

Improving marketable quality of tomato: a simulation of shipping conditions in Ghana

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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 30°C depicted ambient conditions; 15°C and 20°C are optimum temperatures for ripening; and pink and light-red ripeness depicted 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°C, 20°C and 30°C. Critical data was taken on days to red-ripe, CO₂, ethylene production, color, firmness, weight loss, pH, titratable acidity and soluble solids content.

Results

Overall, the influence of vibration and ripeness on marketable shelf life was marginal, however temperature significantly ($P \leq 0.05$) influenced shelf life. Vibration triggered 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°C, 20°C and 15°C respectively, at pink to light-red ripeness under current distribution conditions. Best chemical properties occurred and were maintained at 15°C and 20°C; 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 can be marketed at premium quality if access to cold-chain, lower storage temperatures were, packing houses were available and 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.

Key words: Tomato, handling, road conditions, marketable quality, ripening, trade policy

INTRODUCTION

Tomato 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 a combination of factors such as 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

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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] and [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] and [7]. General recommendations are that tomatoes can be harvested at mature-green stage and ripened under controlled conditions around 12.8-25°C 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 22°C. Optimum temperatures for different ripeness are: mature green (12.8-15.6°C), light-red (10-12.8°C) and red-ripe (6.7-10°C). Tomato at mature-green **stage 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°C, 15°C, 17.5°C, 20°C, 22.5°C and 25°C respectively at 90-95%RH without significant reduction in quality [7] ~~and [8]~~. At temperatures above or below these ranges, the ~~structures-activity~~ of some enzymes controlling metabolic reactions are disrupted [9]. Ripening below 12.8°C results in slower color development ~~while ripening whereas above over~~ 25°C results in ~~more~~ orange colored fruit. At ~~or~~ above 30°C ripening is inhibited due to ~~disruption of~~ alterations in lycopene biosynthesis [9] ~~and [10]~~, and fruit softening ~~is more severe extremely fast~~ [7] ~~and [11]~~. Exposure to temperatures below 12°C causes chilling injury (CI); ~~its~~ symptoms include ~~which causes~~ uneven ripening, reduced aroma volatiles, pitting, shriveling, water-soaked spots, softening and ~~increased~~ susceptibility to decay [6] ~~and [12]~~.

Generally, the use of mechanical equipment for harvesting, packing and transporting fruits increases susceptibility to mechanical injury ~~and~~ respiration rate ~~and sensory profiles~~ [13], [14] and [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 C₂H₄ 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 ~~to~~ 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 fruit physiology and quality at varying ripeness stages and temperatures.

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 a sequence of anticipated hazard elements encountered in a typical distribution cycle.

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 recommended 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 probability of occurring 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			

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

Experimental procedure

Round-type tomatoes (*Lycopersicon esculentum* Mill) at pink (30-60% red) and light-red (60-90% red) ripeness were obtained from a commercial packing house for the study. Fruits were subjected to a vibration test and incubated in ripening chambers set at 15°C, 20°C and 30°C. Storage at 30°C depicted ambient conditions in Ghana while 15°C and 20°C 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.

Respiration rate and ethylene production

Respiration rate ($\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) and ethylene production ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) were determined on day 1 and 3 using a gas chromatograph; since climacteric peaks were not expected again. Three fruits were individually placed in a 3-L hermetic glass containers and 3 mL 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 Porapak Q column (4 ft-1/8 in). The flow rate of the carrier gas (helium) was $25\text{mL}\cdot\text{min}^{-1}$, and the oven and injector/detector were set at 40°C and ambient (25°C), respectively. Ethylene production was measured using a gas chromatograph (Tracor 540; Tremetrics, Austin, TX) fitted with a photo ionization detector and alumina-packed column (3 ft-1/8 in). The flow rate of the carrier gas (helium) was $25\text{mL}\cdot\text{min}^{-1}$, and temperatures of oven and injector/detector were 50°C and 100°C, respectively.

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Fruit firmness

Initial and final fruit firmness (N) at 1mm deformation was measured non-destructively at the equatorial region of 12 tomatoes using an HD Plus texture analyzer with a 5kg load cell.

Physiological 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).

$$TWL (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

Where: W_1 = initial weight, W_2 = final weight

Determination of chemical properties Soluble solids and titratable acidity

At the red-ripe stage, 3 replicates of fruits were homogenized using a blender and centrifuged at 5°C 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. Total titratable acidity (TTA) was analyzed using an automatic 719-S-Titrino. For TTA, 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. TTA was expressed as percent citric acid.

Comment [L4]: How was each replicate prepared

Color

The CIE color scale (L^* , a^* , b^* values) of 12 fruits were measured at the equatorial region on opposite 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 $(a^{*2} + b^{*2})^{1/2}$ 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.

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: temperature, 15°C, 20°C and 30°C. Where significant difference existed, mean separation was by Fisher Least Significant difference (F-LSD) at $P \leq 0.05$.

RESULTS

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 ($P \leq 0.05$) influenced shelf life. Number of days to red-ripe was 2.9-3.7 at 30°C compared with 5.2-6.8 at 20°C and 6.7-9.6 at 15°C. Fruit softening began within 2-4, 8-12 and 10-15 days at 30°C, 20°C and 15°C respectively. The range at 30°C 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 a complex of challenges such as a poor road network, delays in transport arrangements and cumbersome distribution channels.

Table 2: Effect of vibration, temperature and maturity on shelf life

Temperature of storage	Treatments	Maturity stage	Days to red-ripe		Days to Softening	
			Average	Range	Average	Range
15°C	Vibration	Pink	9.6 ^a	7-12	12.2 ^{ab}	10-14
		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
20°C	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
30°C	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 $P \leq 0.05$

Effect on CO₂ rate and ethylene production

Significant interaction ($P \leq 0.05$) between vibration and varying temperature was noticed. Difference in CO₂ rate production was 2 times more between fruits held at 15°C and 20°C and 3 times more between 15°C and 30°C (Table 3). After 1 d of storage vibrated fruits either vibrates or held at higher temperatures showed higher CO₂ production rates (44.3 mg kg⁻¹ h⁻¹) than the control (36.3 mg kg⁻¹ h⁻¹) a day after storage, also fruits held at higher temperatures showed higher CO₂ rates. From the main treatment effect, CO₂ production rates of vibrated and non-vibrated fruits were 23.5 mg kg⁻¹ h⁻¹ and 19.5 mg kg⁻¹ h⁻¹ a day after storage (DAS), and increased to 50.1 mg kg⁻¹ h⁻¹ and 39.1 mg kg⁻¹ h⁻¹ by 3 DAS, respectively. A general rise of CO₂ was noticed from 1 to 3 DAS, but fruits held at 30°C showed a marginal decline; indicative of an advance stage in ripening or fruits were beginning to senesce. CO₂ ranges were 6.4-15.6 mg kg⁻¹ h⁻¹ at 15°C, 30.5-49.1 mg kg⁻¹ h⁻¹ at 20°C and 62.4-74.1 mg kg⁻¹ h⁻¹ at 30°C a day after storage. By 3 DAS, CO₂ rates were 27.1-33.1 mg kg⁻¹ h⁻¹ at 15°C, 34-55.51 mg kg⁻¹ h⁻¹ at 20°C and 44.8-58.1 mg kg⁻¹ h⁻¹ at 30°C.

Comment [L5]: Rewrite

Both vibration and temperature significantly ($P \leq 0.05$) influenced ethylene production. Consistent 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 (6.2 μl kg⁻¹ h⁻¹) than control (4.6 μl kg⁻¹ h⁻¹) a day after storage. Fruits held at 20°C showed normal ethylene rate (8.03 μl kg⁻¹ h⁻¹) compared with 15°C (4.5 μl kg⁻¹ h⁻¹) and 30°C (5.4 μl kg⁻¹ h⁻¹). Ethylene rates were 3-5.1 μl kg⁻¹ h⁻¹ 15°C and 6.3-9.1 μl kg⁻¹ h⁻¹ at 20°C on a day after storage. Fruits held at 30°C showed a mediocre ethylene response (4.4-6.9 μl kg⁻¹ h⁻¹), probably due to disruption of some metabolic processes. By 3 DAS, ethylene ranges were 15°C (4.1-5.7 μl kg⁻¹ h⁻¹), 20°C (4.8-7.8 μl kg⁻¹ h⁻¹) and 30°C (2.5-3.9 μl kg⁻¹ h⁻¹) (Table 3).

Comment [L6]: Intermediate?

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Influence on fruit firmness and weight loss

Differences in fruit firmness among treatments were not too distinct since each experiment was terminated when fruit softening could be detected by hand-feel (Table 3). Initial firmness ranges were 9.9-11.7 N at pink-ripe and 9.6-10.2 N at light-red stages. The interaction of temperature and ripeness showed that fruits initially stored at light-red ripeness and all treatments at 30°C were much soft at red-ripe. Fruits stored at 30°C were much soft at red-ripe (6.9-8.7 N) compared with 20°C (8.4-10.2 N) and 15°C (8.8-10.8 N). Weight loss progressed with prolonged storage and fruits stored at 30°C showed severe losses (Table 3). Vibration triggered increased weight loss; physiological weight loss (W_L) was 2 times more between fruits held at 15°C and 20°C and 3 times more between 15°C and 30°C. High weight loss hastens physiological processes which lead to rapid quality deterioration such as wilting, loss of firmness and flavor. Ripeness did influence overall weight loss but higher temperature caused

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severe loss of weight. For each additional day after storage, weight loss difference was 2 times more between fruits held at 15°C and those at 20°C and 3 times more between 15°C and fruits stored at 30°C.

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

Temperature of storage	Treatments	Maturity stage	Fruit firmness (N)		Ethylene production ($\mu\text{l kg}^{-1} \text{h}^{-1}$)		Respiration rate ($\text{mg kg}^{-1} \text{hr}^{-1}$)		Weightloss (%)	
			Initial	Final	Day 1	Day 3	Day 1	Day 3	Day 1	Day 3
15°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°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°C	Vibration	Pink	8.4 ^{bc}	6.9 ^c	6.9bc	3.9 ^c	74.1 ^{ab}	50.7 ^{ab}	0.77 ^a	1.65 ^a
		Light-red	10 ^{ab}	8.7 ^{bc}	5.9cd	3.5 ^c	75.6 ^a	58.1 ^a	0.79 ^a	1.55 ^{ab}
	Control	Pink	9.5 ^{bc}	8.5 ^{bc}	4.4cd	2.5 ^{cd}	62.4 ^b	44.8 ^c	0.74 ^a	1.32 ^{bc}
		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 $P=0.05$

Effect on chemical properties 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, optimum chemical properties occurred at 15°C and 20°C. The influence of vibration and ripeness were not significant ($P \leq 0.05$) on chemical properties, but significant differences ($P < 0.001$) existed at high temperature. Higher acidity (pH: 4.0-4.3) was recorded at 30°C compared with ranges at 15°C (pH: 4.3-4.5) and 20°C (pH: 4.4-4.6). Higher soluble solids content (3.7-4.0) was recorded at lower temperatures 15°C (3.7-3.9) and 20°C (3.7-4.9) compared with 30°C (3.4-3.7). This trend reflected in the brix/acid ratio, higher ratios were recorded at lower temperatures of 15°C (6.4-9.2) and 20°C (8.0-9.5) compared with 30°C (4.3-7.5). The brix/acid ratio relates to sensorial taste of products; where higher ratios are desirable. Thus, storage at higher temperatures particularly for prolong period could reduce sensory quality due to complexes of metabolic and physiological processes.

Comment [L12]: This is not always the case especially if high ratios results from very low acidity

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

Temperature of storage	Treatments	Maturity stage	pH	Soluble solids content (^o Brix)	Total Titratable Acidity (%citric acid)	Brix/Acid ratio
15°C	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}
20°C	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
30°C	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 $P \leq 0.05$

Color Properties

In Table 5, Vibrations showed had no influence on color properties, a^* , c^* , h^* and L^* values, but significant difference ($P<0.05$) occurred with ripeness and increasing temperature of storage storage temperature (Table V). Redness was reduced at 30°C (a^* :23.8-24.4) compared with 20°C (a^* :25.5-27) and 15°C (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 15°C, 42.6-45 at 20°C and 45.4-49.4 at 30°C. Significant difference ($P<0.001$) was noticed with varying temperature for L^* values. The L^* ranges were 45.3-47 at 30°C compared with 43.9-45.1 at 20°C and 42.4-43.9 at 15°C.

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

Temperature of storage	Treatments	Maturity stage	a^*	Chroma (C^*)	Hue (h^*)	L^*
15°C	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
20°C	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}
30°C	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 $P \leq 0.05$

a^* : denotes greenness when negative and red when positive; Chroma (C^*) measures purity of color; calculated as $(a^*+b^*)^{1/2}$; 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

Influence of Ripening and Temperature

Table 6 summarizes the interaction of varying temperature and ripeness stages on shelf life, physico-chemical and color properties. Fruits at pink ripeness took 8.5, 6.6 and 3.4 days to maintain red-ripe quality compared with the light-red stage which took 7.7, 6 and 3 days at 15°C, 20°C and 30°C respectively. CO_2 rates a day after storage were 10.2mg/kg⁻¹h⁻¹, 39.8mg/kg⁻¹h⁻¹ and 68.2mg/kg⁻¹h⁻¹ at pink-ripe, and 13.7mg/kg⁻¹h⁻¹, 37.3mg/kg⁻¹h⁻¹ and 75.3mg/kg⁻¹h⁻¹ at light-red for fruits, stored at 15°C, 20°C and 30°C respectively. By 3 DAS, CO_2 rates increased to 31.8mg/kg⁻¹h⁻¹, 47.6mg/kg⁻¹h⁻¹ and 47.8mg/kg⁻¹h⁻¹ for initially pink-ripe fruits, and 29.6, 50.6 and 52.4 for initially light-red fruits, stored at 15°C, 20°C & 30°C respectively. Much firm-ripe quality (9.5-10.1N) was noticed with fruits initially stored at pink ripe compared with light-red stage (8.5-9.2N). From the main temperature effect, average weight loss was 0.17% at 15°C, 0.37% at 20°C and 0.78% at 30°C a day after storage, and increased to 0.47% at 15°C, 1.1% at 20°C and 1.55% at 30°C by 3 DAS. Weight loss ranges were 0.15-0.18% at 15°C, 0.35-0.39% 20°C and 0.75-0.8% 30°C at 1 DAS and increased to 0.42-0.52% at 15°C, 1.05-1.09% 20°C and 1.49-1.61% at 30°C by 3 DAS. At red-ripe, chemical properties (pH, SSC and TTA) did not significantly ($P = .05$) vary between fruits initially stored at pink or red-ripe ripeness. However, higher acidity, reduced soluble solids content and increased TTA were noticed with increasing temperature of storage.

Comment [L14]: Interaction?

Comment [L15]: Again I would recommend the authors to focus on the main findings. All data is already on the tables

Comment [L16]: Rewrite

Table 6: Effect of temperature and ripeness on shelf life and physico-chemical properties

Maturity stage	Temperature of storage			Temperature of storage		
	15°C	20°C	30°C	15°C	20°C	30°C
Days to red-ripe (days)				Days to softening (days)		
Pink	8.5	6.6	3.4	12.9	10.2	4.0
Light-red	6.9	5.5	3.0	12.3	8.6	4.0
Mean	7.7	6.0	3.2	12.6	9.4	4.0
P=.07, LSD _(0.05) = 0.8, CV(%)=20.4				P= .02, LSD _(0.05) = 0.8, CV(%)=13.9		
Ethylene rate (ul'kg ⁻¹ h ⁻¹) at 1 DAS				Ethylene rate (ul'kg ⁻¹ h ⁻¹) at 3 DAS		
Pink	3.3	8.5	5.7	5.2	6.9	3.2
Light-red	5.7	7.6	5.1	4.3	5.4	4.3
Mean	4.5	8.1	5.4	4.7	6.1	3.7
P= .05, LSD _(0.05) = 1.4, CV(%)=8				P= .14, LSD _(0.05) = 1.6, CV(%)=2.4		
Respiration rate (mg'kg ⁻¹ h ⁻¹) at 1 DAS				Respiration rate (mg'kg ⁻¹ h ⁻¹) at 3 DAS		
Pink	10.2	39.8	68.2	31.8	47.6	47.8
Light-red	13.7	37.3	75.3	29.6	50.6	61.5
Mean	12.0	38.6	71.9	30.7	49.1	54.6
P= .10, LSD _(0.05) = 7, CV(%)=4.6				P=.34, LSD _(0.05) = 7, CV(%)=13.5		
Weight loss (%) at 1 DAS				Weight loss (%) at 3 DAS		
Pink	0.15	0.35	0.75	0.39	1.05	1.49
Light-red	0.18	0.39	0.8	0.42	1.08	1.61
Mean	0.17	0.37	0.78	0.40	1.06	1.55
P= .09, LSD _(0.05) = 0.07, CV(%)=8.1				P= .72, LSD _(0.05) = 0.19, CV(%)=9.7		
Initial Firmness (N)				Firmness at red-ripe (N)		
Pink	11.7	10.6	8.9	10.1	9.5	7.7
Light-red	9.7	10.2	9.6	8.6	9.2	8.5
Mean	10.7	10.4	9.3	9.4	9.3	8.1
P= .07, LSD _(0.05) = 1.6, CV(%)=9.3				P= .08, LSD _(0.05) = 1.4, CV(%)=9.9		
a* value at red-ripe				Chroma (c*) value at red-ripe		
Pink	26.1	26.7	23.9	37.5	37.1	36.2
Light-red	26.9	25.8	24.1	36.4	35.2	34.4
Mean	26.5	26.2	24.0	36.9	36.2	35.3
P= .04, LSD _(0.05) = 0.9, CV(%)=2.7				P= .48, LSD _(0.05) = 1.0, CV(%)=2.0		
Hue (H*) at red-ripe				L* value at red-ripe		
Pink	26.8	25.7	27.1	43.4	44.8	47.0
Light-red	24.3	23.9	24.5	42	44.4	45.9
Mean	25.6	24.8	25.8	43.2	44.6	46.5
P= .05, LSD _(0.05) = 1.5, CV(%)=1.7				P= .54, LSD _(0.05) = 0.9, CV(%)=1.0		
pH at Red-ripe				SSC at Red-ripe		
Pink	4.5	4.5	4.2	3.9	3.9	3.5
Light-red	4.3	4.5	4.2	3.7	3.9	3.5
Mean	4.4	4.5	4.2	3.8	3.9	3.5
P= .15, LSD _(0.05) = 0.14, CV(%)=0.6				P= .29, LSD _(0.05) = 0.21, CV(%)=1		
TTA (%citric acid)				Brix/acid ratio		

Pink	0.44	0.48	0.69	9	8.2	5.4
Light-red	0.55	0.45	0.65	7.3	8.7	5.9
Mean	0.45	0.46	0.67	8.2	8.4	5.6
P= .22, LSD _(0.05) = 0.14, CV(%)=1.9				P= .11, LSD _(0.05) = 1.7, CV(%)=2.4		

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] and [15], and managing temperature [17] and [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] and [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 pack-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 temperature and prolonged storage periods, but were reduced at lower temperatures of 20°C 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°C, 20°C and 15°C 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 15-20°C. Thus despite the poor and cumbersome 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 and proper handling will significantly reduce physiological processes leading to decay and accelerated senescence.

Several factors such as physiological maturity, temperature and handling are reported to influence tomato quality. However, many authors differ on the influence of these factors on sensory and chemical properties [18], [19], [20]. According to [6], fruits held for 2 days at 12.5°C or 20°C were significantly lower in pH when compared to those stored at 5°C or 10°C. Soluble solids content and titratable acidity showed no significant difference between temperature treatments after 2 days of storage, but glucose, fructose and sucrose equivalents were significantly higher at 5°C and 10°C when compared to higher temperatures. Toor and Savage [20] noticed that lycopene content of tomato stored between 15°C and 25°C was 1.8 fold higher than that of tomatoes stored under chilling condition. Some inorganic ions, Magnesium (Mg²⁺), Potassium (K⁺) and Calcium (Ca²⁺) were observed to be significantly higher at breaker stage than red-ripe in *Nadaffreta* tomato cultivar [20]. They attributed such difference to their involvement as enzyme cofactor in ripening metabolic pathways. Studies by [18] and [8] found that the development and accumulation of sensory flavonoids were best at the red-ripe stage. Nonetheless, chemical composition data collected by these authors did not always concur with their sensory results. During ripening generally, the concentration of reducing sugars, carotenes, ascorbate, rutin and caffeic acid derivatives

Comment [L17]: The authors mean that 20 is better than 30°C? Otherwise this

increase, whereas those of titratable acidity, chlorophylls and chlorogenic acid content decrease [20]. Flavor of fresh tomatoes results from complex interactions between sugars, organic acids, minerals and aroma volatile compounds. Over 400 aroma compounds have been identified in fresh samples, but less than 30 compounds are essential based on their flavor thresholds [6]. The critical ones are hexanal, cis-3-hexanal, trans-2-hexanal, 1-penten-3-one, 6-methyl-5-hepten-2-one, β -ionone, ethanol, methanol, cis-3-hexenol, 2+3-methyl-butanol, 2-isobutylthiazole and 1-nitro-2-phenylethane [6],[21] and [22].

Comment [L18]: In my view All this is not directly connected to the work . Remove

CONCLUSION

The study is in response to current challenges of tomato marketing such as the poor shipping conditions, technical capacities as well as resource constraints of the smallholder traders in domestic markets of Africa. It provides basis for evaluating the influence of shipping conditions on produce quality in atypical distribution cycle under different temperatures and ripeness stages. Vibration triggered 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 cold-chain packing 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.

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