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Abstract: This study assessed quantitative and qualitative postharvest loss of tomato through the supply chain in Northwest Ethiopia using FAO load tracking method. The treatments comprised of four critical steps through the supply chain and three harvesting locations. Two-way ANOVA was used to estimate the combined contributions of harvesting location and supply chain and significant difference was tested at $p < 0.05$. In addition, the effect of refrigerated storage on the quality and shelf life of tomato was studied. The mean postharvest loss of tomatoes within five days of tracking along the unrefrigerated supply chain was 25.91 ± 1.04%. There was significant difference ($p < 0.05$) in postharvest loss, weight loss, firmness, colour L* and a*/b* value of tomatoes through the supply chain among the three districts. Low temperature storage improved the quality and extended the shelf life of tomatoes by delaying their ripening time in terms of colour, firmness and weight loss.

Keywords: load tracking; postharvest handling; quality; storage; supply chain; Ethiopia.

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1 Introduction

Tomato (*solanum lycopersicum*) is a commercial vegetable crop with a total production of 180.76 million tons worldwide (FAOSTAT, 2019). Ethiopia is endowed with favorable environmental and edaphic conditions that are suitable for commercial production of tomatoes (ATA, 2016). Tomato is widely grown in the country and contributes to food availability and security, and to some extent as a source of foreign exchange earnings of the country through exporting to the regional market (Emana et al., 2017). The annual production of tomato in Ethiopia is estimated to be 23,583.75 tons produced on 4,322.31 ha of land where smallholder farmers are the dominant producers (CSA, 2019). In Ethiopia, the tomato supply chain involves input suppliers, producers, traders (local assemblers and wholesalers), retailers, and consumers (Mohammed Kassaw et al., 2019).

Tomato is prone to loss in edibility, nutritional quality, calorific value, market value and consumer acceptability (Kader, 2005). Postharvest loss (PHL) of tomatoes in developing countries is excessive (Kader, 2002; Muhammad et al., 2012). The major causes of PHL in tomato are mechanical damages, physiological deteriorations and biological factors (Adeoye et al., 2009). Postharvest (PH) quality of tomato is affected by various interacting factors beginning in pre-harvest including type of cultivar, cultural practices employed, stage of maturity, prevailing temperature and relative humidity as well as handling and storage practices (Isack and Lyimo, 2015).

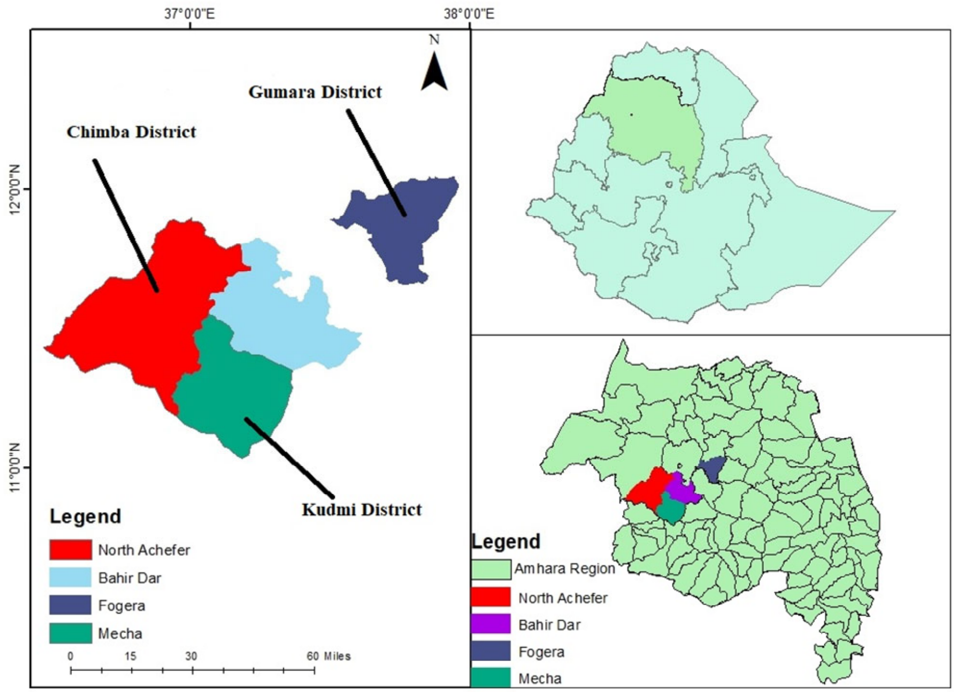
PHL along the supply chain (SC) of tomato in Ethiopia varies greatly from one production area to another. According to Abera et al. (2020), PHL of tomato in selected districts of East Shewa Zone including in hotels and cafes was about 39.3%. Similarly, an estimated PHL of nearly 45 % in the Eastern region and 20% in Bora and Dugda districts were reported by Kasso and Bekele (2018) and Emana et al. (2017), respectively. In researches conducted in South Wollo of Amhara region, PHL of tomato ranged from 18% to 22% (Hussen et al., 2013). There is insufficient information about the extent as well as causes of quantitative and qualitative PHL of tomato across the different steps of the SC in Ethiopia. Moreover, limited studies (Kasso and Bekele, 2018; Emana et al., 2017; Hussen et al., 2013) were done using survey methods which may lead to inaccurate estimates. The research done by Kuyu et al. (2019) was the only study which used load tracking method to estimate the extent of PHL of potato tubers along SC in Ethiopia. Load tracking and sampling assessment method which is recommended by FAO (2015) was adopted in the present study to assess quantitative and qualitative PHL of tomato along the SC. Besides, the storage behaviour and shelf life of tomato harvested at turning stage from Chimba districts in relation to its colour, firmness, and weight loss was also evaluated at 15°C storage.

2 Materials and methods

2.1 Study areas

Three tomato producing districts: Chimba, Gumara, Kudmi and Bahir Dar City, Northwest Ethiopia were selected in this study (Figure 1). Chimba district is found in North Achefer woreda which is located around 30 km away from Bahir Dar City and about 25 km of the road is bumpy. Gumara district is found in Fogera woreda which is located about 40 km away from Bahir Dar City and has an asphalted road. Kudmi is one of the districts in Mecha woreda which is found 42 km away from Bahir Dar City and about 7 km of the road is bumpy. Bahir Dar is the regional capital and largest city of Amhara national regional state, Ethiopia. Tomato is harvested in the study districts during dry season (from March to May) and produced by means of irrigation (Mohammed Kassaw et al., 2019). Farmers in Gumara and Kudmi districts use furrow irrigation whereas farmers in Chimba district use drip irrigation.

Figure 1 Geographical locations of study areas, Amhara region, Northwest Ethiopia (see online version for colours)



2.2 Treatments and experimental design

A two-factor experiment in a randomised complete block design consisting of growing location and SC, was implemented with four replications. For quantitative loss (quantitative PHL) assessment, a 3 × 4 factorial treatment combination of growing locations (Chimba, Gumara, and Kudmi district) and SC levels (farm, transportation, wholesale, and retail) was conducted. For qualitative loss (weight loss, colour, firmness, titratable acidity, total soluble solid, pH and vitamin-C), a 3 × 3 factorial treatment combination of growing location (Chimba, Gumara, and Kudmi district) and SC levels (farm, wholesale, and retail) was used.

2.3 Sampling method

2.3.1 Load tracking and sampling assessment

FAO (2015) postharvest assessment method which is based on load tracking and sampling assessment was used to assess PHLs of tomato through the SC.

From each district one producer, with a comparatively large-sized farm and a key supplier for wholesalers in fruit and vegetable market at Bahir Dar city, producing 'Galilea variety' of tomato was selected. From the producers in Gumara and Kudmi districts, six wooden boxes of tomatoes were collected and transported to Bahir Dar city tomato market by using Toyota Minibus Hiace. Whereas, from farm to main pavement road in Kudmi district animal cart was used to transport tomato. From Chimba district, about 84 wooden boxes of tomatoes were collected and transported to Bahir Dar city tomato market with ISUZU NPR track. From these loads, five wooden boxes were randomly sampled and tagged at the initial stage. Out of this, four wooden boxes with a weight of around 65 kg were carefully chosen and the initial data were recorded at farm gate. While tracking the samples in the SC, data on the quantitative and qualitative PHLs of tomatoes were collected for each stage of the SC: farm (during harvest, sorting and packing), transportation (throughout transportation to marketplace), wholesale storage systems for two days prior to retailing, and retailing for a maximum of three days of storage. The number of days was decided based on the SC trend observed in the study area.

2.3.2 Storage study

A total of 21 kg of tomato at turning stage were harvested from Chimba district; transported immediately to the laboratory and precooled at 15°C for 12 hours at arrival to remove field heat before storage. Produce was then randomly separated into three equal batches of 7 kg for each replications. Time frame between harvest and cooling was around three-hour. Tomatoes were then kept in a refrigerator (RSNE445E22, Beko fridge) at 15°C and 30 to 80% of relative humidity for 18 days until 30% quantitative PHL occurred. Six tomatoes from each replication (r = 3) were analysed for weight loss, colour and firmness.

2.4 Data collection

2.4.1 Weather conditions

Temperature (°C) and relative humidity (%) values were recorded at one minute interval along the SC during the load tracking and assessment period. Temperature was recorded using data logger (HOBO® temp, UX100-001, accuracy: ± 0.21°C from 0° to 50°C, range: –20°C to 70°C, USA) and relative humidity was measured using temp/RH data logger (UX100-011, accuracy: ± 2.5% from 10% to 90% typical to a maximum of ± 3.5%, range: 1% to 95%, USA).

2.4.2 Postharvest handling practices of tomato implemented in the study areas

PH handling practices of tomatoes during harvest (harvest stage and time, harvest method), sorting/grading, loading-unloading, as well as handling practices at wholesale and retail levels were documented through observation and key informant interview.

2.4.3 Determination of quantitative loss

2.4.3.1 Determination of quantitative postharvest loss (QPHL)

PHLs of tomatoes were estimated as a percent in weight basis at each stage of the SC. Any tomatoes which was unmarketable due to visible decay or severe injury and not preferred by customers was regarded as a produce loss. PHLs was calculated using equation (1) and expressed as percent. Total PHLs of tomato was estimated by summing percent of losses at each stage of the SC.

$$PHL(\%) = \frac{W_{unmarkatable}}{W_T} \times 100 \quad (1)$$

where

$W_{unmarkatable}$ weight of unsalable tomato because of physical injury (including bruising and wilting), diseases and insect pests (kg).

W_T total weight of harvested tomatoes (kg).

2.4.4 Qualitative loss assessment

2.4.4.1 Weight loss

The weight loss of tomatoes was estimated according to Javanmardi and Kubota (2006). A total of eight representative tomatoes from each treatment per replicate were randomly taken on farm and their weight loss was measured at each stage of the SC. The weight loss was estimated using equation (2) and expressed as percent.

$$Weight\ Loss(\%) = \frac{Initial\ weight\ of\ tomatoes - Final\ weight\ of\ tomatoes}{Initial\ weight\ of\ tomatoes} \times 100 \quad (2)$$

2.4.4.2 Colour

Colour of the tomato was analysed according to the method described by Khairi et al. (2015) using colourimeter (CM-600d spectrophotometer, Konica Minolta, Tokyo, Japan). For each treatment, eight tomatoes were measured from each stage of the SC and scanned to determine the average L*, a*, and b* values. Redness values of tomatoes were reported as (a*/b*).

2.4.4.3 Firmness

Firmness of tomato was measured according to the method described by Kitinoja and Hussein (2005) (texture analyser, TA-XT plus, stable micro system texture analyser, Godalming, surrey GU7 1YL, UK) with 2 mm diameter flat plate round stainless steel probe. A total of 6 tomatoes from each treatment per replication were measured from each stage of the SC. The mean value was recorded and presented as newton (N).

2.4.4.4 pH

The pH of the tomato juice was determined as described by Rangana (1979) using digital pH meter with a glass electrode (PHS-25CW, Benchtop pH/mV meter, Shanghai, China).

2.4.4.5 Titratable acidity

The titratable acidity (TA) of tomato juice was measured following the method developed by Rangana (1979) with some modifications. 50 ml of filtered tomato juice was titrated with standard 0.1M NaOH up to an endpoint of pH 8.2 using digital pH meter (PHS-25CW, Benchtop pH/mV meter, Shanghai, China).

2.4.4.6 Total soluble solids

The total soluble solids (TSS) of tomatoes were determined as described by Rangana (1979) using a digital portable refractometer (PAL-1, Atago, Japan).

2.4.4.7 Vit-C content

Vitamin-C (Vit-C) content (mg/100g) was measured using a method described by Khan et al. (2006) using UV-Vis Spectrophotometer (Agilent technology, G6860A, Serial No: MY15400019, Cary 60 UV-Vis, Malaysia) at an absorbance of 521 nm.

2.5 Data analysis

The data were subjected to a two-way analysis of variance to determine the combined effects of SC and growing locations on quantitative and qualitative PHLs of tomatoes using SAS version 9.2 software (Cary, NC, USA). To separate the means Tukey HSD test was used at $p < 0.05$ for treatments revealed a significant difference. For the storage study data are presented as mean ± standard deviations.

3 Results and discussion

3.1 Postharvest handling practices of tomato implemented in the study areas

Based on information collected from the key informant interviews and field observation, the major postharvest handling practices of tomatoes along the SC in the study districts consist of harvesting, sorting, field packing and loading, transportation, handling practices at wholesaler and retailer levels are presented in Figures 2 and 3.

3.2 Weather conditions along the SC

Temperatures and relative humidity values recorded along the SC during the sampling period are presented Table 1. Generally, the recorded temperature was above 20°C (average of 24°C) and all the district experience low relative humidity (average of 41.48%). Temperature varied from 23.94 to 25.19°C at the farm, 22.94 to 24.39°C throughout transportation, 22.49 to 24.10°C at wholesale, and 22.90 to 25.51°C at retail levels with a relative humidity ranging from 30.46 to 57.24% (Table 1). Weather conditions along the SC did not differ significantly in all districts. The recorded temperatures along the SC were relatively high while the relative humidity was below the recommended handling condition for tomato. Optimal temperature and relative humidity for keeping and storing tomatoes at all ripening stages is between 10°C to 15°C and 85% to 95%, respectively (Kader, 2002; Nunes et al., 2009). Temperatures above 10°C and low relative humidity results in weight loss due to high transpiration rate, hasten deterioration, increase the rate of loss of nutritional quality and reduce the shelf life of the product (Kader, 2002; Nunes et al., 2009).

Figure 2 Tomato SC activities from farming to field packing in the study districts (see online version for colours)

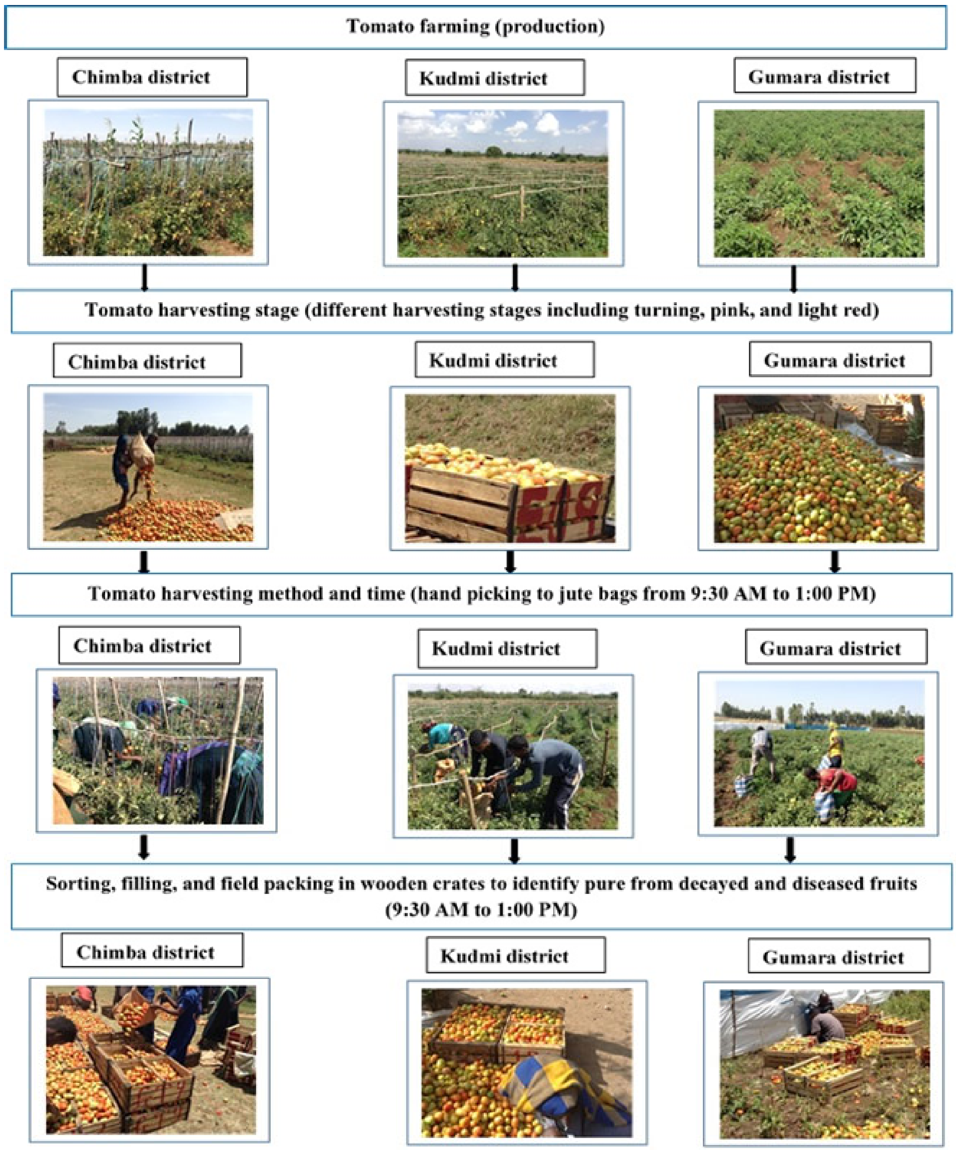


Figure 3 Tomato SC activities from loading to retail marketing in the study districts (see online version for colours)

Table 1 Weather conditions (mean ± standard deviations) along the SC of tomatoes from selected districts in Ethiopia

Supply chain (SC)	*Chimba district*		*Gumara district*		*Kudmi district*	
	Temperature (°C)	*Relative humidity (%)*	*Temperature (°C)*	*Relative humidity (%)*	*Temperature (°C)*	*Relative humidity (%)*
Farm	23.94 ± 0.76	57.24 ± 6.58	25.19 ± 0.84	33.40 ± 1.55	24.85 ± 0.67	52.33 ± 2.66
Transportation	22.95 ± 0.07	30.46 ± 1.58	22.94 ± 0.26	37.82 ± 0.47	24.39 ± 0.22	34.69 ± 6.87
Wholesale	22.49 ± 0.86	46.54 ± 13.25	23.44 ± 1.11	38.45 ± 4.22	24.10 ± 1.08	40.74 ± 11.91
Retail	22.90 ± 2.18	54.90 ± 13.49	25.51 ± 3.06	34.88 ± 5.97	25.26 ± 2.49	36.30 ± 10.83

3.3 Quantitative loss

3.3.1 QPHLs of tomatoes

QPHLs of tomatoes was significantly ($P < 0.0001$) influenced by the interaction effect of growing location and SC. QPHLs of tomatoes ranged between 1.23 and 12.58% along the SC and growing locations (Table 2). Relatively higher PHL was observed at farm level in Gumara (8.62%) which might be related with the tomato growing practice used in the district. The bulk of tomatoes were directly in contact with the ground, tomatoes were not properly staked in this district, which results in bruises, damages, and decay of tomatoes. Staking can make spraying and harvesting easier, increase yield and percentage of marketable tomatoes (Sowley and Yahaya, 2013) by reducing the incidence and severity of blight and soil-borne disease (Lyimo et al., 1998). Another reason for the high PHL might be associated with inappropriate harvesting time, lack of harvesting skills and use of inappropriate packaging materials with firm and cutting surfaces which cause mechanical damages to tomatoes. In addition, insect pests and diseases are some of the noticeable factors triggering losses at the farm. This observation was in line with reports of Abera et al. (2020) and Bantayehu et al. (2019). The magnitude of QPHL at the farm stage recorded in this study are consistent with previous studies by Kitinoja and Cantwell (2010) from Rwanda (7.8%), and Addo et al. (2015) from Ghana (4.6 to 10.85%).

During transportation, significantly higher (8.24%) PHL of tomatoes was observed when the tomatoes were transported from Chimba to Bahir Dar compared to other districts (Table 2). This might be caused by poor packaging system, road access, and means of transportation (the districts used animal carts, public bus and trucks for transportation). Higher mechanical injury was observed due to over-filling of tomatoes in wooden boxes. This finding corresponds to the result reported by Abera et al. (2020), Kasso and Bekele (2018), and Macheka et al. (2013). In addition, the findings of this study is in agreement with Pathare and Al-Dairi (2021) and Pretorius and Steyn (2019) who reported that long distance of bumpy road increased the loss of the transported tomatoes due to high vibration and impact. The magnitude of PHL recorded during transportation are similar with that described by Addo et al. (2015) (2.3 to 7.4%).

At wholesale and retail level, QPHL of tomatoes was significantly higher for samples which came from Gumara compared to Chimba and Kudmi (Table 2). This may be associated with the tomato growing practice, and suboptimal handling practices by the farmers in the area (relatively low relative humidity and high temperature) which accelerates physiological damage of the tomatoes. Besides, the loss at levels of wholesaler and retailer in the market was linked with poor handling system, packaging, and storage systems. In addition, inadequate sanitation and hygiene situations, and presence of rodents which all have a cumulative effect to accelerate the PHL. Abera et al. (2020), Bantayehu et al. (2019) and Kasso and Bekele (2018) reported a similar result. Furthermore, the magnitude of PHL (3.35 to 4.30%) recorded in our study in agreement with the findings reported by Buntong et al. (2013) at wholesale level in Cambodia (3.5%). Tomato temperature monitoring is reported as a crucial factor in postharvest quality control systems (Toor and Savage, 2006). Higher postharvest storage temperature had a substantial effect on the extent of tomato PHLs along the SC, which was observed in this study (Table 1).

Table 2 Postharvest losses of tomatoes

Supply chain (SC)	*Districts (D)*	*QPHL (%)*
Farm	Chimba	6.17^{e}
	Gumara	8.62^{cd}
	Kudmi	7.15^{ed}
Transportation	Chimba	8.24^{cd}
	Gumara	1.23^{h}
	Kudmi	2.66^{gh}
Wholesale	Chimba	3.35^{gf}
	Gumara	4.30^{f}
	Kudmi	3.78^{gf}
Retail	Chimba	9.38^{cb}
	Gumara	12.58^{a}
	Kudmi	10.28^{b}
*P-value (S*D)*		*< 0.0001*
SE ±		*0.27*
CV (%)		*8.32*

Notes: Means in a column with different superscript letters are significantly different ($p < 0.05$). The results are reported as means of quadruplicate determinations. QPHL = quantitative postharvest loss (%), CV (%) = coefficient of variation, SE = standard error.

In this study, the total QPHLs along the SC for tomato were obtained from Gumara (26.72%), Kudmi (23.88%), and Chimba (27.21%) districts with a mean aggregate PHLs of 25.91% within five days of storage period and retailing of tomato. This finding is comparable with that reported by Buntong et al. (2013) from Cambodia (23%) and Sharma et al. (2005) from India (11.9 to 21.4%). In conclusion, minimising the PHLs of tomatoes by adoption of postharvest technologies (Nyamah, 2020) and improving marketing channels is very important to increase the income and profitability of small holder farmers and other stakeholders involved along the SC as well as important for employment generation and food security. This is in line with the recommendations of Mohammed Kassaw et al. (2019) that was studied in the same areas.

3.4 Qualitative loss

3.4.1 Weight loss

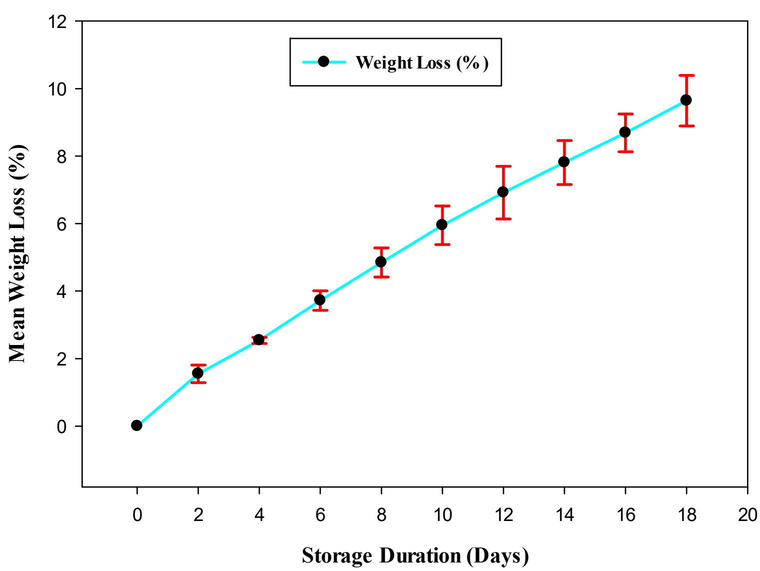
In this study, weight loss of tomato was significantly ($P < 0.01$) influenced by interaction effects of growing location and SC. The weight loss values of tomatoes ranged from 0.57 to 5.19% along the SC as indicated in Table 3. Considering all growing locations, the mean weight loss value of tomatoes significantly increased along the SC (Table 3). After 5 days of handling the tomatoes along the SC, the weight loss values were in the range of 4.73 to 5.19%. Besides, the weight loss percentage values were higher (0.91%) in tomatoes transported from Chimba district than other districts at the farm level due to long transport distance. This is in line with reports of Pathare and Al-Dairi. (2021).

Table 3 Weight loss, colour and firmness of tomatoes

Supply chain (SC)	*Districts (D)*	*WL*	*Tomato colour*				*Firmness (N)*
			*L**	*a**	*b**	*a*/b**	
Farm	Chimba	0.91^{d}	48.02^{bc}	9.96	31.73	0.31^{c}	7.77^{a}
	Gumara	0.72^{ed}	52.43^{a}	4.89	33.47	0.15^{d}	8.02^{a}
	Kudmi	0.57^{e}	50.60^{ba}	7.79	32.66	0.24^{dc}	7.87^{a}
Wholesale	Chimba	2.94^{c}	44.05^{de}	21.15	29.60	0.71^{b}	6.62^{b}
	Gumara	3.17^{c}	43.98^{de}	20.25	31.02	0.66^{b}	6.02^{c}
	Kudmi	3.04^{c}	46.27^{dc}	19.78	29.74	0.67^{b}	6.3^{5cb}
Retail	Chimba	4.73^{b}	39.90^{f}	25.79	25.03	1.03^{a}	4.92^{d}
	Gumara	5.19^{a}	40.83^{f}	25.18	24.70	1.02^{a}	4.56^{d}
	Kudmi	4.88^{b}	41.90^{fe}	24.83	25.02	1.00^{a}	4.74^{d}
*P-value (S*D)*		*< 0.01*	*< 0.01*	*0.07*	*0.52*	*< 0.05*	*< 0.01*
SE ±		*0.04*	*0.53*	*0.82*	*0.66*	*0.02*	*0.09*
CV (%)		*2.93*	*2.34*	*9.24*	*4.52*	*7.74*	*2.90*

Notes: Means in a column with different superscript letters are significantly different ($p < 0.05$). The results are reported as means of quadruplicate determinations. WL = weight loss (%), SE = standard error, CV (%) = coefficient of variation.

Figure 4 Changes in weight loss (%) of tomatoes during storage at 15°C (see online version for colours)



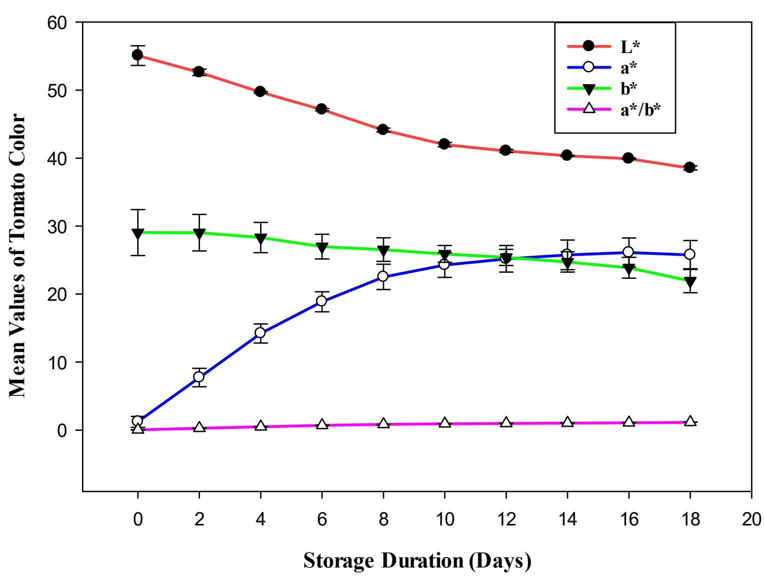
Tomatoes harvested at turning stages from Chimba district and stored at 15°C for 18 days showed a sharp and linear increase in weight loss value from 0.00 to 9.64% (Figure 4). At 15°C storage, the weight loss after six days was 3.72% which was lower than the weight loss value observed within five days of handling along the SC, clearly showing the importance of low temperature storage. This is due to fact that storing tomatoes at relatively low temperature (15°C) reduces physiological respiration and transpiration and thus reduces PHLs as indicated by Tolasa et al. (2021). Similar results were also reported by Javanmardi and Kubota (2006) where weight loss of tomatoes stored in ambient conditions was faster than those stored in cold storage (10°C to 12°C; 92% to 95% RH). The weight loss values were generally increasing with storage period and higher storage temperature in the present study, which is also in accordance with reports of Pinheiro et al. (2013). Weight loss in vegetables is driven by transpiration and respiration and such processes are dependent on both temperature and relative humidity (Javanmardi and Kubota, 2006). Moreover, mechanical injuries influence the respiration rate that causes unwanted metabolic processes that facilitates ripening and weight loss (Opara and Pathare, 2014).

3.4.2 Colour

In the present study, a significant ($P < 0.01$) difference in tomato colour lightness (L*) value was existed between interaction effect of the growing location and SC. Tomato colour L* value harvested from the studied districts ranged between 39.90 and 52.43 (Table 3). After five days of handling along the SC, the L* value was in the range of 39.90 to 41.90. Considering the growing locations, there was a decrease in tomato colour L* value along the SC.

The tomatoes harvested at turning stage from Chimba district and stored at 15°C for 18 days showed a decrease in tomato colour L* value from 55.08 to 38.55 (Figure 5). At this storage temperature the L* value was changed to 47.13 within six days of storage. The decrease in tomato colour L* value was associated with increased storage period and temperature which results in an increase in the darkening of tomatoes due to carotenoid synthesis during storage (Khairi et al., 2015; Pinheiro et al., 2013).

Figure 5 Changes in tomato colour during storage at 15°C (see online version for colours)



Tomato colour a* and b* did not show any significant ($P > 0.05$) difference between interaction effects of growing location and SC. Tomato colour a* value was varied from 4.89 to 25.79, whereas b* value was in the range of 24.70 to 33.47 (Table 3). After five days of handling along the SC, the a* and b* colour values were varied from of 24.83 to 25.79 and 24.70 to 25.03, respectively. There was a significant increase and decrease in tomato colour a* and b* value along the SC, respectively.

The tomatoes harvested at turning stage from Chimba district and stored at 15°C for 18 days showed an increase and decrease in tomato colour a* and b* value from 1.24 to 25.76 and 29.05 to 21.97, respectively (Figure 5). Within 6 days of storage at this temperature a* and b* values were 18.88 and 27.01, respectively and clearly showed the benefit of low temperature storage in maintain tomato colour. The increase in colour a* and decrease in colour b* value was due to increase storage period and temperature. This results in intense red colour development due to continue of ripening (Majidi et al., 2014; Pinheiro et al., 2013).

There were a significant differences ($P < 0.05$) in tomato colour a*/b* value between interaction effects of growing location and SC. Tomato colour a*/b* value varied from 0.15 to 1.03. Considering all the growing locations, there was a slight increase in tomato colour a*/b* value along the SC (Table 3).

Similarly, tomatoes harvested at turning stage from Chimba district and stored at 15°C for 18 days exhibited a slight increase in tomato colour a*/b* value from 0.04 to 1.17 (Figure 5). Batu (2004) stated that Minolta colour a*/b* values increased with an increase in USDA colour stages due to increased storage times and temperatures (Khairi et al., 2015). This results development of red colour (López Camelo and Gómez, 2004).

3.4.3 Firmness

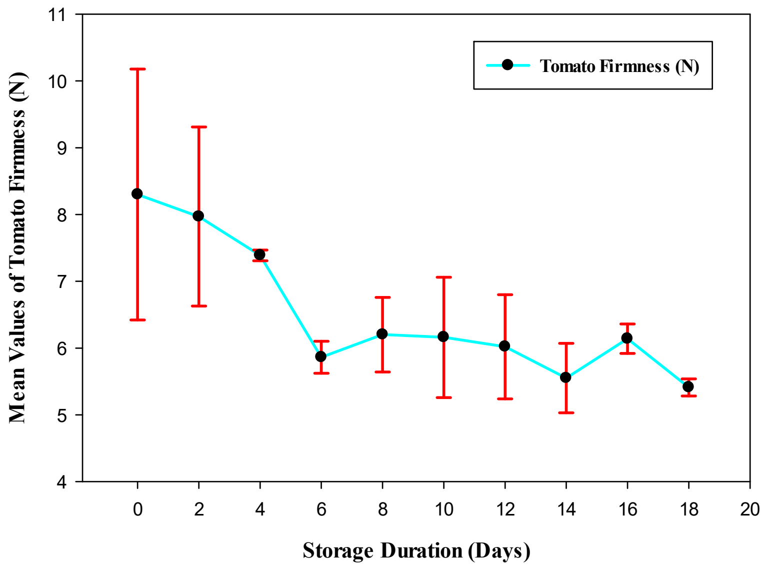
There is a significant ($P < 0.01$) interaction effect among growing location and SC in firmness of tomatoes. Tomato firmness value ranged between 4.56 and 8.02 N along the SC. Considering all the growing locations, there was a significant decrease in tomato firmness value along the SC (Table 3). After five days of handling along the SC, the firmness value was in the range of 4.56 to 4.92 N.

The tomatoes harvested at turning stage from Chimba district and stored at 15°C for 18 days showed a decrease in firmness value from 8.30 to 5.41 N (Figure 6). In this study, tomato stored at 15°C for 18 days were firmer than SC studies stored at ambient temperature for five days. After six days storage at this storage temperature, the firmness value was 5.86 N, clearly showed the advantages of low temperature storage in minimising firmness loss. In the current study, the firmness of tomato progressively decreased with increase in storage period, temperature and maturity. This result is in line with Pathare and Al-Dairi (2021) and Lahaye et al. (2013). The decrease in tomato firmness was associated with high respiration rate, loss of moisture through transpiration, senescence and breakdown of the tomato cell wall during ripening (Alenazi et al., 2020).

3.4.4 pH value

The result of this study did not exhibit a significant ($P > 0.05$) difference in pH value of tomatoes between interaction effects of growing location and SC. At retail level tomatoes from Chimba district had the highest pH value (4.59), followed by Kudmi (4.53), and Gumara district (4.50). On the other hand, at farm level tomatoes from Kudmi showed the lowest pH value (4.33) (Table 4). The pH value of tomatoes increased from 4.33 to 4.59 along the SC. The pH value of tomatoes in our study increased with an increased in tomato ripening and storage periods which is in agreement with findings of Tolasa et al. (2021) and Tolesa and Workneh (2017). The rise in pH value may be due to different organic acids absorbed during respiration in to sugars and the enzymatic breakdown of pectin during the storage period (Albertini et al., 2006).

Figure 6 Changes in tomato firmness (N) during storage at 15°C (see online version for colours)



3.4.5 TA content

The titratable acidity (TA) of tomatoes from the three growing locations ranged from 0.22 to 0.38%. At farm level, tomatoes from Kudmi district exhibited the highest TA value (0.38%), followed by those from Gumara district (0.36%), and Chimba district (0.34%). At retail level, tomatoes from Chimba district had the lowest TA value (0.22%) (Table 4). There was a decrease in tomato TA values along the SC associated with advancement of maturity with an increase in storage time and temperature, which is in line with the findings of Al-Dairi et al. (2021) and Tolesa and Workneh (2017). Increased storage period and temperature could increase tomato ripening which is oppositely related to the acidity of fresh produce (Sinha et al., 2019).

3.4.6 TSS content

Total soluble solid (TSS) values of tomatoes from the three districts in the range of 4.13 to 4.69%. At retail level, tomatoes from Chimba district showed the highest TSS value (4.69%), followed by Kudmi district (4.63%) whereas at farm level from Kudmi district had the lowest total soluble solid value of tomatoes (4.13%) (Table 4). There was a gradual increase in TSS of tomatoes from farm to retail. The increase in TSS can be associated with ripening of the tomatoes (Al-Dairi et al., 2021). Ripening leads to the degradation of pectin substances into simple sugars, thus increasing the TSS content (Javanmardi and Kubota, 2006).

Table 4 pH, TA, TSS, and vitamin-C content of tomatoes

Supply chain (SC)	*Districts (D)*	*pH*	*TA*	*TSS*	*Vit-C*
Farm	Chimba	4.41	0.32	4.34	10.03
	Gumara	4.37	0.36	4.16	9.20
	Kudmi	4.33	0.38	4.13	9.66
Wholesale	Chimba	4.49	0.29	4.56	8.38
	Gumara	4.43	0.33	4.31	7.44
	Kudmi	4.40	0.34	4.41	8.16
Retail	Chimba	4.59	0.22	4.69	4.60
	Gumara	4.50	0.27	4.53	4.05
	Kudmi	4.53	0.25	4.63	4.41
*P-value (S*D)*		*0.16*	*0.08*	*0.22*	*0.65*
SE ±		*0.01*	*0.01*	*0.04*	*0.15*
CV (%)		*0.58*	*5.18*	*1.66*	*4.00*

Notes: Means in a column with different superscript letters are significantly different ($p < 0.05$). The results are reported as means of quadruplicate determinations. TA = titratable acidity (%), TSS = total soluble sloid (%), Vit-C = vitamin-C (mg/100g) SE = standard error, CV (%) = coefficient of variation.

3.4.7 Vit-C content

Vitamin-C (Vit-C) content of tomatoes sampled from the three districts varied from 4.05 to 10.03 mg/100g and the highest content was recorded for tomatoes obtained from Chimba district at farm level. At retail level, tomatoes from Gumara district showed the lowest Vit-C content (4.05 mg/100 g) (Table 4). The Vit-C content values observed at farm level were comparable with that reported by Vanderslice et al. (1990) for fresh tomatoes (10.60 mg/100 g). The content of tomato ascorbic acid continues to decrease once the product begins to senescence or mechanically stressed (Kader, 2002). There was a gradual loss of Vit-C content along the SC. The decrease in Vit-C content may be due to exposure to prolonged storage at higher temperatures, transport in open-air vehicles and open-air market sales which is in line with findings by Opara et al. (2012) and Mditshwa et al. (2017). Besides, the loss of Vit-C can be magnified by water loss due to high enzymatic oxidation (Nunes et al., 1998).

3.5 Pearson correlation coefficient analysis

The Pearson correlation coefficients between the quantitative and qualitative loss parameters along the SC and storage studies are presented in Tables 5 and 6.

QPHL showed a positive correlation with weight loss ($r = 0.429$), colour a* ($r = 0.205$), colour a*/b* ($r = 0.369$), pH ($r = 0.391$), and TSS ($r = 0.269$) at $P < 0.05$ (Table 5). However, QPHL revealed a negative correlation with colour L* ($r = –0.305$), colour b* ($r = –0.585$), firmness ($r = –0.482$), TA ($r = –0.460$), and Vit-C ($r = –0.663$) at $P < 0.01$ (Table 5).

Table 5 Quality parameter values Pearson correlation coefficients along the SC

	QPHL	*WL*	*L**	*a**	*b**	*a*/b**	*Firmness*	*pH*	*TA*	*TSS*	*Vit-C*
QPHL											
WL	0.429ns										
L*	–0.305ns	–0.950**									
a*	0.205ns	0.966**	–0.972**								
b*	–0.585ns	–0.951**	0.916**	–0.894**							
a*/b*	0.369ns	0.990**	–0.974**	0.984**	–0.957**						
Firmness	–0.482ns	–0.994**	0.943**	–0.947**	0.954**	–0.980**					
pH	0.391ns	0.864**	–0.912**	0.856**	–0.891**	0.892**	–0.845**				
TA	–0.460ns	–0.850**	0.898**	–0.829**	0.911**	–0.879**	0.838**	–0.991**			
TSS	0.269ns	0.869**	–0.909**	0.896**	–0.900**	0.912**	–0.836**	0.957**	0.956**		
Vit-C	–0.663ns	–0.953**	0.871**	–0.853**	0.953**	–0.925**	0.969**	–0.837**	0.841**	–0.784*	

Notes: *. Correlation is significant at $P < 0.05$ **. Correlation is significant at $P < 0.01$.
ns = not significant.
QPHL = quantitative postharvest losses, WL = weight loss, TA = titratable acidity, TSS = total soluble solid, Vit-C = vitamin-C.

Similarly, for the quality parameters stored at 15°C, weight loss correlated positively with colour a* (r = 0.925) and colour a*/b* (r = 0.970), but negatively correlated with colour L* (r = –0.981), colour b* (r = –0.974), and firmness (r = –0.881) at P < 0.05 (Table 6).

Table 6 Storage quality parameter values Pearson correlation coefficients at 15°C

	WL	*L**	*a**	*b**	*a*/b**	*Firmness*
WL						
L*	–0.981**					
a*	0.925**	–0.974**				
b*	–0.974**	0.933**	–0.846**			
a*/b*	0.970**	–0.994**	0.988**	–0.917**		
Firmness	–0.881**	0.921**	–0.940**	0.852**	–0.942**	

Notes: **. correlation is significant at P < 0.01. WL = weight loss.

4 Conclusions

QPHLs of tomatoes in the study districts ranged from 23.88 to 27.21% with mean overall loss of 25.91% throughout the SC. Loss at the retail level was the highest (9.38 to 10.28%) followed by loss at the farm level (6.17 to 8.62%). Our findings show a significant decrease in tomato firmness, colour (L* and b* values), TA and Vit-C content from farm to retail levels. On the other hand, there was a significant increase in weight loss, colour (a* and a*/b*), pH and TSS values along the SC.

This study could be used as a basis and provide valuable information on PHLs of tomatoes to farmers, wholesaler, retailer, researchers, policy makers, and other actors involved in the SC for possible intervention. This could lead to application of appropriate low-cost technologies at the appropriate stages of the SC of tomato to reduce the loss. Besides, training or awareness creation regarding appropriate handling and storage practices of tomatoes should be given to actors at all levels to minimise both quantitative and qualitative PHLs along the SC.

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