.

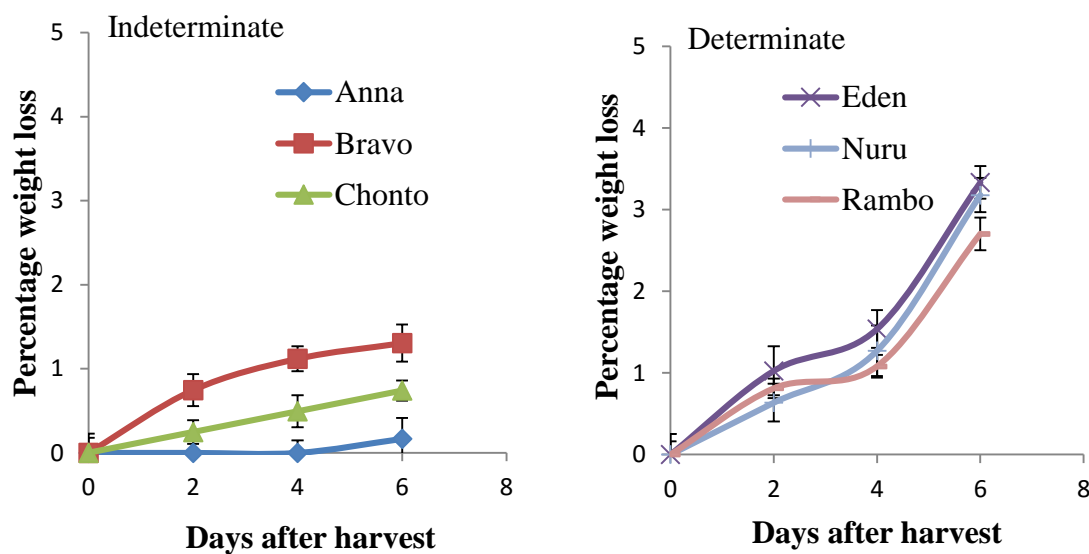


Figure 1: *Percentage weight loss of six tomato varieties harvested at the mature green stage

KEY: *Values represent the mean and standard error (S.E.) of three replicates consisting of 6 tomatoes each

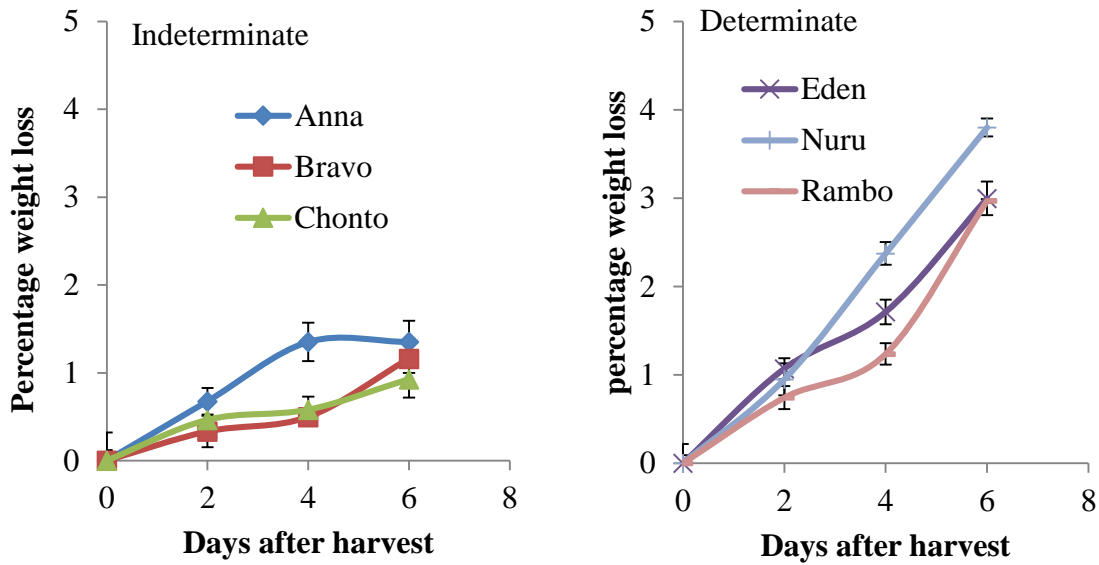


Figure 2: *Percentage weight loss of six tomato varieties harvested at the turning stage

KEY: *Values represent the mean and standard error (S.E.) of three replicates consisting of 6 tomatoes each

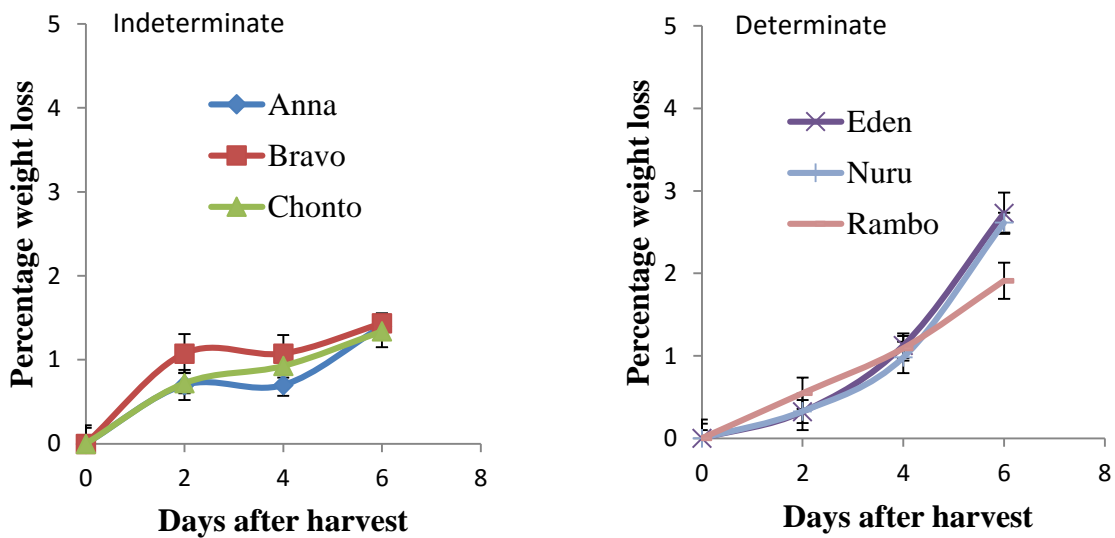


Figure 3: *Percentage weight loss of six tomato varieties harvested at the red ripe stage

KEY: *Values represent the mean and standard error (S.E.) of three replicates consisting of 6 tomatoes each

There was a significant difference ($p < 0.05$) in the respiration rate and ethylene production rates of the tomatoes between the varieties and storage days of the tomatoes in the three maturity stages (Figures 4-9). The highest respiration rate peak was observed in Bravo F1 variety with $56.8 \text{ ml CO}_2 \text{ Kg}^{-1} \text{ h}^{-1}$, Anna F1 $59.1 \text{ ml CO}_2 \text{ Kg}^{-1} \text{ h}^{-1}$ and Chonto F1 $44.8 \text{ ml CO}_2 \text{ Kg}^{-1} \text{ h}^{-1}$ for the mature green, turning and red ripe stages of ripening, respectively (Figures 4-6). The lowest respiration rate peaks were in Nuru F1 $38.6 \text{ ml CO}_2 \text{ Kg}^{-1} \text{ h}^{-1}$, Eden F1 $30.5 \text{ ml Kg}^{-1} \text{ h}^{-1}$ and Eden F1 $25.1 \text{ ml CO}_2 \text{ Kg}^{-1} \text{ h}^{-1}$ for the mature green, turning and red ripe tomatoes, respectively (Figures 7-9). Ethylene production was highest in day 4 in the Chonto F1 variety ($5.44 \mu\text{l C}_2\text{H}_4 \text{ kg}^{-1}\text{h}^{-1}$) in the red ripe tomatoes while the lowest ethylene production peak was observed on day 4 in the Nuru F1 variety ($0.39 \mu\text{l C}_2\text{H}_4 \text{ kg}^{-1}\text{h}^{-1}$) at the red ripe stage of maturity. It was observed that the indeterminate tomato varieties had relatively higher rates of respiration at all the three stages of maturity in comparison to the determinate varieties.

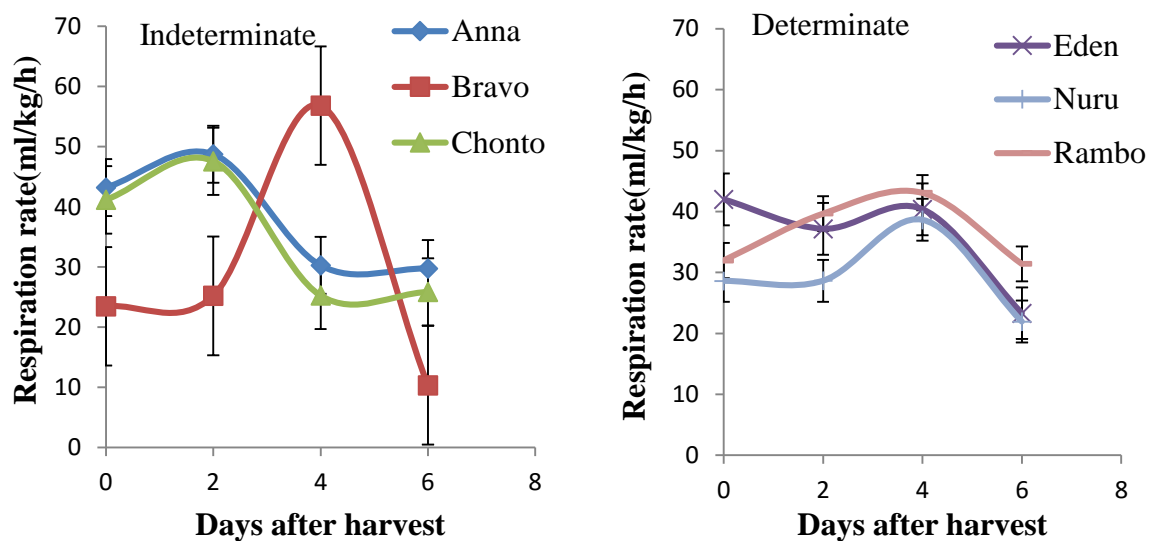


Figure 4: *CO₂ (mL Kg⁻¹ h⁻¹) production in six tomato varieties at mature green stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

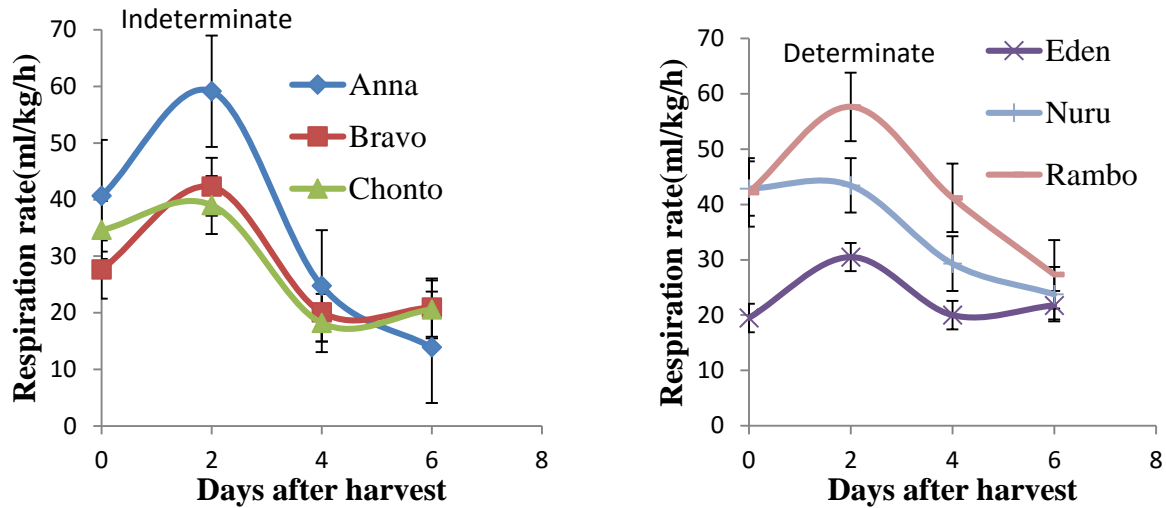


Figure 5: *CO₂ (mL Kg⁻¹ h⁻¹) production in six tomato varieties at turning stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

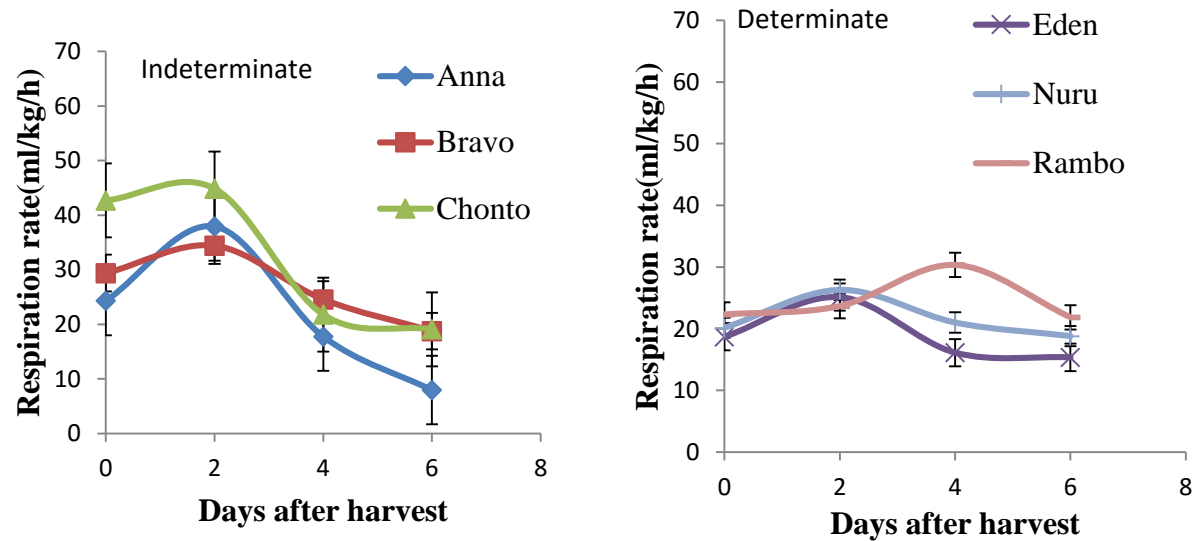


Figure 6: *CO₂ (mL Kg⁻¹ h⁻¹) production in six tomato varieties at red ripe stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

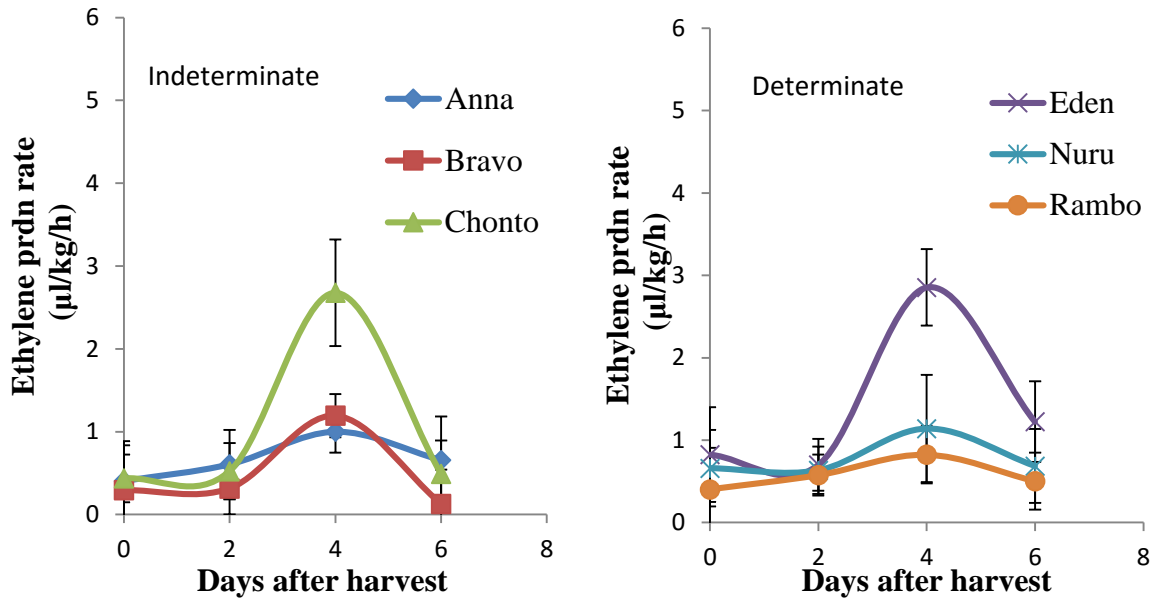


Figure 7: *Ethylene ($\mu\text{l Kg}^{-1}\text{h}^{-1}$) production in six tomato varieties at mature green stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

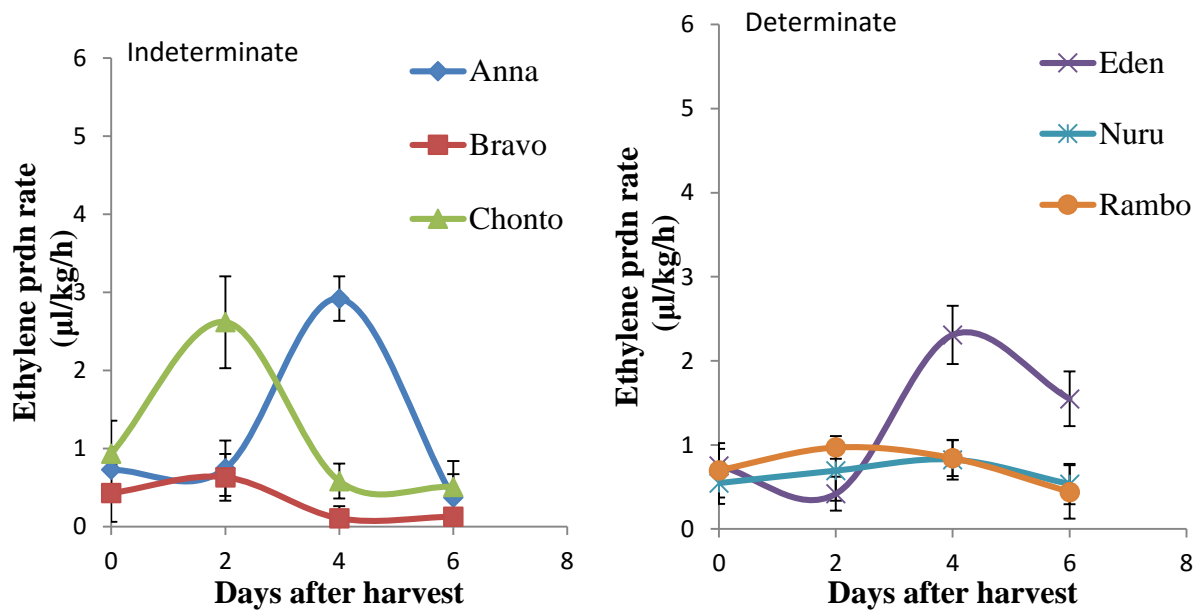


Figure 8: *Ethylene ($\mu\text{l Kg}^{-1}\text{h}^{-1}$) production in six tomato varieties at turning stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

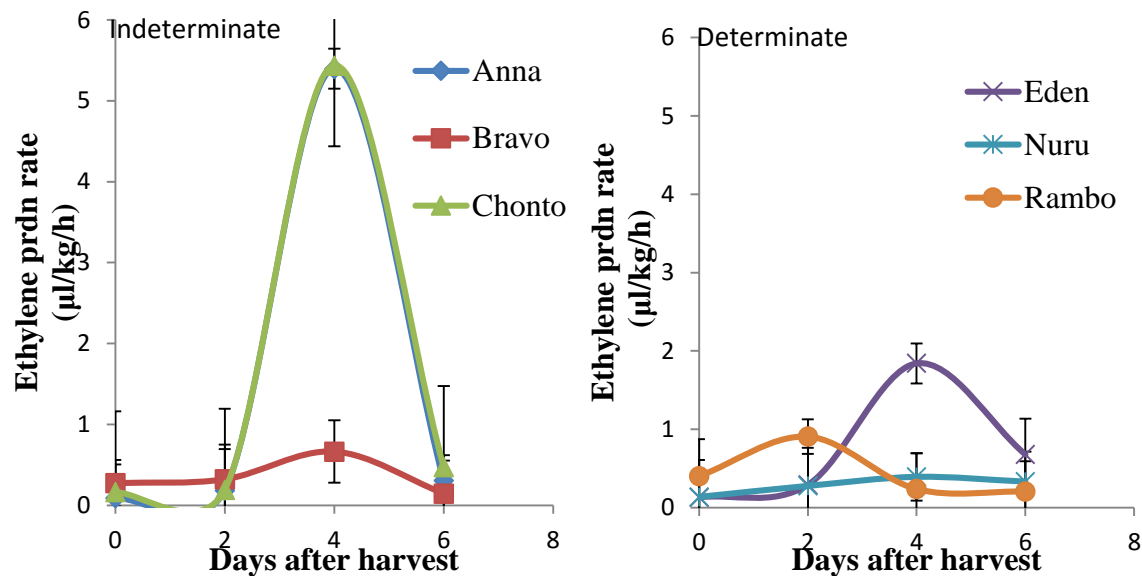


Figure 9: *Ethylene ($\mu\text{l Kg}^{-1}\text{h}^{-1}$) production in six tomato varieties at red ripe stage

KEY: *Each value is the mean of three replicates consisting of 6 tomatoes each

DISCUSSION

The external color was expressed in terms of hue angle, which is the most important measure in the perception of tomato quality [19, 20], due to the fact that external fruit color relates better to perception of color by the human eye. The color of tomato fruit is an important quality factor of fresh tomatoes for consumers' preference and is also used to indicate the stage of ripeness [21]. For prolonging shelf life in tomatoes, it is desirable that the color changes take place as slowly as possible. There was a greater change in color when the tomato fruits were harvested at the mature green as compared to the tomatoes harvested at the turning or red ripe stage. These could be attributed to the fact that color development rate of fruits increases with ripening as the fruit changes color from green to red. Chlorophyll degrades rapidly as the fruit ripens while lycopene accumulates at the later stage of ripening to give the tomato the intense red color [22]. In case of a delay in ripening, there may be a period between chlorophyll degradation and lycopene accumulation presenting a yellow–orange hue of β -carotene [19]. This phenomenon is displayed by some tomato varieties that were harvested at the mature green stage. The process of color change is accelerated by ethylene induction.

It has been shown that the rate of weight loss in tomatoes is affected by storage period, storage temperature and treatment on the tomatoes like waxing [23]. The internal atmosphere of the fruit is assumed to be saturated with water vapor and therefore water is prone to evaporate from the harvested tomatoes' surface and intracellular space to the surrounding atmosphere. The rate of the water loss is dependent on the factors such as maturity, amount of solutes in the produce, size, shape and surface area. From the results it is clear that the riper the fruit the more water it loses as it has more water vapor that

creates the internal saturation. The low % weight loss in the indeterminate varieties could be explained in their big size that gives a small volume to surface ratio for water to transpire. According to Ball [24], postharvest weight loss in vegetables is usually due to the loss of water through transpiration. Weight loss can lead to wilting and shriveling which both reduce market value and consumer acceptability [25].

Plant tissues are usually in equilibrium with the atmosphere at the same temperature and relative humidity of 99.0-99.5%; therefore, any storage conditions having a lower atmospheric water vapor pressure will cause water loss from produce exposed to that condition [26]. The weight loss of tomato increased progressively during storage and was greatly affected by the variety, maturity stage and the storage time.

All the tomato varieties in the three stages of maturity showed increase in respiration and ethylene production rate in the early days of storage, then had a peak which was followed by a steady decline as the storage period prolonged. This is a characteristic behavior of climacteric fruits which have a peak in respiration and a burst of autocatalytic ethylene to help the ripening process [27]. Increase or decrease in respiration rates of tomatoes therefore is dependent on factors such as variety, maturity stage, surrounding gas composition and temperature [28, 29].

According to Kader [4] tomato fruits generally produce moderate amounts of ethylene of between one (1) and $10 \mu\text{l C}_2\text{H}_4 \text{ kg}^{-1}\text{h}^{-1}$ at 20°C , which is the range that most varieties in this study fell, though there are some which had low values (below $1 \mu\text{l C}_2\text{H}_4 \text{ kg}^{-1}\text{h}^{-1}$). The low ethylene rates could be associated to the low experiment temperature (25°C), the difference in varieties and maturity stages. The low rates are not the issue in the ripening process as tomatoes are very sensitive to ethylene, and as little as $0.5 \mu\text{L L}^{-1}$ ethylene is enough to trigger the ripening process [30]. In addition the low rates are desirable in prolonging the shelf life of tomatoes.

CONCLUSION

From the study it is clear tomato varieties have significant difference ($p < 0.05$) in their postharvest characteristics. The indeterminate varieties had more desirable qualities like lower percentage weight loss, hence shriveling is minimized thus retaining their attractive appearance and appeal to the consumer. All the varieties had lower rates of respiration and ethylene production and, therefore, are suitable for use in markets where delayed or slowed ripening is desired. Among the indeterminate varieties the Anna F1 variety displayed the best qualities.

Harvesting tomatoes at the turning stage of maturity was better if uniform color development and extended storage period is required. Harvesting at the mature green stage may result in development of yellow-orange color as a result of delayed ripening or immaturity while harvesting at the red ripe stage results in quick spoilage of tomatoes if not delivered in the market on time. To obtain high lycopene content it is advisable to harvest the tomatoes at the red ripe stage.

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Table 1: Hue angles (°) after harvest at the mature green stage for six tomato varieties

Mature green stage				
Variety	Days			
	0	2	4	6
Anna F1	75.6±0.11 ^d	68.7±0.25 ^c	63.1±0.02 ^b	47.7±0.44 ^a
Bravo F1	74.7±1.00 ^c	77.0±0.38 ^d	71.5±0.18 ^b	61.3±0.23 ^a
Chonto F1	72.2±0.30 ^c	67.9±0.42 ^b	68.1±0.14 ^b	51.2±0.12 ^a
Eden F1	74.8±0.54 ^d	72.9±0.30 ^c	55.4±0.17 ^b	47.4±0.05 ^a
Nuru F1	72.5±0.72 ^c	78.6±0.50 ^d	51.5±0.30 ^b	45.7±0.19 ^a
Rambo F1	74.8±0.56 ^d	69.2±0.22 ^c	55.2±0.22 ^b	49.2±0.13 ^a

Values are presented as mean ± SD. In each row different letters mean significant differences ($p < 0.05$)

Table 2: Hue angles (°) after harvest at turning stage for six tomato varieties

Variety	Turning stage			
	Days			
	0	2	4	6
Anna F1	60.8±0.15 ^d	58.1±0.32 ^c	46.3±0.30 ^b	44.5±0.22 ^a
Bravo F1	53.8±0.24 ^c	54.6±0.44 ^d	52.8±0.04 ^b	50.2±0.32 ^a
Chonto F1	60.9±0.23 ^d	55.1±0.02 ^c	49.5±0.01 ^b	46.9±0.05 ^a
Eden F1	57.9±0.30 ^d	51.9±0.51 ^c	46.4±0.23 ^b	44.5±0.30 ^a
Nuru F1	67.4±0.02 ^c	49.0±0.23 ^b	49.5±0.18 ^b	42.5±0.15 ^a
Rambo F1	70.1±0.10	53.3±0.12 ^c	47.0±0.29 ^b	43.6±0.03 ^a

Values are presented as mean ± SD. In each row different letters mean significant differences ($p < 0.05$)

Table 3: Hue angles (°) after harvest at the red ripe stage for six tomato varieties

Red ripe stage				
Days				
Variety	0	2	4	6
Anna F1	42.0±0.35 ^d	40.9±0.21 ^c	39.8±0.25 ^b	36.9±0.53 ^a
Bravo F1	45.5±0.42 ^d	43.7±0.10 ^c	42.9±0.29 ^b	39.9±0.21 ^a
Chonto F1	45.7±0.21 ^c	46.1±0.35 ^d	43.9±0.51 ^b	41.4±0.20 ^a
Eden F1	43.8±0.32 ^d	42.6±0.20 ^c	40.7±0.23 ^a	41.8±0.23 ^b
Nuru F1	45.6±0.15 ^c	43.8±0.43 ^b	43.6±0.23 ^b	42.0±0.21 ^a
Rambo F1	46.2±0.24 ^c	45.9±0.01 ^b	45.5±0.31 ^b	44.8±0.50 ^a

Values are presented as mean ± SD. In each row different letters mean significant differences ($p < 0.05$)

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