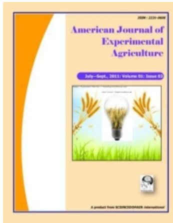

American Journal of Experimental Agriculture
3(2): 392-402, 2013

SCIENCEDOMAIN *international*
www.sciencedomain.org

Improving Marketable Quality of Tomato: a Simulation of Shipping Conditions in Ghana

I. Sugri[1*], S. A. Sargent[2], F. Kusi[1], A. D. Berry[2], R. A. L. Kanton[1] and W. Pelletier[2]

[1]CSIR-Savanna Agricultural Research Institute, P.O. Box 46, Bawku, UER-Ghana.
[2]Horticultural Sciences Department, University of Florida/IFAS, Gainesville-Fl 32611-0690, USA.

Authors' contributions

This work was carried out in collaboration between all authors. Author IS was involved in study design, implementation and write-up; author SAS was involved in study design, supervision and editing; author FK participated in initial project design and write-up, author ADB carried-out laboratory analysis and data management, author RALK participated in study design, supervision and editing, author WP conducted the vibration simulation analysis. All authors read and approved the final manuscript.

Research Article

Received 20th November 2012
Accepted 5th March 2013
Published 21st March 2013

ABSTRACT

Aim: The study assessed the influence of a sequence of anticipated hazard elements (impact, compression, vibration) and shipment conditions on marketable quality under varying temperatures and ripeness stages.
Study Design: The vibration test simulates a truck operating at highway speed and determines the ability of shipping units to withstand vertical and compression forces resulting from stacking during transport. Storage at 30ºC depicted ambient conditions; 15 and 20ºC are optimum temperatures for ripening; and pink and light-red ripeness depict typical harvest maturity in Ghana.
Place and Duration of Study: The study was conducted at the Postharvest Science Laboratory of the Horticultural Sciences Department of the University of Florida from September to December 2011.
Methodology: Round-type tomato at pink and light-red ripeness were subjected to a vibration test and incubated in ripening chambers set at 15, 20 and 30ºC. Critical data was taken on days to red-ripe, CO_2, ethylene production, color, firmness, weight loss, pH,

**Corresponding author: Email: suguribia@yahoo.com;*

titratable acidity and soluble solids content.
Results: Overall, the influence of vibration and ripeness on marketable shelf life was marginal; however temperature significantly ($P \le 0.05$) influenced shelf life. Vibration increased weight loss, respiration and ethylene production, which were plummeted at lower temperature. Days to red-ripe indicated that tomato should preferably be marketed by 2-4, 8-12 and 10-15 days at 30, 20 and 15ºC respectively, at pink to light-red ripeness under current distribution conditions. Best chemical properties were maintained at 15 and 20ºC; vibration and ripeness did not influence chemical properties, but increasing temperature affected all physico-chemical properties.
Conclusion: The study concludes that despite the cumbersome shipping conditions, tomatoes could be marketed at premium quality if lower storage temperatures were accessible. These facilities are beyond the purchasing power of small-holder traders, thus the involvement of the State and/or Private Sector to providing these facilities would be beneficial; particularly in urban markets where retail prices will merit such investments.

Keywords: Tomato; handling; road conditions; marketable quality; ripening; trade policy.

1. INTRODUCTION

Tomato (*Solanumlycopersycum* L) production is a major source of income for majority of households in the Upper East region of Ghana. During the dry season, large-scale production is carried out under irrigated conditions around dug-outs, small irrigation dams and along the White and Black *Volta* river banks [1]. As high as 10-20% postharvest losses occur due to delays in transport arrangements and long distances to urban markets [2]. This huge loss is unacceptable since economic resources would have been expended, and given that myriads of recommendations exist on postharvest quality management. A glut occurs at harvest and follows shortly by acute scarcity, which results in excessive price fluctuations. This constraint exists in most parts of Africa. For instance in Nigeria, [3] identified postharvest storage and processing as main causes of seasonal fluctuations of supply and price, high quality loss and socio-economic loss to producers. In most parts of Africa, tomatoes are harvested at vine-ripe due to lack of cool-chain and ripening facilities to handle mature-green to turning stages. However, as tomatoes ripen and senesce during typical shipping operations, greater care is required to minimize physical damage. Processing the fruits into preserved products could ameliorate this situation [4,5], unfortunately processing equipment is lacking, and some families prefer to use fresh tomato for cooking.

Depending on the target market, tomato handling, transportation and marketing may require sophisticated technologies and facilities. However, simple recommendations exist to extend shelf life at ambient conditions [6,7]. General recommendations are that tomatoes can be harvested at mature-green stage and ripened under controlled conditions around 12.8-25ºC at 90 to 95% relative humidity (RH) using 100-150ppm ethylene treatment for 24 to 72 hours. Once ripening has begun, optimum temperature to maintain sensory and nutritive quality is 22ºC. Optimum temperatures for different ripeness are: mature green (12.8-15.6ºC), light-red (10-12.8ºC) and red-ripe (6.7-10ºC). Mature-green fruit can be stored for 18, 15, 12, 10, 8 and 7 days, and pink stage for 10, 8, 6, 4, 3 and 2 days at 12, 15, 17.5, 20, 22.5 and 25ºC respectively at 90-95%RH without significant reductions in quality [7,8]. At temperatures above or below these ranges, the activities of some enzymes controlling metabolic reactions are disrupted [9]. Ripening below 12.8ºC results in slower color development whereas over 25ºC results in orange colored fruit. Above 30ºC ripening is inhibited due to alterations in lycopene biosynthesis [9,10], and fruit softening extremely fast [7,11]. Exposure to temperatures below 12ºC causes chilling injury (CI); which causes uneven ripening, reduced aroma volatiles, pitting, shriveling, water-soaked spots, softening and increased susceptibility to decay [6,12].

Generally, the use of mechanical equipment for harvesting, packing and transporting fruits increases susceptibility to mechanical injury and respiration rate [13,14,15]. Work done by [13] found that tomato fruits were subjected to several impacts during handling and packing; undergoing at least 15 handling steps. The proportion of visibly damaged tomatoes increased from 15% before to 35% after dumping, while internal bruising increased from 5.2% to 23.8% for tomatoes sampled from the floating tank and grading table, respectively. Mechanical injury has been correlated with metabolic disorders and quality changes in fruits and vegetables [15]. For instance, changes in aroma volatile profiles in round-type tomato were induced by mechanical impact [14]. They attributed such alterations to disruption in the metabolism of fatty acids (linoleic and linolenic acids), amino acids (isoleucine), and pigments (cyclic and open-chain carotenoids) during fruit ripening. According to [15], even a single 40cm drop during handling increased C_2H_4 production and respiration rate after 1h of impact and subsequently reduced shelf life. Bruised locular tissue of tomato contained 15% less vitamin C content than non-bruised tomatoes [16]. Tomatoes handled at ‘‘turning’’ stage developed 4 times more bruising injury than those handled at mature-green stage, and 8 times more than immature-green tomato. Internal bruising was more pronounced on tomatoes handled at breaker-stage than at mature-green stage [13].

Nonetheless, an efficient transport system is critical for effective agricultural marketing. The goal of transport is to convey produce from production centers to consumer markets with minimal loss of quality. An inefficient transport system is a disadvantage to farmers since it has direct influence on cost, produce quality and overall postharvest losses. In Ghana, large cargo trucks without temperature, humidity and vibration controls are used to ship tomato to urban markets, which ranges from 100-800km. This study is part of interventions to improve marketable quality of tomato in Ghana. The test design simulates a truck operating at highway speed and determines the ability of shipping units to withstand vertical vibration and dynamic compression forces resulting from stacking during transport (ASTM Standards, 2008; D4169-08). The objective was to assess influence of a sequence of anticipated hazard elements (impact, compression, vibration) and shipment conditions on marketable quality at varying ripeness stages and temperatures.

2. MATERIALS AND METHODS

The vibration test was conducted according to the American Society for Testing and Materials (ASTM) vehicle random vibration method (ASTM Standards, 2008; D4169-08). The practice provides uniform basis for evaluating the ability of shipping units to withstand the distribution environment. This is accomplished by subjecting the material to a test consisting of sequence of anticipated hazard elements encounted in a typical distribution cycle.

2.1 Design Considerations

Three design considerations relating to handling hazard elements, acceptance criteria and machine operations were considered (Table 1) using ASTM Standard, 2008 (D4169-08).Manual handling of hazard elements is recommeded for single containers, smaller package and shipment unit weighing up to 90.7kg. Mechanical handling is appropriate for unitized loads, large cases and containers. Acceptance criteria relates to desired conditions of the product and package at the end of distribution cycle, where criterion 1: product is damage free; criterion 2: package is intact and; criterion 3: both criteria 1 and 2. The power spectral density for truck transport (g^2/Hz) at assurance level I & II is illustrated in Table 1a. Assurance level is the level of test intensity based on its probality of occuring in a typical distribution cycle. For free fall and shock machine tests, recommended drop heights, number and sequence of drops and the shipping unit orientation of impact are illustrated in Table 1b.

Table 1. Design considerations: a. power spectral density under random vibration; and b. drop height at assurance level I & II

a.: Power spectral density level (g^2/Hz)			b.: Drop height (mm)		
Frequency (Hz)	**Assurance level I**	**Assurance level II**	**Shipping weight (Kg)**	**Assurance level I**	**Assurance level II**
1	0.0001	0.00005	0-9.1	610	381
4	0.02	0.01	9.1-18.1	533	330
16	0.02	0.01	18.1-27.2	457	305
40	0.002	0.001	27.2-36.3	381	254
80	0.002	0.001	36.3-45.4	305	229
200	0.00002	0.00001	45.4-90.7	254	178
overall, grams	0.73	0.52			
duration, min	180	180			

Source: ASTM Standards: Standard Practices for Performance Testing of Shipping Containers and Systems. ASTM Standards (D4169-08); 2008, 267-357pp.

2.2 Experimental Procedure

Round-type tomatoesat pink (30-60% red) and light-red (60-90% red) ripeness were obtained from a commercial packing house. Fruits were subjected to a vibration test and incubated in ripening chambers set at 15, 20 and 30ºC. Storage at 30ºC depicted ambient conditions in Ghana while 15 and 20ºC are recommended temperatures for ripening tomatoes. Three lugs of fruit (each containing 70 fruits) were stacked on top of another to simulate stacking on a pallet, then placed on a vibration table and vibrated for 1 hour. Average shelf life was expressed as the number of days from storage to red-ripe stage (stage 6 or table-ripe). Experiments were terminated when fruit softening could be detected by hand. Critical data was taken on respiration rate, ethylene production, color, firmness, weight loss, pH, total titratable acidity, soluble solids content and Brix:acid ratio.

2.3 Respiration Rate and Ethylene Production

Respiration rate (mgkg^{-1}h^{-1}) and ethylene production (µLkg^{-1}h^{-1}) were determined on day 1 and 3 after storage using a gas chromatograph. Three fruits were individually placed in a 3-L hermetic glass containers and 3mL of gas sample was withdrawn from the container headspace after 1 hour. Carbon dioxide concentration was measured using a gas chromatograph (Series 580; GOW MAC, Bridgewater, NJ) fitted with a thermal conductivity detector and Porapack Q column (38.71cm^2). The flow rate of the carrier gas (helium) was 25mLmin^{-1}; the oven and set at 40ºC; and injector/detector were operated at ambient condition (25ºC). Ethylene production was measured using a gas chromatograph (Tracor 540; Tremetrics, Austin, TX) fitted with a photo ionization detector and alumina-packed column (29.03cm^2). The flow rate of the carrier gas (helium) was 25mLmin^{-1}, and temperatures of oven and injector/detector were 50ºC and 100ºC, respectively.

2.4 Fruit Firmness

Initial and final fruit firmness (Nmm^{-2}) was measured non-destructively at the equatorial region of 12 tomatoes using an HD Plus texture analyzer with a 5kg load cell.

2.5 Weight Loss

Total weight loss (TWL) of 12 fruits was determined as a percentage of initial weight to the final weight during the storage period as indicated below. Mean daily weight loss (%) was further calculated by dividing total weight loss by the shelf life (days).

$$\textbf{TWL}\ (\%) = \frac{\boldsymbol{W1 - W2}}{\boldsymbol{W1}}\textbf{X100}$$

Where: W_1 = initial weight, W_2 = final weight

2.6 Soluble Solids and Titratable Acidity

At the red-ripe stage, 3 replicates of 4 fruits were homogenized using a blender and centrifuged at 5ºC for 20 min. The resulting supernatant was filtered through cheesecloth and then frozen for analysis. For soluble solids content (SSC), 1 to 2 drops of the supernatant were placed on the prism of a digital refractometer (Model 10480, Reichert-Jung) and SSC was reported as °Brix. The pH of supernatant was determined using Corning Model 140 pH meter with a Corning G-P RJ probe. For total titratable acidity (TA), 6g of each sample supernatant was diluted in 50mL of deionized water and titrated with 0.1N NaOH to an endpoint of pH 8.2, using an automatic 719-S-Titrino. TA was expressed as percent citric acid.

2.7 Color

The color (*L**, *a**, *b**values) of 12 fruits was measured at the equatorial region on opposites sides of each fruit by using a chromameter (model CR-400; Konica Minolta Inc., Japan). The light source was illuminant C, and the white plate (CR-A43; *L**= 96.86, *a**= −0.02, and *b**= 1.99) provided by the manufacturer was used for calibration. The a* values denote greenness when negative and red when positive; Chroma (C*) expressed as $(a^{*}+b^{2})^{½}$ measures purity of color; Hue (h*): denotes shades of yellowness and redness of color ($\tan^{-1}b^{*}/a^{*}$); L* values measures lightness scale of 0=black to 100=white.

2.8 Data Analysis

Data was subjected to analysis of variance (ANOVA) using Genstat (Release 9:2 TE) statistical package. Data was analyzed as a 2x2x3 factorial experiment in a completely randomized design. Factor 1: vibration and control; factor 2: pink and light-red ripeness; factor 3: varying temperatures at 15, 20 and 30 °C. Where significant difference existed, mean separation was by Fisher Least Significant Difference (F-LSD) at $P \le 0.05$.

3. RESULTS

3.1 Influence on Marketable Quality

Marketable life was expressed as the number of days after storage that the fruits maintained salable quality (Table 2). The overall influence of vibration and ripeness on shelf life was marginal, however temperature significantly ($P \le .05$) influenced shelf life. Number of days to red-ripe was 2.9-3.7 at 30ºC compared with 5.2-6.8 at 20ºC and 6.7-9.6 at 15ºC. Fruit softening began within 2-4, 8-12 and 10-15 days at 30, 20 and 15ºC respectively. The range at 30ºC explains the high postharvest losses along the tomato supply chain; as time to reach consumer markets can take 1-3 days in Ghana due to poor road network, delays in transport arrangements and cumbersome distribution channels.

Table 2. Effect of vibration, temeperature and maturity on shelf life

Storage temperature	Treatments	Maturity stage	Days to red-ripe		Days to softening	
			Average	Range	Average	Range
	Vibration	Pink	9.6^{a}	7-12	12.2^{ab}	10-14
15ºC		Light-red	7.1^{b}	6-9	11.7^{b}	10-13
	Control	Pink	7.4^{b}	6-8	13.7^{a}	12-15
		Light-red	6.7^{bc}	6-8	13.0^{ab}	12-15
20ºC	Vibration	Pink	6.8^{bc}	5-8	11.3^{b}	8-12
		Light-red	5.8^{c}	5-8	9.0^{c}	9-12
	Control	Pink	6.3^{bc}	5-8	9.1^{c}	9-10
		Light-red	5.2^{c}	4-8	8.2^{c}	7-9
30ºC	Vibration	Pink	3.7^{d}	2-4	4^{d}	2-4
		Light-red	2.9^{d}	2-4	4^{d}	2-4
	Control	Pink	3.1^{d}	2-4	4^{d}	2-4
		Light-red	3.2^{d}	2-4	4^{d}	2-4

Mean values along columns with same letters are not significantly different at $P \le 0.05$

3.2 Effect on CO_2 Rate and Ethylene Production

Both vibration and temperature significantly ($P \le 0.05$) influenced CO_2 production. A general rise of CO_2 was noticed from day 1 to 3 after storage, but fruits held at 30^{o}C showed a marginal decline. After 1 d of storage fruits either vibrated or held at higher temperatures showed higher CO_2 production rate than the control. Difference in CO_2 production between fruits held at 15ºC and 20ºC was 2 times higher, and 3 times higher between 15ºC and 30ºC (Table 3). From the main treatment effect, CO_2 production rates of vibrated and non-vibrated fruits were 23.5mgkg^{-1}h^{-1} and 19.5mgkg^{-1}h^{-1} after 1 d of storage, and increased to 50.1mgkg^{-1}h^{-1} and 39.1mgkg^{-1}h^{-1} after 3 d of storage, respectively. Overall, CO_2 production ranges were 6.4-15.6mgkg^{-1}h^{-1} at 15ºC, 30.5-49.1mgkg^{-1}h^{-1} at 20ºC and 62.4-74.1mgkg^{-1}h^{-1} at 30ºC after 1 d of storage, and increased to 27.1-33.1mgkg^{-1}h^{-1} at 15ºC, 34-55.51mgkg^{-1}h^{-1} at 20ºC and 44.8-58.1mgkg^{-1}h^{-1} at 30ºC after 3 d of storage.

Both vibration and temperature significantly ($P \le 0.05$) influenced ethylene production. Climacteric peaks were not attained since fruits were at advance stages of ripening (Table 3). From the main treatment effect, vibrated fruits showed higher ethylene production (6.2µLkg^{-1}h^{-1}) than control (4.6µLkg^{-1}h^{-1}) after 1 d of storage. Fruits held at 20ºC showed normal ethylene rate (8.03µLkg^{-1}h^{-1}) compared with 15ºC (4.5 µLkg^{-1}h^{-1}) and 30ºC (5.4 µLkg^{-}

$^{1}h^{-1}$). Ethylene production ranges were 3-5.1 µLkg^{-1}h^{-1} at 15ºC and 6.3-9.1 µLkg^{-1}h^{-1} at 20ºC after 1 d of storage. Fruits held at 30ºC showed intermediate ethylene response (4.4-6.9 µLkg^{-1}h^{-1}) after 1 d of storage. By 3 d after storage, ethylene production ranges were 15ºC (4.1-5.7 µLkg^{-1}h^{-1}), 20ºC (4.8-7.8 µLkg^{-1}h^{-1}) and 30ºC (2.5-3.9 µLkg^{-1}h^{-1}).

3.3 Firmness and Weight Loss

Initial firmness range was 9.9-11.7Nmm^{-2} at pink-ripe and 9.6-10.2 Nmm^{-2} at light-red stages. Fruits initially stored at pink were much firm (9.5-10.1Nmm^{-2}) at red-ripe compared with those at light-red stage (8.5-9.2 Nmm^{-2}). Irrespective of ripeness stage or vibration, all fruits stored at 30^{o}C were much soft at red-ripe (6.9-8.7 Nmm^{-2}) compared with 20^{o}C (8.4-10.2 Nmm^{-2}) and 15^{o}C (8.8-10.8 Nmm^{-2}) (Table 3). Weight loss (WL) increased with prolonged storage, and fruits stored at 30^{o}C showed higher losses (Table 3). Ripeness did influence overall WL but vibration increased WL. For each additional day after storage, difference in WL was 2 times higher between fruits held at 15^{o}C and 20^{o}C and 3 times higher between 15^{o}C and 30^{o}C. Weight loss ranges were 0.15-0.18% at 15^{o}C, 0.35-0.39% 20^{o}C and 0.75-0.8% 30^{o}C at 1 d of storage, and increased to 0.42-0.52% at 15^{o}C, 1.05-1.09% 20^{o}C and 1.49-1.61% at 30^{o}C after 3 d of storage. High weight loss hastens physiological processes which lead to rapid quality deterioration such as wilting, loss of firmness and flavor.

3.4 Soluble Solids and Titratable Acidity

The overall influence of vibration, maturity and temperature on selected chemical properties (pH, soluble solids content (SSC), total titratable acidity (TTA) and brix/acid ratio at the red-ripe stage are showed in Table 4. In all interactions, best chemical properties occurred at 15 and 20ºC. The influence of vibration and ripeness were not significant ($P \leq .05$) on chemical properties, but significant differences ($P < 0.001$) existed at high temperature. Higher acidity (pH: 4.0-4.3) was recorded at 30ºC compared with ranges at 15ºC (pH: 4.3-4.5) and 20ºC (pH: 4.4-4.6). Higher soluble solids content (3.7-4.0) was recorded at lower temperatures 15ºC (3.7-3.9) and 20ºC (3.7-4.9) compared with 30ºC (3.4-3.7). This trend reflected in the brix/acid ratio, which relates to taste of products. Higher ratios were recorded at lower temperatures of 15ºC (6.4-9.2) and 20ºC (8.0-9.5) compared with 30ºC (4.3-7.5).

Table 3. Effect of vibration, temperature and maturity on some physiological processes

Storage Temperature	Treatments	Maturity stage	Fruit firmness (Nmm^{-2})		Ethylene production (µLkg^{-1}h^{-1})		Respiration rate (mgkg^{-1}hr^{-1})		Weightloss (%)	
			Initial	Final	Day 1	Day 3	Day 1	Day 3	Day 1	Day 3
15^{o}C	Vibration	Pink	12.3^{a}	10.8^{a}	3.01d	5.7^{ab}	13.9^{e}	29.7^{d}	0.14^{c}	0.40^{d}
		Light-red	8.9^{bc}	8.8^{ab}	6.3bc	4.4^{bc}	7.6^{e}	27.1^{d}	0.16^{c}	0.45^{d}
	Control	Pink	11.2^{ab}	9.5^{ab}	3.5d	4.6^{bc}	6.4^{e}	33.9^{d}	0.17^{c}	0.39^{d}
		Light-red	11.2^{ab}	9.3^{ab}	5.1cd	4.1^{bc}	15.6^{e}	32.1^{d}	0.20^{c}	0.38^{d}
20^{o}C	Vibration	Pink	11.3^{ab}	10.2^{a}	9.1a	7.8^{a}	49.1^{c}	51.2^{ab}	0.34^{b}	1.14^{c}
		Light-red	9.6^{bc}	8.4b^{c}	8.9ab	5.9^{ab}	45.5^{c}	55.5^{ab}	0.43^{b}	1.17^{c}
	Control	Pink	9.9^{bc}	8.7b^{c}	7.9ab	6^{ab}	30.5^{d}	34^{d}	0.36^{b}	0.96^{c}
		Light-red	10.7^{a}	10.1^{a}	6.3bc	4.8^{bc}	37.8^{cd}	45.7^{c}	0.35^{b}	0.99^{c}
30^{o}C		Pink	8.4^{bc}	6.9^{c}	6.9bc	3.9^{c}	74.1^{ab}	50.7^{ab}	0.77^{a}	1.65^{a}
	Vibration	Light-red	10^{ab}	8.7^{bc}	5.9cd	3.5^{c}	75.6^{a}	58.1^{a}	0.79^{a}	1.55^{ab}
		Pink	9.5^{bc}	8.5^{bc}	4.4cd	2.5^{cd}	62.4^{b}	44.8^{c}	0.74^{a}	1.32^{bc}
	Control	Light-red	9.2^{bc}	8.4^{bc}	4.8cd	3^{c}	64.9^{ab}	46.7^{bc}	0.82^{a}	1.66^{a}

**Mean values along columns with same letters are not significantly different at P≤.05*

Table 4. Effect of vibration, temeperature and maturity on chemical properties at red-ripe

Storage temperature	Treatments	Maturity stage	pH	Soluble solidscontent (^{o}Brix)	Total Titratable acidity (%citric acid)	Brix/Acid ratio
15ºC	Vibration	Pink	4.5±0.02^{a}	3.9±0.25^{a}	0.5±0.01^{bc}	8.8±0.29^{ab}
		Light-red	4.4±0.11^{ab}	3.8±0.26^{a}	0.5±0.11^{bc}	8.3±2.24^{ab}
	Control	Pink	4.5±0.07^{ab}	3.9±0.06^{a}	0.4±0.07^{c}	9.2±1.43^{a}
		Light-red	4.3±0.27^{bc}	3.7±0.12^{ab}	0.6±0.19^{bc}	6.4±2.53^{bc}
20ºC	Vibration	Pink	4.6±0.04^{a}	3.9±0.15^{a}	0.5±0.04^{bc}	8.2±1.08^{ab}
		Light-red	4.5±0.05^{ab}	3.7±0.31^{ab}	0.5±0.03^{bc}	8.0±0.38^{ab}
	Control	Pink	4.4±0.03^{ab}	3.9±0.10^{a}	0.5±0.01^{bc}	8.2±0.10^{ab}
		Light-red	4.5±0.06^{ab}	4.0±0.12^{a}	0.4±0.02^{c}	9.5±0.37^{a}
30ºC	Vibration	Pink	4.1±0.12^{c}	3.4±0.00^{b}	0.7±0.17^{ab}	5.0±1.13^{cd}
		Light-red	4.0±0.02^{dc}	3.4±0.17^{b}	0.8±0.07^{a}	4.3±0.19^{d}
	Control	Pink	4.2±0.13^{bc}	3.7±0.06^{ab}	0.7±0.22^{ab}	5.8±1.66^{cd}
		Light-red	4.3±0.14^{bc}	3.7±0.21^{ab}	0.5±0.09^{bc}	7.5±1.47^{abc}

**Mean values along columns with same letters are not significantly different at P≤0.05*

3.5 Color

Vibration had no influence on color properties, a*, *c**, h* and L values, but significant difference (P≤0.05) occurred with ripeness and storage temperature (Table 5). Redness was reduced at 30ºC (a*:23.8-24.4) compared with 20ºC (a*:25.5-27) and 15ºC (a*:25.5-26.8). The hue (h*) which denotes shades of yellowness and redness of color (tan^{-1}b*/a*) did not vary and fell close to optimum ranges at red ripe. The hue value ranges were 41.9-46.8 at 15ºC, 42.6-45 at 20ºC and 45.4-49.4 at 30ºC. Significant difference (*P<0.001*) was noticed with varying temperature for L* values. The L* ranges were 45.3-47 at 30ºC compared with 43.9-45.1 at 20ºC and 42.4-43.9 at 15ºC.

Table 5. Effect of vibration, temeperature and maturity on fruit color at red-ripe

Storage temperature	Treatments	Maturity stage	a*	Chroma (C*)	Hue (h*)	L*
15ºC	Vibration	Pink	19.9^{c}	33.9^{c}	46.8^{ab}	43.9^{cd}
		Light-red	24.3^{a}	33.9^{c}	42.7^{bc}	42.4^{d}
	Control	Pink	22.0^{b}	34.9^{bc}	44.6^{b}	42.9^{cd}
		Light-red	24.5^{a}	34.4^{bc}	41.9^{c}	43.4^{d}
20ºC	Vibration	Pink	22.1^{b}	34.3^{bc}	45.0^{b}	45.1^{bc}
		Light-red	23.6^{a}	33.9^{c}	43.1^{bc}	44.9^{cd}
	Control	Pink	24.3^{a}	35.1^{ab}	42.7^{c}	44.6^{cd}
		Light-red	24.5^{a}	34.5^{bc}	42.6^{c}	43.9^{cd}
30ºC	Vibration	Pink	23.8^{ab}	36.6^{a}	49.2^{a}	47.0^{a}
		Light-red	23.8^{ab}	33.9^{c}	45.8^{b}	45.3^{b}
	Control	Pink	24.1^{a}	35.8^{ab}	43.7^{bc}	47.0^{a}
		Light-red	24.4^{a}	34.9^{bc}	44.4^{bc}	46.6^{ab}

**Mean values along columns with same letters are not significantly different at P≤0.05*
a: denotes greenness when negative and red when positive; Chroma (C*) measures purity of color; calculated as $(a^*+b^2)^{½}$; Hue (h*): denotes shades of yellowness and redness of color (tan^{-1}b*/a*); L* values measures lightness scale of 0=black to 100=white*

4. DISCUSSION

Despite the depth of information to improve postharvest quality, little progress has occurred in tomato marketing in most parts of Africa. Most recommendations have worked for export-oriented growers but the potential benefit to domestic markets is still lacking. Apparently, integrating such recommendations requires technologies and infrastructure which is not within the resource limits of smallholder traders. Generally, maintaining premium quality requires the integration of various steps from field to consumer retail markets [7]. Two most critical means of maintaining quality during postharvest handling are minimizing mechanical injury [13,15], and managing temperature [17,11]. Temperature by far is the important environmental factor in the postharvest life of tomato fruit because it has tremendous influence on the rate of biological processes, including respiration, weight loss, red color and firmness [17,11]. Due to long distances to urban markets and cross-border trade in West Africa, the produce is shipped under harsh road conditions and high ambient temperatures [3]. Several kinds of mechanical damage occur to produce during shipping. Thus, reducing quality and postharvest losses along the supply chain have remained critical challenges. Attempts to get tomato harvested from “turning” to “light-red” stages have yielded not significant progress; as quality is strongly associated with red-ripeness. Presently, tomatoes are harvested at red-ripe and shipped to urban markets. As urban populations and food requirements rapidly increase, there is need for commensurate policy to provide quality food at reasonable prices. Less complex cooling systems, refrigerated storage and construction of packing houses in urban markets would be necessary for fresh fruits and vegetables.

Vibration triggered physiological processes such as weight loss, respiration rate and ethylene emission. These physiological responses were rapid at high temeperature and prolonged storage periods, but were reduced at lower temperatures of 20 and 15 °C. The onset of softening (Table 2) indicates that, under typical distribution cycles tomatoes should preferably be marketed by 2-4, 8-12 and 10-15 days at 30, 20 and 15ºC respectively. Overt quality breakdown such as decay, shriveling and off-flavors sets in 2-3 days after this stage. This range explains the high postharvest losses along the tomato supply chain. Time to reach consumer markets can take 1-3 days in Ghana due to poor road networks and delay in transport arrangements. The results (Table 4) indicate that chemical properties: pH, soluble sugars, total titrable acidity and brix/acid ratio, which influence fruit sensory quality were not altered by the vibration treatment, ripeness and/or storage at 15 and 20ºC. Thus despite the poor shipping conditions, tomatoes can still be marketed at premium quality if access to refrigerated transport and cold-chain packing houses were available at destination markets. In that case, distances, time, ripeness and road conditions to destination markets will be less consequential on marketable quality for up to 2 weeks. In addition, training on proper handling will significantly reduce physiological processes leading to decay and accelerated senescence.

5. CONCLUSION

The study evaluated the influence of shipping conditions on produce quality in a typical distribution cycle under different temperatures and ripeness stages. Vibration increased weight loss, respiration and ethylene production, but did not influence the fruit physico-chemical properties. Under current distribution constraints, fruits will maintain premium quality for only 2-4 days, but can be extended to 8-15 days if cold-chain packing houses are available. However, access to such facilities is beyond the purchasing power of small-holder traders, thus the involvement of the State and/or Private Sector to providing these facilities would be beneficial; particularly in urban markets where retail prices will merit such investments.

ACKNOWLEDGEMENT

We Acknowledge the Norman E. Borlaug International Agricultural Science and Technology Fellowship Program for supporting the data collection at the Horticultural Sciences Department at the University of Florida.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ofori-Sarpong E. Impact of climate change on agriculture and farmers coping strategies in the Upper East region of Ghana. West Afr. J. Appl. Sci. 2001;2:21-35.
2. Babatola LA, Ojo DO, Lawal OI. Effect of storage condition on tomato (*Lycopersiconesculentum* Mill.) quality and shelf life. J. of Biological Sci. 2008; 8(2):490-493.

3. SRID, Statistics, Research and Information Department. Ministry of Food and Agriculture, Ghana; 2010.
4. Safdar MN, Mumtaz A, Amjad M, Siddiqui N, Hameed T. Development and quality characteristics studies of tomato paste stored at different temperatures. Pak. J. Nutr. 2010;9:265-268.
5. NurHossain MD, Fakruddin MD, Nurul-Islam MD. Effect of chemical additives on the shelf life of tomato juice.Amer. J. Food Tech. 2011;6(10):914-923.
6. Maul F, Sargent SA, Balaban MO. Aroma volatile profiles from ripe tomatoes are influenced by physiological maturity at harvest: An application of the electronic nose technology. J. Am. Soc. Hort. Sci. 1998;123:1094-1101.
7. Sargent SA, Brecht JK, Olczyk T. Handling Florida vegetables series-round and Roma tomato types. UF-IFAS Extension Service SS-VEG. 2007;928:1-7.
8. Gautier H, Diakou-Verdin V, Benard C, Reich M, Buret M. How does tomato quality (Sugar, Acid, and Nutritional Quality) vary with ripening stage, temperature and irradiance? J. Agr. Food Chem. 2008;56(4):1241-1250.
9. Lurie S, Handoros A, Fallik E, Shapira R. Reversible inhibition of tomato fruit gene expression at high temperature (effects on tomato fruit ripening). Plant Physiol. 1996;110:1207-1214
10. Masarirambi MT, Brecht JK, Sargent SA. Tomato color development following exposure to ethylene at high temperatures. Proc. Fla. State Hort. Soc. 1995;108:268-272.
11. Tadesse TN, Farneti B, Woltering E. Effect of ethylene and 1-Methylcyclopropene (1-MCP) on color and firmness of red and breaker stage tomato stored at different temperature. Amer. J. of Food Tech. 2012;7(9):542-551.
12. Tadesse TN, Farneti B, Woltering E. Investigation on the cause(s) of tomato fruit discoloration and damage under chilling condition using external antioxidant and hot water treatment. Asian J. of Plant Sci. 2012;11(5):217-225
13. Sargent SA, Brecht JK, Zoellner JJ. Sensitivity of tomatoes at mature-green and breaker ripeness stages to internal bruising. J. Amer. Soc. Hort Sci. 1992;117:119-123.
14. Moretti CL, Baldwin EA, Sargent SA, Huber DJ. Internal bruising alters aroma volatile profiles in tomato fruit tissue. Hort Sci. 2002;37:378-382.
15. Lee E, Sargent SA, Huber JD. Physiological changes in Roma-type tomato induced by mechanical stress at several ripeness stages. Hort Sci. 2007;42:1237-1242.
16. Moretti CL, Sargent SA, Huber JD, Calbo AG. Chemical composition and physical properties of pericarp, locule and placental tissues of tomatoes with internal bruising. J. Am. Soc. Hort Sci. 1998;123:656-660.
17. Akter H, Khan SA. Effect of gamma irradiation on the quality (color, firmness and total soluble solids of tomato (*Lycopersiconesculentum* Mill.) stored at different temperature. Asian J. Agric. Res. 2011;6:12-20.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=203&id=2&aid=1133