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Full Length Research Paper

Effects of variety on yield, physical properties and storability of tomato under ambient conditions

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Three processing and six fresh market tomato varieties were evaluated for yield and related traits. The tomato varieties harvested at "mature green" stage were evaluated for changes in physical quality characteristics during the storage period of 32 days under ambient conditions. Both field and storage studies were undertaken using randomized complete block design with three replications. Physical properties including average fruit weight, fruit volume, specific gravity, juice content and weight loss were assessed during the storage period. The storage room air temperature and relative humidity varied from 15.4 to 16.2°C and 34.8 to 52.4%, respectively. Tomato varieties had significant ($P \leq 0.001$) effects on yield and quality. Fresh market tomato variety *Fetane* was the highest yielder. *Marglobe Improved* had the highest physical quality characteristics while *Fetane* showed the lowest values. The highest weight loss was obtained in Metadel compared with all other varieties throughout the storage period. Melkashola had the highest physical quality characteristics than the other two processing varieties while weight loss was almost similar with *Roma VF* during most of the storage periods. Fresh market tomato fruits had superior physical quality characteristics such as higher fruit weight, volume, specific gravity and juice content than processing fruit varieties. Weight loss was the lowest for processing tomatoes during storage which is an indicator of better shelf life.

Key words: Tomato, pre-harvest, postharvest, yield, quality, variety.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) belongs to the family Solanaceae. It is one of the worlds major vegetables with a total area and production of 4.4 million ha and 115 million metric tones, respectively (FAO, 2004). The climatic and soil conditions of Ethiopia allow cultivation of a wide range of fruit and vegetables including tomato. In 2005, tomato production in Ethiopia reached about 35,407 metric tones from a total harvested area of 4788 ha. There is a vast potential for the internal market for domestic fresh tomato fruit primarily in densely populated urban areas and for the processing industries for foreign market, such as Djibouti and Somalia (Workneh, 2002).

Tomatoes are grouped into two major categories (the determinate (bush) and the indeterminate (tall) groups). Determinate tomatoes, including both processing and fresh market types, are smaller and more compact than indeterminate varieties (Atherton and Rudich, 1986). The indeterminate varieties are mostly used in field and greenhouse production in areas where high quality fresh fruit are required for salad and when there is adequate manual labor for staking the plants and picking the fruit over a prolonged marketing period (George, 1989).

A number of factors affect the yield and quality of tomato fruits of which genotypic variability is the most important one. There exists a lot of variation in tomato varieties for yield characteristics. Moore et al. (1958) reported significant differences in some fruits yield and

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quality parameters among different varieties tested. The influence of variety on yield and quality has been documented (Stevens et al., 1977). Fruit number and weight (Balibrea et al., 1997) determine the yield of tomato. There is positive correlation between fruit number and yield. Adedeji et al. (2006) indicated that important quality parameters of tomato fruits varies with the types of cultivar including fruit size, volume, juice, specific gravity, maturity etc. The author also explained that factor such as specific gravity, juice, fruit size are specific to a variety which can be used to determine maturity stages and schedule harvest. Absence of defects like sunburn, cracks, blossom end rots; decays, etc are also important criteria for marketable quality of tomato fruits (Duguma, 2000).

Nowadays, several tomato varieties are released nationally and have been recommended by Melkasa Agricultural Research Center for commercial production and small scale farming systems in Ethiopia. Tomato production has been restricted to certain regions of the country because of several reasons among which traditional postharvest handling technologies and resulting losses are problems that deserve attention. Thus, these necessitate evaluation of these varieties for yield, physical as well as storability under natural environmental conditions. Moraru et al. (2004) also indicated that the performance of each cultivar should be evaluated using growth and yield indicators such as physical in order to identify the most appropriate cultivar for direct consumption, processing and for commercial production. Therefore, this study was initiated to partly fill the information gap through evaluating growth, yield, physical characteristics of nationally released six fresh markets (non-processing) and three processing tomato varieties in the eastern part of the country. The specific objective of the study was to compare yield and physical quality of six fresh markets and three processing types of tomato varieties.

MATERIALS AND METHODS

Experimental material and field design

Seeds of three processing (*Roma VF*, *Melkasalsa* and *Melkashola*) and six fresh market (*Metadel*, *Eshete*, *Marglobe Improved*, *Fetane*, *Heinz-1350* and *Bishola*) tomato varieties were raised in a glass house for about two weeks and were pricked into nursery bed. Simultaneously, the experimental plot field land was ploughed, leveled and prepared for the field experiment. The plot size was 4.5 m × 5 m with a total number of 60 plants per plot at spacing of 75 cm between rows and 50 cm between plants. The spacing between plots in each replication and between adjacent replications was 1.5 and 2 m, respectively. Seedlings were transplanted to the main field using Randomized Complete Block Design with three replications. The inorganic fertilizers, diammonium phosphate (DAP) and urea were applied to each plot at the rate of 92 kg ha^{-1} P_2O_5 and 96 kg ha^{-1} N, respectively. Other agronomic practices (weeding, cultivation, furrow irrigation, staking, etc.) were applied during the growth season to all plots uniformly. Plots were irrigated every other day for the first two weeks and then at weekly intervals.

Recommended fungicides (Ridomil+- MZ 63% -3.5kg ha^{-1}) to control leaf disease (blight) and cypermethrin (100 g.a.i ha^{-1}) to control insect pests (ball worm aphids) were sprayed at seven days intervals from transplanting to 20 days before first harvest.

Field experiment data collection

The following agronomical data were recorded from the central four rows sixteen randomly taken plants per plot of each variety and their mean value was recorded for statistical analysis. Days to first harvest or maturity (DFH) was recorded as number of days from field planting to first picking of fruits from 50% of the sample plants. Number of cluster per plant (CP) was the number of clusters per plant counted at physiological maturity using randomly taken sample plants. Number of fruits per cluster (FC) was the total numbers of fruits per cluster counted at physiological maturity using randomly taken sample plants. Number of harvests was recorded as the number of harvests from first picking to final picking. Duration of harvest was recorded as the number of days taken starting from first picking to final picking. Total number/weight of fruits was calculated as the sum total number/weight of fruits of successive harvests from the central four rows, which was used to calculate yield per hectare. Marketable and unmarketable fruit number and weight was at each harvest time, fruits were categorized as marketable and unmarketable fruits. Fruits with cracks, damaged by insect, diseases, birds and sunburn as well as extra small sized fruits or under sized fruits (fruit sizes less than 99 g for round types and less than 50 g for plum or Roma types of tomato) (USDA, 1991; University of California, 2004) etc. were considered as unmarketable. Those, which were free from visible damage and size more than the minimum indicated above, were considered as marketable. Mean fruit size was randomly taken sample fruits per plot were measured during peak harvest and the mean value was used to calculate mean fruit size. The size of the fruit was determined using a vernier caliper (Model CD-6[11]P Mintotyo corp.). The diameter was measured along the longitudinal (stem to blossom end) and cross-sectional axis (transverse diameter).

Postharvest experiments and data collection

Treatments and design

Fruits of the three processing and six fresh market tomato varieties grown at Dire Dawa were obtained from the central four rows per plot. Sample fruits harvested at mature green stage were analyzed for five physical quality parameters. Uniform unblemished fruits having similar size and colour were taken and hand washed with tap water to remove field heat, soil and to reduce microbial populations on the surface and then stored under ambient conditions using Randomized Complete Block Design with three replications at Haramaya University. Each variety had a sample size of 90 fruits per replication, which were assessed for shelf life over the storage period. On each sampling date, seven fruits per experimental unit were randomly taken from each replication for physical quality analysis at four days interval during 32 days under ambient conditions.

Data collection

Temperature and relative humidity

The storage air temperature and the relative humidity were measured throughout the storage period. Temperature was recorded using digital psychrometer (ALNOR® Model 8612 S/N03057107) to record ambient temperature. Over the entire

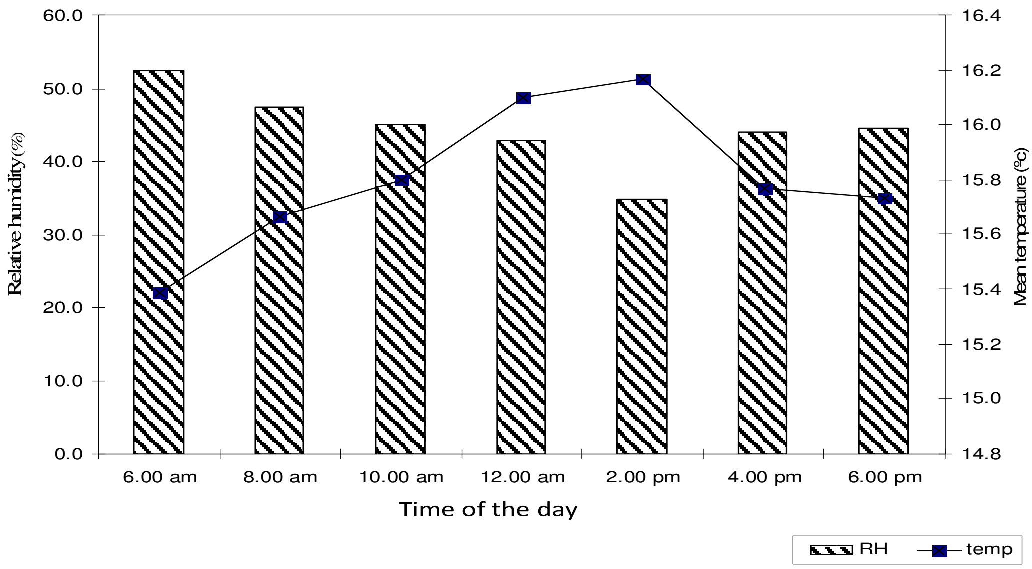

Figure 1. Daytime relative humidity (%) and mean temperature (°C) of the storage room during a storage period of 32 days at Haramaya University; data are means of three replications.

period of the study, the readings were taken in 2 h interval of only the daytime. The relative humidity of the air was monitored using the same psychrometer that was used for temperature measurement.

Fruit weight

Five sample fruits of each variety per replicate were randomly taken and the average fruit weight (g) was recorded at four days interval during the storage period of 32 days under ambient conditions.

Fruit volume

Five sample fruits of each variety per replicate were randomly taken and floated in a water jar and their displacement was recorded at four days interval during the storage period of 32 days under ambient conditions. Average fruit volume (ml) was taken by subtracting the initial water level in the jar from the final and by the number of fruit immersed.

Fruit specific gravity

Specific gravity of tomato fruits was determined every four days during the storage period of 32 days under ambient conditions by calculating the ratio of weight of the fruit to volume of the fruit (g ml^{-1}).

Fruit juice content

The juice of five randomly taken sample fruit from each replication was extracted using a juice extractor (6001x Model No. 31JE35 6x.00777). After extraction, extracted juice was measured using a graduated glass cylinder at four days interval during the storage period of 32 days under ambient conditions. The intact tomato fruit weight was also recorded prior to juice extraction. Then, juice content was expressed in milliliter of juice per kilogram of fruit weight (ml kg^{-1}).

Weight loss

Physiological weight loss of fruits was recorded at four day interval over the storage period of 32 days under ambient storage conditions. Weight loss (WL) was determined using the methods as described by Pirovani et al. (1997). The percentage weight loss was calculated for each sampling interval using the formula given below and the cumulative weight loss was expressed as the percentage for the respective treatments.

$$WL = \frac{W_i - W_f}{W_i} x100\,\%$$

where; Wi = initial weight, and Wf = final weight.

Statistical analysis

Significance tests were made by analysis of variance (ANOVA) for RCBD with SAS (SAS Corporation, Cary, NC, USA version 6.12 TS020) software (SAS, 1996). Comparisons of the treatment means were done using Duncan's multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Temperature and relative humidity

Figure 1 displays daytime average air temperature and relative humidity of storage room during the storage of tomato fruit at Haramaya University. The storage room air temperature and relative humidity varied from 15.4 to16.2°C and 34.8 to 52.4%, respectively. The temperature of the storage room was in the range that was previously reported by Tefera et al. (2007) for evaporatively cooled

Table 1. Plant characters and yield components of processing and fresh market tomato varieties

Tomato variety	DFH (days)	DH (days)	NH (No.)	TRD (cm)	LGD (cm)	CL/P (No.)	F/CL (No.)
Processing							
Roma VF	71.67^{cd}	55.00^{c}	7.85^{b}	4.16^{c}	5.84^{a}	33.98^{b}	4.12^{b}
Melkasalsa	70.00^{d}	56.67^{b}	7.95^{b}	3.30^{d}	5.32^{abc}	53.24^{a}	4.85^{a}
Melkashola	72.33^{c}	54.23^{c}	7.77^{b}	4.42^{c}	5.72^{ab}	33.48^{b}	4.24^{b}
Fresh market							
Metadel	82.64^{a}	59.13^{a}	8.45^{a}	5.83^{b}	4.71^{c}	22.11^{cd}	2.05^{c}
Eshete	83.68^{a}	59.30^{a}	8.47^{a}	5.79^{b}	4.90^{bc}	25.47^{c}	2.16^{c}
Marglobe Improved	84.34^{a}	59.17^{a}	8.45^{a}	6.49^{a}	4.97^{bc}	19.44^{cd}	2.04^{c}
Fetane	75.00^{b}	54.20^{b}	7.74^{b}	6.17^{ab}	5.73^{ab}	32.09^{b}	3.89^{b}
Hienz 1350	75.13^{b}	48.00^{d}	6.86^{c}	5.88^{b}	5.26^{abc}	18.51^{d}	2.08^{c}
Bishola	75.50^{b}	46.20^{e}	6.29^{d}	6.23^{ab}	5.43^{abc}	24.46^{cd}	1.92^{c}
Significance	***	***	***	***	***	***	***
SE $\pm$	0.572	0.08	0.55	0.16	0.25	1.89	0.16
CV (%)	1.29	1.78	1.77	5.18	8.24	11.19	9.14

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05; ns, ***, Non significant and significant difference at P ≤ 0.001, respectively; DFH, days to first harvest; DH, duration of harvest; NH, number of harvests; LGD, longitudinal diameter; TRD, transverse diameter; CL/P, clusters per plant; F/CL, fruits per cluster.

chamber under Dire Dawa conditions that maintained temperature between 14.3 and 19.2°C for storage of mango over similar duration. Hence, the ambient storage conditions did not have extremes of temperature and relative humidity that could affect the stored fruit.

A comparison of the ambient temperature shows that Dire Dawa is about 59% hotter than that of Haramaya (Tefera et al., 2007). This indicates that Haramaya had a temperature range that could be comparable with the evaporative cooler chamber that improved shelf life of tomatoes (Meaza, 2005; Hirut et al., 2008). Thus, this could have a better implication for knowing the shelf life and quality maintenance of tomatoes stored under cooler areas of the country because most of warm season fruits like tomato are produced in warmer area of the country and sold in cooler areas like Addis Ababa.

Moreover, Hardenburg et al. (1986) mentioned that storage under relatively low temperature is the most efficient method to maintain quality of most fruit and vegetables due to its effects on reducing respiration rate, transpiration, ethylene production, ripening, senescence, and rot development.

It is generally agreed that mature green tomato can be stored for relatively longer period at a temperature of 10 to 15°C and 85 to 95% relative humidity (Castro et al., 2005). In this background, it is interesting to note here that the temperature of the storage room also offered similar conditions except that the relative humidity was low.

Plant characters and yield components

Plant characters and yield components of fresh market and processing tomato varieties were significantly (P ≤ 0.001) different among the varieties (Table 1). The fresh market tomato varieties *Eshete*, *Metadel* and *Marglobe Improved* were about 8 days late to first harvest as compared to the rest of fresh market tomato varieties. On the other hand, the processing tomato varieties *Roma VF* and *Melkashola* were late by two days when compared with *Melkasalsa* that had similar days to first harvest with Roma VF. The fresh market tomato varieties *Eshete*, *Metadel* and *Marglobe Improved* were late by two weeks when compared with processing tomato varieties. Bohner and Bangerth (1988) reported that time from transplant to first harvest of plum types and large fruited type tomatoes ranged between 70 to 90 days, being the earlier for plum types and the late for large fruited types of tomatoes, which is in agreement with the present findings. Moreover, Moraru et al. (2004) also indicated the presence of a wider range of variability in days to first harvest amongst ten tomato varieties.

Duration of harvest recorded for *Eshete*, *Metadel*, and *Marglobe Improved* were about 13 days more than the fresh market tomato variety Bishola. Similarly, the processing tomato variety *Melkasalsa* had 2 days more duration of harvest than *Roma VF* and *Melkashola*.

Comparison of tomato varieties showed that the fresh market tomato varieties *Eshete*, *Metadel*, and *Marglobe Improved* had about 5 days more duration of harvests than the processing tomato varieties *Roma VF* and *Melkashola*. This could be closely associated with variability in growth habits, which are greatly genetically controlled. Atherton and Rudich (1986) also reported that indeterminate varieties of tomato produce branching systems that grow indefinitely. This gradual fruit set creates a longer harvest period so that fruits are harvested in series of picks when they reach the desired maturity stage.

The fresh market tomato varieties *Eshete*, *Metadel* and *Marglobe Improved* had 35% more number of harvests as compared to *Melkashola* that had the lowest number of harvests. Going by, the processing types of tomato varieties had very narrow differences in the number of harvests where *Melkasalsa* had 2.32% higher number of harvests as compared to *Melkashola* that had the least number of harvests in the group. The best explanation could be the close association between number of harvests and duration of harvests that are greatly determined by the plant growth habit. In this study, a positive correlation (r = 0.602***) were observed between the number of harvests and duration of harvests. In other studies, Atherton and Rudich (1986) indicated that determinate tomatoes, including both the processing and fresh market varieties, are smaller and more compact than indeterminate varieties. They produce flowers and set fruit within a relatively shorter period. This makes it possible to harvest the fruit in a relatively less number of picks.

Cross-sectional (transverse diameter) dimensions and longitudinal (stem to blossom end) diameters of the fruits were significantly ($P \leq 0.001$) different among the tomato varieties. *Marglobe Improved* (6.49 cm) had 5.32% longer transverse diameter than the other five fresh market tomato varieties. Alternatively, *Fetane* had 4% longer longitudinal diameter as compared to the other five fresh market tomato varieties. The processing tomato variety *Roma VF* and *Melkashola* had about 30% wider transverse diameter when compared with *Melkasalsa* that showed the lowest transverse diameter in the group. The processing tomato variety *Roma VF* fruits had the longest longitudinal diameter (5.84 cm) while the least fruit length was recorded in Metadel (4.71 cm). The remaining processing types as well as *Marglobe Improved*, *Fetane* and *Bishola* from the fresh market varieties did not differ significantly from Roma VF. It is notable that in the processing tomato varieties longitudinal diameter is larger than transverse diameters while in fresh market tomatoes longitudinal diameter of the fruits was smaller than the transverse diameter.

This result agrees with that of Viswanathan et al. (1997) that the diameter along the cross-section is mostly greater than the longitudinal diameter in nonprocessing tomatoes. Atherton and Rudich (1986) also indicated that tomato cultivars differ greatly in fruit shape and may be spherical, elongated or pear-like. Thus, their respective longitudinal and cross-sectional diameters measurements determine their shape.

The number of clusters per plant and fruits per cluster were significantly ($P \leq 0.001$) different among the tomato varieties. The processing type *Melkasalsa* showed 58% more number of clusters per plant as well as 16.0% more fruits per cluster when compared with *Roma VF* and *Melkashola*. Similarly, *Fetane* had 46.0% more number of cluster per plant as well as 90.0% more fruits per cluster when compared with the other five fresh market tomato varieties. *Fetane* also gave comparable values of number of clusters per plant and fruits per cluster as compared with processing tomato varieties *Roma VF* and *Melkashola*. However, the later variety was at par on both traits. Cluster number and fruit numbers could be related to the yielding ability of the varieties which could be substantiated by the positive correlations between these traits and yield observed (data not shown). This indicates that higher number of clusters and fruits give superior yield. Balibrea et al. (1997) also described that fruit yield is a function of fruit number per plant. The author indicated that fruit yield was strongly influenced by the number of clusters as well as by the number of fruits set per cluster. Atherton and Rudich (1986) also reported that the highest fruit-yielding cultivar had more clusters and fruits that would be of great interest to tomato growers or producers.

Yield

The total, unmarketable and marketable fruit number and yield of processing and fresh market types of tomato varieties studied were found to be significantly ($P \leq 0.001$) different (Table 2). An overview of Table 2 indicates that the processing cultivars produced more number of fruits per plant compared with the fresh market types. Similarly, total and marketable yield per hectare were found to be more in processing cultivars than in the fresh market types except for *Fetane* that recorded the highest and comparable yield to the highest yielding processing cultivar (*Melkasalsa*).

This study clearly indicates that fresh market tomato varieties of indeterminate growth were low yielder as compared to determinate types of both fresh market and processing types of tomato varieties tested. Wudiri and Henderson (1985) indicated non processing tomatoes of indeterminate growth habit are low yielding because vegetative growth is favored over reproductive growth.

Comparison between fresh market tomato varieties showed that *Fetane* had 47.0 and 55.0% more total and marketable number as well as 47 and 64% more total and marketable weight of fruits than the lowest yielder *Marglobe Improved*, respectively. Among the processing tomato varieties *Melkasalsa* had 101 and 103% more total and marketable number as well as 12 and 13% more total and marketable weight of fruits as compared to the lowest yielder *Roma VF*, respectively.

The result of the present study indicated that the fresh market tomato variety *Fetane* had more yield than *Roma VF* and *Melkashola*. However, Melkasalsa remained at par with *Fetane*. The variation in yielding ability of the tomato varieties studied could be attributed to fruit set and number of marketable fruits, which is genetically,

Table 2. Total, unmarketable, marketable fruit number and weight of processing and fresh market tomato varieties.

Tomato variety	Number of fruits per plant			Fruit yield (tons ha^{-1})		
	TNF	UMN	MN	TWF	UMW	MW
Processing						
Roma VF	81.13^{c}	5.13^{bc}	76.00^{c}	41.80^{bcd}	2.22^{f}	39.58^{b}
Melkasalsa	162.69^{a}	8.45^{a}	154.25^{a}	46.73^{ab}	1.84^{f}	44.89^{a}
Melkashola	92.42^{b}	4.53^{c}	87.88^{b}	42.94^{bcd}	2.92^{e}	40.02^{b}
Fresh market						
Metadel	58.11^{e}	5.37^{b}	52.74^{ed}	37.86^{ed}	5.80^{ab}	32.06^{cd}
Eshete	50.60^{ef}	3.34^{d}	47.26^{edf}	33.56^{ef}	2.89^{e}	30.67^{d}
Marglobe Improved	48.81^{f}	4.65^{bc}	44.16^{ef}	32.20^{f}	4.66^{c}	27.53^{d}
Fetane	71.80^{d}	3.47^{d}	68.33^{c}	47.17^{a}	1.94^{f}	45.23^{a}
Hienz 1350	44.75^{f}	5.12^{bc}	39.63^{f}	39.98^{cd}	5.34^{b}	34.63^{c}
Bishola	58.82^{e}	5.35^{b}	53.47^{d}	39.32^{d}	6.06^{a}	33.26^{c}
Significance	***	***	***	***	***	***
SE$\pm$	2.777	0.22	2.82	1.62	0.19	1.54
CV (%)	6.47	7.57	7.06	6.94	7.60	7.41

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05 (DMRT); ***, Significant difference at P ≤ 0.001. M, marketable number or yield; U, unmarketable number or yield; T, total number or yield.

controlled which is in agreement with the findings of Gould (1992) and Duguma (2000).

It has been observed that a positive correlations exists between marketable yield and clusters per plant (r = 0.615***), fruits per cluster and total number of fruits (r = 0.812***) while a negative correlation were observed between yield and fruit weight (r = -0.713***). Balibrea et al. (1997) also described the existence of a positive correlation between fruit yield and its components like fruit number and cluster number of the plant. The fresh market tomato variety *Bishola* had the highest amount of unmarketable fruit yield compared with all varieties except Metadel. The processing varieties *Melkasalsa* and *Roma VF* and the fresh market variety *Fetane* had the lowest unmarketable yield.

However, the former variety had the highest unmarketable number of fruits. Most of the unmarketable fruits in the processing varieties were under sized while some also included those of damaged by birds, and sunburn. However, in fresh market types unmarketable fruits were due to cracking, soft rot, sunburn, misshapen or deformed and damaged by birds. Thus, the fruit yield of the tomato varieties tested was comparable to the results of other studies reported by Desalegn (1998) and Desalegn et al. (2008).

Physical characters of tomato fruits during storage

Fruit weight

Table 3 shows the average fruit weight of processing and fresh market types of tomato varieties subjected to 32 days of storage under ambient environmental conditions. Tomato variety significantly (P ≤ 0.001) differed in the average fruit weight during the 32 days of storage period. At harvest, the fresh market tomato varieties *Bishola* and *Marglobe Improved* had about 35% more average fruit weight than *Fetane* that had the lowest fruit weight value. The processing tomato varieties did not differ significantly in average fruit weight, however; *Roma VF* and *Melkashola* had relatively larger sized fruits than Melkasalsa.

Comparison between the two types of varieties indicated that the fresh market tomato varieties *Bishola* and *Marglobe Improved* had about three fold times more average fruit weight than the processing tomato varieties at the time of harvest. This could be associated with their genetic potential. It agrees with the findings of Mohammed et al. (1999) that fresh market fruits had larger mean fruit weight when compared with fruits of processing tomato varieties. Thus, it indicates that the fresh market tomato varieties have superior physical quality attributes than processing tomato varieties. There was a general trend of decrease in average fruit weight as the storage period progressed. This result is in agreement with the previous findings by Atta-Aly and Bretch (1995) in which significant increase in fruit weight loss was shown as ripening progressed from mature-green to red ripe stage. Such reduction in fruit weight as the storage period advances could be associated with increased rate of respiration and loss of moisture. Workneh and Kebede (2004) also reported that moisture loss is associated with losses of saleable weight during storage of fruits at

Table 3. Average fruit weight (g) of processing and fresh market tomato varieties stored under ambient conditions for 32 days.

Tomato variety	Storage period (days)								
	0	4	8	12	16	20	24	28	32
Processing									
Roma VF	68.5^{d}	59. 0 ^{ed}	54.5^{ef}	53.5^{e}	51.5^{h}	50.8^{h}	47.5^{f}	43.8^{h}	43.5^{h}
Melkasalsa	54.7^{d}	47.8^{e}	46.5^{f}	44.6^{f}	42.7^{i}	40.5^{i}	39.6^{g}	35.5^{i}	32.5^{i}
Melkashola	70.7^{d}	63.57^{d}	62.2^{e}	60.8^{d}	60.6^{g}	58.3^{g}	57.5^{e}	52.3^{g}	45.6^{g}
Fresh market									
Metadel	171.0^{b}	165.6^{b}	158.7^{c}	157.9^{b}	154.2^{b}	148.7^{b}	130.0^{b}	119.3^{a}	91.1^{c}
Eshete	156.7^{b}	159.3^{b}	154.7^{bc}	146.1^{b}	144.3^{d}	118.3^{e}	107.3^{d}	103.1^{e}	86.7^{e}
Marglobe Improved	188.5^{a}	183.2^{b}	174.3^{b}	163.1^{a}	156.4^{e}	153.7^{c}	139.7^{a}	126.7^{a}	116.0^{a}
Fetane	139.2^{c}	134.9^{c}	128.1^{d}	122.5^{c}	117.2^{f}	116.7^{f}	105.1^{d}	91.9^{f}	88.2^{f}
Hienz 1350	162.0^{b}	159.4^{b}	157.3^{bc}	155.9^{a}	152.7^{c}	129.4^{d}	117.4^{c}	113.4^{d}	90.1^{d}
Bishola	188.3^{a}	178.2^{a}	171.5^{a}	159.8^{a}	154.7^{a}	151.6^{a}	131.3^{b}	119.7^{b}	111.0^{b}
Significance	***	***	***	***	***	***	***	***	***
SE$\pm$	3.31	3.48	2.84	1.21	1.93	1.64	1.88	0.01	0.01
CV (%)	5.18	6.82	4.34	2.05	0.47	0.26	3.35	0.02	0.08

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05 (DMRT), ***, Significant difference at P ≤ 0.001.

Table 4. Average fruit volume (ml) of processing and fresh market tomato varieties stored under ambient conditions.

Tomato variety	Storage period (days)								
	0	4	8	12	16	20	24	28	32
Processing									
Roma VF	76.5^{c}	65.5^{c}	57.6^{ef}	56.4^{f}	55.8^{e}	54.3^{e}	53.5^{ef}	52.3^{e}	50.5^{d}
Melkasalsa	62.14^{c}	53.2^{c}	49.1^{f}	47.0^{g}	46.4^{f}	46.2^{f}	43.5^{f}	42.0^{f}	38.1^{e}
Melkashola	80.3^{c}	70.6^{c}	64.9^{e}	64.4^{e}	65.2^{d}	60.4^{e}	59.2^{e}	59.0^{e}	55.3^{d}
Fresh market									
Metadel	183.9^{a}	177.3^{a}	158.0^{c}	156.3^{b}	151.0^{a}	150.8^{a}	135.9^{bc}	135.1^{a}	106.2^{bc}
Eshete	178.9^{ab}	171.8^{ab}	163.6^{abc}	144.8^{c}	142.0^{b}	126.2^{c}	114.7^{d}	111.9^{c}	104.4^{c}
Marglobe Improved	198.1^{a}	188.3^{a}	172.3^{a}	160.1^{a}	146.3^{ab}	146.6^{a}	146.2^{ab}	137.9^{d}	128.4^{a}
Fetane	153.8^{b}	147.6^{b}	133.2^{d}	126.6^{d}	122.4^{c}	114.9^{d}	114.2^{d}	102.3^{e}	100.0^{c}
Hienz 1350	174.9^{ab}	170.7^{ab}	162.7^{bc}	153.9^{b}	149.9^{a}	137.5^{b}	125.6^{cd}	122.0^{b}	105.6^{bc}
Bishola	194.5^{a}	186.7^{a}	169.9^{ab}	157.1^{ab}	150.9^{a}	151.5^{a}	150.3^{a}	130.1^{ab}	116.9^{ab}
Significance	***	***	***	***	***	***	***	***	***
SE$\pm$	9.31	7.81	2.97	1.20	2.18	2.43	3.80	3.19	3.89
CV (%)	11.21	9.89	4.09	1.76	3.31	3.83	6.28	5.56	7.35

Means within the same column followed by a common letter are not significantly different at P ≤ 0.001 (DMRT), ***, Significant difference at P ≤ 0.001.

ambient conditions. Thus, this study indicates that tomato varieties greatly differ in the reduction of fruit weight as the storage period advances which partly justifies the dominance of processing varieties in the production and marketing of tomatoes as compared with nonprocessing (fresh market) varieties that have poor shelf life.

Fruit volume

The average fruit volumes of processing and fresh market tomato varieties stored under ambient conditions were found to be significantly (P ≤ 0.001) different throughout the storage period of 32 days (Table 4). At

Table 5. Fruit specific gravity (g. ml^{-1}) of processing and fresh market tomato varieties stored under ambient conditions.

Tomato variety	Storage period (days)								
	0	4	8	12	16	20	24	28	32
Processing									
Roma VF	0.898	0.901	0.926^{e}	0.947^{d}	0.949^{b}	0.936^{b}	0.889	0.845	0.831
Melkasalsa	0.880	0.905	0.919^{e}	0.943^{d}	0.947^{b}	0.914^{c}	0.874	0.838	0.828
Melkashola	0.899	0.909	0.930^{e}	0.949^{d}	0.958^{b}	0.937^{b}	0.908	0.886	0.834
Fresh market									
Metadel	0.932	0.954	1.005^{b}	1.015^{b}	1.022^{a}	1.003^{a}	0.957	0.921	0.887
Eshete	0.924	0.928	0.962^{d}	1.009^{c}	1.016^{a}	0.965^{ab}	0.934	0.899	0.861
Marglobe Improved	0.983	0.987	1.012^{a}	1.019^{a}	1.029^{a}	1.016a	0.971	0.928	0.918
Fetane	0.908	0.912	0.958^{e}	0.967^{d}	0.957^{b}	0.941^{b}	0.921	0.891	0.844
Hienz 1350	0.927	0.936	0.967^{c}	1.013^{b}	1.018^{a}	0.986^{ab}	0.936	0.919	0.862
Bishola	0.957	0.961	1.009^{a}	1.017^{a}	1.025^{a}	1.015^{a}	0.963	0.922	0.904
Significance	ns	ns	***	***	***	***	ns	ns	ns
SE$\pm$	0.042	0.037	0.001	0.011	0.012	0.016	0.020	0.022	0.038
CV (%)	7.923	7.768	0.139	0.130	2.098	2.857	3.797	4.217	7.528

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05 (DMRT), ns, Non- significant; ***, significant difference at P ≤ 0.001.

harvest, the fresh market tomato variety *Fetane* had stastically lower fruit volume when compared with the other five fresh market tomato varieties. Similarly, *Roma VF* and *Melkashola* showed more fruit volume although not statistically different as compared to Melkasalsa that had the lowest record in the processing tomato varieties. Average fruit volume of all varieties decreases progressively during ripening of tomatoes from the mature green to red ripe stages in the storage. This indicates that during ripening of fruits there is a loss of moisture resulting in shriveling of fruits so that fruits displace less water and hence have less volume. Fruit volume and fruit weight had stronger positive correlation (r = 0.977***). Carlson et al. (2006) also indicated the presence a highly positive correlation among surface area, average fruit weight and average fruit volume of Salad and Roma types of tomato varieties. Hence, as average fruit weight decreases during storage there is also a progressive loss of fruit volume. This could be due to increased rate of respiration and activities of cell wall degrading enzymes as ripeness advanced that result in loss of moisture and sealable weight as well as shrinkage of the fruits. Hewitt et al. (2006) indicated that the rate of assimilate hydrolysis through respiration by fruits is the major factor that may also influence the solid content of tomato fruits and there by the volume of the fruit. Furthermore, internal quality disorders have a great impact on the physical appearance of the fruits that intern genetically controlled. Abou-Aziz et al. (1976) reported that physiochemical quality and quantity changes in tomatoes vary with cultivar.

Specific gravity

Table 5 displays the specific gravity of processing and fresh market tomato varieties stored under ambient conditions for 32 days. In this study, the specific gravity values varied between 0.828 and 1.029. The values were in the range that was earlier reported by Ereifej et al. (1997). The specific gravities of the nine varieties studied did not differ significantly (P ≥ 0.05) at 0, 4, 24, 28 and 32 days of storage period. This indicates that that the tomato fruits at these storage periods may not have much difference in their respiration rate. Of course, the result is in agreement with the findings of Joslyn (1970) and Adedeji et al. (2006) that indicated the specific gravity of a plant tissue is an index of its maturity. After 24 days of storage period, there was a decline in the specific gravity values of the varieties indicating that all varieties passed their peak ripening stage and that the rate of metabolism of the cultivars has narrowed down.

Eunkyung (2005) reported that stage of ripeness affects respiration rate as accelerated climacteric peak followed by no significant change in respiration of tomato caused by a drop at light-red stage. The later could be could be due to decreased availability of respiratory substrates as most of assimilates were hydrolyzed. It was clearly described in Table 6 that specific gravity of tomato fruits during storage showed an initial increase, which was then followed by a decrease. Joslyn (1970) also reported that specific gravity of tomato fruits increases progressively during ripening of tomatoes from the mature green to red ripe stages and then decline as fruits

Table 6. Fruit juice content (ml kg^{-1}) of processing and fresh market tomato varieties during storage under ambient conditions.

Tomato variety	Storage period (days)								
	0	4	8	12	16	20	24	28	32
Processing									
Roma VF	811.8^{g}	778.3^{h}	708.6^{g}	673.3^{g}	642.6^{f}	525.2^{h}	492.8^{g}	419.3^{g}	376.7^{g}
Melkasalsa	738.0^{h}	705.1^{i}	682.0^{h}	663.6^{h}	619.4^{g}	518.5^{i}	461.5^{h}	419.7^{g}	361.2^{h}
Melkashola	823.6^{f}	788.7^{g}	724.6^{f}	706.9^{f}	654.2^{e}	544.3^{g}	513.3^{f}	465.2^{f}	395.3^{f}
Fresh market									
Metadel	861.1^{c}	817.7^{d}	771.0^{d}	759.2^{c}	740.0^{b}	645.4^{d}	579.3^{d}	517.4^{d}	415.8^{c}
Eshete	853.0^{d}	810.8^{e}	767.6^{d}	751.3^{d}	716.0^{c}	633.8^{e}	548.4^{e}	513.4^{d}	411.2^{d}
Marglobe Improved	912.4^{a}	907.3^{a}	823.1^{a}	800.7^{a}	773.4^{a}	736.7^{a}	689.2^{a}	597.9^{a}	525.4^{a}
Fetane	836.7^{e}	804.1^{f}	759.2^{e}	731.5^{e}	702.6^{d}	583.7^{f}	516.1^{f}	483.3^{e}	345.8^{e}
Hienz 1350	861.3^{c}	835.7^{c}	784.6^{c}	757.7^{c}	742.6^{b}	660.2^{c}	602.3^{c}	546.3^{c}	419.1^{c}
Bishola	870.9^{b}	846.2^{b}	801.3^{b}	782.2^{b}	766.5^{a}	679.9^{b}	617.8^{b}	561.2^{b}	462.4^{b}
Significance	***	***	***	***	***	***	***	***	***
SE$\pm$	1.737	2.018	1.678	1.535	2.350	2.097	1.870	1.576	2.179
CV (%)	0.358	0.431	0.383	0.361	0.576	0.591	0.581	0.543	1.011

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05 (DMRT), ***, significant difference at P ≤ 0.001, respectively.

senesce.

Comparisons of tomato varieties showed that specific gravity were highest in fresh market tomato fruits compared with processing varieties throughout the storage period. The variability could be attributed to the close association of specific gravity with fruit size, volume and weight as well as to genotypic variability. Adedeji et al. (2006) also reported that factor such as specific gravity is specific to a variety which can be used to determine maturity stages and schedule harvest.

Fruit juice content

Table 6 shows the juice content of processing and fresh market types of tomato varieties stored under ambient conditions for 32 days. The varieties significantly (P ≤ 0.001) varied in their fruit juice content during the storage period. At harvest, the fresh market tomato *Marglobe Improved* had 9% more juice content than *Fetane*. Coming to processing tomato varieties, *Melkashola* showed 11% more juice content compared with *Melkasalsa*. After 32 days storage period, *Marglobe Improved* had the highest juice than all other varieties. Melkashola also had the highest juice while Melkasalsa had the lowest record in the group throughout the storage period. The differences could be due to genotypic variation that had great contribution for the variability in fruit juice content which is in agreement with the findings of Adedeji et al. (2006) in that juice content is specific to the variety or the genotype.

During the 32 days of storage period, there were general trends of decline in juice content of all tomato varieties tested which is in agreement with the findings of Workneh (2002) and Tefera et al. (2007) that showed decrease in tomato juice and an increase in total soluble solids as the storage period advanced. As the storage period advances, there was concomitant increase in respiration rate that reduces the dry matter contents of the fruits while raising loss of moisture, which could be a major cause for reduction in the juice content of the fruits.

Young et al. (1993) also reported a decrease in the percent dry matter of two tomato genotypes throughout maturation of the fruits. Hewitt et al. (2006) reported that hydrolytic reactions in fruits utilizes dry matters such as starch, total titratable acids while raising moisture loss from fruits thereby reducing juice. Thus, the juice becomes more concentrated and granulated that could have great importance for processing industries as it reduces the cost of dehydration.

Physiological weight loss

Table 7 shows significant (P ≤ 0.001) variation in the physiological weight loss (percentage) of processing and fresh market tomato varieties during the 32 days of storage at ambient conditions. The fresh market variety Metadel exhibited the highest percentage weight loss while the processing variety, *Melkasalsa*, had the lowest throughout most part of the storage period. On day 4, Metadel showed 25% more weight loss than *Fetane* that had the lowest value among the fresh market varieties. On the other hand, among the processing tomato varieties

Table 7. Physiological weight loss (%) of processing and fresh market tomato varieties stored under ambient conditions.

Tomato variety	Storage periods (days)							
	4	8	12	16	20	24	28	32
Processing								
Roma VF	1.693[f]	2.523[f]	4.513[f]	6.923[g]	8.753[cd]	11.373[g]	13.373[g]	16.71[d]
Melkasalsa	1.570[g]	2.337[g]	4.210[g]	6.130[i]	7.820[e]	10.260[i]	11.740[i]	15.01[f]
Melkashola	1.663[f]	2.527[f]	4.447[f]	6.707[h]	8.228[ed]	10.747[h]	12.267[h]	15.60[e]
Fresh market								
Metadel	2.222[a]	3.928[a]	6.537[a]	8.807[a]	12.757[a]	15.607[a]	17.607[a]	20.94[a]
Eshete	2.043[b]	3.653[b]	6.333[b]	8.137[b]	12.410[a]	14.260[b]	16.260[b]	19.43[b]
Marglobe Improved	1.893[d]	2.753[e]	5.153[e]	7.373[e]	10.813[b]	12.273[e]	14.723[e]	17.96[c]
Fetane	1.777[e]	2.732[e]	5.057[e]	7.157[f]	9.098[c]	11.857[f]	13.857[f]	17.06[d]
Hienz 1350	1.960[c]	2.880[d]	5.540[d]	7.624[d]	11.253[b]	13.228[d]	15.229[d]	18.26[c]
Bishola	2.003[bc]	3.277[c]	6.050[c]	7.983[c]	12.093[a]	13.900[c]	15.933[c]	19.03[b]
Significance	***	***	***	***	***	***	***	***
SE±	0.016	0.026	0.037	0.048	0.255	0.070	0.081	0.196
CV (%)	1.501	1.537	1.202	1.114	4.259	0.958	0.961	1.909

Means within the same column followed by a common letter are not significantly different at P ≤ 0.05 (DMRT), ***, indicates significant difference at P ≤ 0.001.

7% more weight loss was recorded in *Roma VF* as compared to *Melkasalsa*, which had also statistically similar weight loss with *Melkashola*. A comparison indicates that the fresh market tomato variety Metadel had 41.5% more weight loss when compared with Melkasalsa that had the lowest value among all varieties tested. The difference in the physiological weight loss could be due to variation in the rate of respiration among the genotypes as higher rate of respiration is related to higher loss of water and the dry matter of the fruits. After 32 days of storage, comparison of tomato varieties based on mean showed that fresh market tomatoes showed about 19% more weight loss than processing tomato varieties. This could be closely associated with the high soluble solid content and faster rate of respiration of fresh market tomatoes.

Overall, there was an increase in weight loss as the storage period progress. This result is in agreement with the previous findings by Atta-Aly and Bretch (1995) in which significant increase in fruit weight loss was observed as ripening progressed. Similar findings were also reported by Tefera et al. (2007) and Hirut et al. (2008) that weight loss of fruits were increased as the storage period advanced; increase rate of weight loss could be related to stage of ripeness of tomatoes as there could be increased fruit permeability as ripening progresses. Biale (1975) postulated that changes in cell membrane permeability might conceivably account for the wide variety of both anabolic and catabolic processes associated with ripening.

Intense fruit transpiration rates are positively related with fruit soluble solids content, a major criterion of quality about 10% physiological loss in weight is considered as an index of termination of shelf life (threshold level) of commodities (Pal et al., 1997). Acedo (1997) also stated that 10% weight loss makes most fruit wilt or shrivel and lose the appearance of being “fresh”. Accordingly, the mean value of physiological weight loss from processing type’s tomatoes such as *Roma VF*, *Melkasalsa* and *Melkashola* reached the threshold level between 20 and 24 days. Regarding fresh market tomatoes, the threshold levels were reached between day 16 and 20 of storage at ambient conditions.

Conclusions

Yield and yield components significantly (P ≤ 0.001) differed among the tomato varieties. The processing varieties *Melkasalsa*, *Roma VF* and *Melkashola* were early maturing types while the fresh market varieties, *Metadel*, *Eshete* and *Marglobe Improved* were late maturing with longer duration and higher number of harvests. However, days to first harvest were late by about 3 days in *Fetane, Heinz 1350* and *Bishola* than the formers. *Fetane* had the highest number of clusters, fruits per cluster, total and marketable number as well as weight of fruits than the other five fresh market varieties. Whereas, *Marglobe Improved* and *Bishola* had the highest fruit weight, volume and juice content than the other seven varieties. Similarly, Melkasalsa had the highest number of clusters, fruits per cluster, total and marketable number as well as weight of fruits than *Roma VF* and *Melkashola*. The fresh market tomato variety

Bishola had more unmarketable fruit than *Melkasalsa*, the highest yielder variety (processing type). Significant (P ≤ 0.001) difference in physical properties among the tomato varieties were observed during the 32 days of storage period under ambient conditions. At harvest, the fresh market tomato variety *Marglobe Improved* had highest values of average fruit weight, volume and juice content while the lowest value were recorded in *Fetane*. Similarly, the processing tomato variety *Melkashola* had the highest values of average fruit weight, volume and juice content while the lowest were found in *Melkasalsa*. At harvest, there were no significant differences in fruit specific gravity in all tomato varieties. Physical quality characteristics were highest in fresh market varieties compared with the processing types throughout the storage period. An overall indication of yield performance of each varieties showed that the fresh market variety *Fetane* was the highest yielder followed by *Melkasalsa*, *Melkashola*, and *Roma VF*, *Heinz 1350*, *Bishola*, *Metadel*, *Eshete* and *Marglobe Improved*, respectively but *Melkasalsa* was at par with *Fetane*. Fresh market tomato fruits had also superior physical quality characteristics such as higher fruit weight, volume, specific gravity and juice content than processing fruit varieties.

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