Postharvest Losses and Quality Variations of Tomatoes in Wholesale Markets: A Case Study of Sri Lankan Supply Chain

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***Abstract*—Reducing postharvest losses is crucial in enhancing food security by improving the affordability and availability of safe and nutritious food. In Sri Lanka, the tomato supply chain faces greater postharvest losses mainly during transportation to wholesale markets. This study was conducted with the objectives of recognizing both the quantitative and qualitative loss of the tomatoes in one major wholesale market, in Sri Lanka, "Peliyagoda" sourced from different regions in Sri Lanka, and to recognize the reasons/ postharvest practices affecting such differences. Wholesale boxes of tomatoes from three major tomato growing areas in Sri Lanka, "Suriyawewa", "Balangoda" and "Kurunegala" were purchased from the "Peliyagoda" wholesale market and quantitative loss was assessed as a percentage of unmarketable tomatoes. They were further categorized as physical damage, physiological damage, and pathological and entomological damage. Then, the tomatoes of each box were analyzed for their qualitative parameters such as weight, color, firmness, and total soluble solids along with the shelf life of the tomato. Our results indicated that 22%-33% of postharvest losses occur across these regions, primarily due to physical damages (18%-20%). Box 2 and 3 from Balangoda and Kurunegala, harvested during the rainy season, experienced higher losses (10%-13%) due to physiological damage. Quality losses, including color change, firmness loss, and shorter shelf life (12 days), were prominent in improperly sorted boxes from Suriyawewa which contained >50% light red to red tomatoes. Future studies should extend the analysis throughout the supply chain, aiming to identify the root causes of these losses and enhance food security through facilitating necessary interventions.** **Keywords— Postharvest losses, tomato supply chain, food security, qualitative analysis, Sri Lankan market**

I. Introduction

Food security is a global concern which is greatly influenced by postharvest losses. Reducing postharvest losses is essential in minimizing food loss, enhancing food availability, and retaining nutritional quality, thus individuals have access to safe, sufficient, and nutritious food, aligning with broader food security objectives.

Tomato (*Solanum lycopersicum* L.) is one of the most popular commercial crops and the most produced vegetable in the world with a production of approximately 189.1 million metric tonnes [5]. Tomatoes contain essential vitamins, minerals, fiber, protein, amino acids, monounsaturated fatty acids, carotenoids, and phytosterols thus have numerous health benefits including the prevention of constipation, the lowering of high blood pressure, maintaining of the lipid profile and, the detoxification of toxins [1]. Furthermore, tomatoes are a valuable source of bioactive compounds that help in the prevention of cardiovascular disease (CVD), cancer, and neurodegenerative diseases. In Sri Lanka, where tomato production reaches around 90 thousand metric tonnes [5], tomatoes are commonly grown across diverse agroecological regions well-suited to their cultivation. However, Sri Lankan tomato value chain faces a significant challenge, in the form of high postharvest losses (PHL) which range between 40-60%.

Postharvest losses can occur at any phase along the food supply chain during handling, storage, transportation, and processing [2]. In Sri Lanka, a significant portion of the losses occur during transportation of tomatoes between the farm gate to the wholesale market [3]. When considering the high transporting expense, wholesalers often overload the produce and improper practices such as siting and sleeping on the poly-sacks in which fruits and vegetables are securely packed during transportation, rigorous handling while loading and unloading, cause substantial mechanical injuries to fresh products [3]. Also, various other factors like physiological breakdowns, diseases and insect pests [1], improper transportation facilities, inappropriate packaging, exposure to unfavorable temperatures, RH and gaseous environment, lack of appropriate tools, equipment and technology significantly influence the postharvest losses of tomato [3]. These factors collectively lead to decreased quality, weight loss, reduced nutritional value, decreased consumer acceptability, and ultimately, economic losses with increased environmental impacts [3]. To reduce these losses, it is essential to first quantify these losses and identify the causes of quantitative and qualitative losses. In developing countries, concerns about reducing quantitative losses (i.e., weight, volume, or total wastage of agricultural produce) generally take more attention over qualitative losses such as loss of edibility, nutritional quality, caloric value, and consumer acceptability of the produce [1]. It is also widely acknowledged that qualitative losses are far more difficult to evaluate than quantitative losses [1].

Therefore, in this study, we aim to recognize both the quantitative and qualitative loss of the tomatoes in Sri Lanka's one of the major wholesale markets, "Peliyagoda" wholesale market from different origins, to recognize the reasons or postharvest practices affecting such differences and to recognize the quality parameters that contributed to the postharvest loss.

II. Methodology

A. Experimental Site

The study was conducted in the 'Peliyagoda' wholesale market (Previously known as _Manning Market) (6° 57' N to 79° 52' E, 7 m.a.sl). Purchased tomato boxes' information is mentioned in the Table I. The boxes belonged to three major tomato growing districts in Sri Lanka; Suriyawewa, Balangoda and Kurunegala. All three boxes were packed in corrugated cardboard boxes and purchased within the period of 19th July to 25th September 2023. Maximum temperature, rainfall and humidity data for each location when produce was at farmgate. Suriyawewa recorded the highest maximum temperature at 33°C, followed by Balangoda and Kurunegala, both at 32°C. Balangoda had the highest relative humidity at 80%, while Suriyawewa had 76%, and Kurunegala had 78%. Rainfall data showed that Balangoda experienced the most rainfall with 30 mm, in contrast to Kurunegala's 1 mm and Suriyawewa, where there was no recorded rainfall. Upon reaching Peliyagoda, box 2 faced a higher level of rainfall (15mm) compared to the box 3 (0 mm) and box 1 (0 mm). Quality evaluations were carried out in the Botany Research laboratory, at the Open University of Sri Lanka, Nawala, Sri Lanka. (6°54′N to 79°53E, 9 m.a.sl).

TABLE I. WEATHER PATTERNS AT FARMGATE AND WHOLESALE MARKET LOCATIONS

Box	**Box 1**	**Box 2**	**Box 3**
Date	17/08/2023	14/09/2023	25/09/2023
Type	CFB[a]	CFB	CFB
Location	Suriyawewa	Blangoda	Kurunegala
Temp. (C°)	33	32	32
RH (%)	76	80	78
RF (mm)	0	30	1
Peliyagoda Temp (C°)	31	30	31
Peliyagoda RH (%)	78	80	78
Peliyagoda RF (mm)	0	15	0

[a]CFB= Corrugated fiberboard boxes

B. Quantitative Assessment of Marketable and Unmarketable Tomatoes

Total weight of the tomatoes in the box was measured. Unmarketable tomatoes were separated and categorized as; due to physical damage (cuts, punctures, bruises, scratches, slits, crushes, abrasions, and cracks), physiological damage (wilting, shrinkage, heat stress, cuticle cracks, puffiness, craft facing and internal breakdown) and pathological and entomological damage (Fungi and bacteria, infestation by trips, white flies and mites). Their weights were taken separately and postharvest loss% (PHL%) was calculated according to following equation.

$$\text{Postharvest loss (\%)} = \frac{\text{Weight of unmarketable tomatos (kg)} \times 100}{\text{Total weight of tomatoes (kg)}}$$

Next, marketable tomatoes were weighed and divided into six stages as mature green, breaker, turning, pink, light red and red according USDA classification. Weight of the tomatoes at each stage of maturity was also expressed as a percentage from the total weight.

C. Qualitative Assessment of Tomatoes

In each of the maturity stages,10 tomatoes were selected for analysis. Where there were fewer than 10 tomatoes available at a particular stage, all the available fruits were included in the study. Fruits were analyzed for the following quality parameters.

Average weight (g) of a tomato was taken using scale (OHAUS, PA413).

Color (L*, a* and b* tri stimulus values) of tomatoes were taken at two opposite sides using the mobile `Color Meter` app © (version 1.0.3). Firmness was measured at two opposite points on the equator of each fruit; one side was measured with skin and the other side, a thin (<1mm) skin was removed using a sharp knife and the firmness was measured using digital penetrometer (AGY-15, China).

To measure the TSS content of tomato, a few drops tomato juice was obtained from crushing tomato fruits separately using a hand squeezer and measured using the refractometer [Model, WZ-113, China (Mainland)] Results were expressed as °Brix.

Shelf-life assessment was conducted for ten tomatoes from each maturity stage stored under room temperature. The number of days to reach unmarketable state for each fruit were noted.

D. Statistical Analysis

Qualitative data were subjected to statistical analysis with a completely randomized design (CRD) consisting two factors; Box, maturity stage and their interaction effects were identified using two-way analysis of variance (ANOVA) at the 5% confidence interval. All statistics were carried out using SPSS statistical program (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY).

III. Results and Discussion

A. Quantitative Assesment of Tomatoes

Among three tomato boxes analysed, (Box 1 – Suriyawewa, Box 2 – Balangoda and Box 3 – Kurunegala), Box 2 had the highest average fruit weight of 68.019g, while Box 1 and Box 3 had average fruit weights of 35.82g and 30.89g, respectively. It's worth noting that these variances in tomato weight may be attributed to the tomato cultivars cultivated in each respective district. Highest marketable fruit percentage (78.30%, w/w) was obtained from box 1 (Table II). Box 2 and Box 3 exhibited similar percentages of marketable tomato quantities, standing at 67.30% and 66.98% (w/w), respectively. In all three boxes, tomatoes were found in various maturity stages, mature green, breaker, turning, pink, light red and red, and there was no apparent sorting applied to the bulk tomato boxes. Notably, Box 2 and Box 3 had most tomatoes in stages 2, 3, and 4, whereas Box 1 had tomatoes of latter four stages (Stages 3, 4, 5, 6), as indicated in Table II. Tomatoes in the red stage are fully ripped and their tissues are softer than the tomatoes in green stage. So, when tomatoes in green and red stages are stacked together, ripened tomatoes are more prone to mechanical damages and compression damages during transportation [3]. Therefore, it is advised to harvest tomatoes at breaker stage and follow proper sorting to minimize postharvest loss in the value chain.

However, Box 2 and Box 3 showed relatively higher postharvest losses (PHL), around 32.74% and 33.02% (w/w) respectively, as indicated in Table II. In contrast, Box 1 displayed a comparatively lower PHL of 21.70% (w/w). Therefor0e, improper sorting/ inclusion of more red stage tomato may not be the reason for higher quantitative losses. Upon conducting a thorough analysis of the factors contributing to losses, it was evident that physical damages resulted in nearly equivalent losses for all three boxes, with postharvest loss percentages (PHL%) of 19.03% for box 1, 17.89% for box 2, and 20.40% for box 3. Notably, the issue of physiological damages showed more losses in box 2 (12.76%) and box 3 (10.88%), whereas box 1 exhibited a significantly lower rate of 0.66%. The uniformity in physical damage levels and the same packaging system (CFB) and transportation via lorries suggest that the adverse conditions in the tomato harvesting, packing, and handling procedures across the districts are a common factor.

However, the distinctive weather patterns prevailing in each geographical region emerged as a critical determinant in the extent of losses attributed to physiological damages. For instance, box 1 contained tomatoes grown in the dry zone and harvested during the dry season, whereas box 2 and box 3 contained tomatoes from the wet and intermediate zones, respectively. The rainy season after a dry spell can increase physiological damages to tomatoes. Elevated humidity levels and temperature fluctuations in the growth period can lead to issues such as wilting, cuticle cracks, puffiness, and internal breakdown which explains the higher postharvest losses in box 1 and box 2 due to physiological damages. Such weather conditions also facilitate fungal and bacterial pathogens.

TABLE II. Quantitative Postharvest Loss

	Box 1 (Suriyawewa)	Box 2 (Balangoda)	Box 3 (Kurunegala)
Average fruit weight (g)	35.82[a]	68.019[b]	30.89[a]
Marketable %	78.30%	67.30%	66.98%
Mature green	0.50%	0.85%	1.64%
Breaker	2.67%	23.65%	25.02%
Turning	14.36%	16.54%	16.43%
Pink	29.72%	15.31%	20.32%
Light red	13.69%	8.95%	3.45%
Red	39.07%	1.95%	0.11%
PHL %	21.70%	32.74%	33.02%
Physical damage %	19.03%	17.89%	20.40%
Physiological damage %	0.66%	12.76%	10.88%
Pathological damage %	2.00%	2.08%	0.92%

[a]Values followed by different superscript letters are significantly different within a row according to Tuckey test ($p < 0.05$).

B. Qualitative Assesment of Tomatoes

Tab. 3 shows the results of the qualitative assessment. According to the results of color measurement, stage of maturity has significant effect on colour development. When transitioning from mature green to red stage, L* tend to decrease, a* increase and b* showed no consistent trend (data not shown). L* value in the tomatoes of each wholesale box ranged between 38.5 to 47.38.

CIELAB (Commission Internationale de l'Éclairage) method is the most commonly used method for food color measurement as it closely approximates the color perception of humans [4]. In this system, L* denotes the degree of darkness to lightness from black to white (L* = 0 to 100), while the a* axis shows the greenness to redness on a scale of -100 to +100. Parameter b* provides an approximation of the yellowness and blueness on an array of colors from yellow (a positive number) to blue (a negative number) [4]. In both commercial practice and scientific literature concerning tomato fruits and their derivatives, the a*/b* ratio has emerged as a widely utilized reference criterion for assessing color quality [4]. The a*/b* ratio of immature green tomatoes is < 0; when the tomatoes ripen and get more reddish color, it rises to 0 and above [4]. Correspondingly, it was observed that all three tomato boxes in our study exhibited a*/b* ratios exceeding 0, with box 2 standing out as having a significantly lower a*/b* ratio. Furthermore, our analysis revealed that box 2 showcased significantly highest L* value implying box 2 mainly held less ripened tomatoes, finding that also aligns with our quantitative analysis results.

When considering the obtained values for firmness, maturity stage had significant influence but not the box. However, tomatoes from "Suriyawewa" area had the lowest peel firmness of 4.77 N (Table III), while tomato grown in "Balangoda" and "Kurunegala" areas showed nearly an equal firmness value which is higher than the firmness of tomato in box 1. Tomatoes in all three boxes showed approximately same firmness without skin and it ranged between 3 N - 3.5 N. High respiration rate, moisture loss through transpiration, senescence, and disintegration of the tomato cell wall during ripening linked to the decrease in firmness of tomato [2]. Tomato peel act as a barrier to most of the micro-organisms and when the peel firmness is low or damaged the loss is higher.

The mean TSS values ranged in following order, box 2 (4.62) < Box 1 (4.69) < box 3 (4.74) without any significant difference. Stage of maturity had significant effect on TSS development. During ripening, pectin substances in tomato fruit breakdown into simple sugars [2]. This degradation leads to the increase in the TSS content. Highest TSS value can be observed in the red stage while mature green stage shows the lowest TSS value.

Tomatoes were stored under 25°C, RH, for 14 days. Tomatoes from Suriyawewa area showed significantly lower shelf life and it was nearly 12 days while Box 2 (Balangoda) and box 3 (Kurunegala) exhibited around 13 days shelf life. This variation may have occurred due to containing unsorted and higher proportion of red maturity stage (39%) tomatoes in box 1 which has led to gradual deterioration of quality and shorter shelf life. Also, it is worth noting that shelf life may further decline in the actual retail conditions where tomatoes are roughly handled and stored in less ventilated spaces, compared to the laboratory conditions.

TABLE III. QUALITATIVE POSTHARVEST LOSS

		Box 1	Box 2	Box 3	Significance		
					(B)	*(S)*	***(B*S)***
Color	**L***	38.50[a]	47.38[b]	40.84[a]	*	*	*
	a*	24.14	20.95	25.90	ns	*	*
	b*	44.37	45.54	44.05	ns	*	*
	a/b	0.59[a]	0.45[b]	0.62[a]	*	*	*
Firmness	$\mathbf{F_s}$	4.77	5.37	5.54	ns	*	ns
	$\mathbf{F_f}$	3.03	3.40	3.06	ns	*	ns
TSS		4.69	4.62	4.74	ns	*	*
Shelf life		11.85[a]	12.98[b]	13.16[b]	*	*	*

[a] Values followed by different superscript letters are significantly different within a row according to Tuckey test ($p < 0.05$).

IV. CONCLUSION

In conclusion, our comprehensive assessment of tomato wholesale boxes from different regions; Suriyawewa, Balangoda, and Kurunegala has revealed significant variations in both quantitative and qualitative aspects, offering valuable insights on factors affecting tomato quality and postharvest losses. Our findings revealed differences in the quantitative loss with Box 1 showing the highest marketable percentage, which implies potential influences of local weather conditions in tomato production on physiological damage. Our study underscores that sorting practices and fruit maturity significantly affect qualitative postharvest losses, affecting attributes such as tomato color, firmness, TSS levels, and ultimately shelf life. The notably higher average fruit weight in Box 2 from Balangoda suggests potential disparities in tomato cultivars among regions as a contributing factor. This research provides a foundational understanding of postharvest losses in the wholesale tomato market in Sri Lanka. To further the findings, future studies should encompass the entire value chain, tracking tomatoes from the farm level to the wholesale market over an extended time period even though the load tracking methodologies are challenging due to economic constraints. Obtaining more representative samples could be helpful in drawing insights on the root causes of postharvest losses, facilitating the implementation of interventions to enhance food security.

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