Post-harvest Losses of Plum Fruits cv. 'Methley' of Different Harvesting Stages in Two Storage Conditions

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Abstract

An experiment was conducted to assess quality parameters and post-harvest losses of a plum variety 'Methley' in ambient and refrigerated condition in cool environment of Lumle, Nepal during June-July in 2022. The fruits were harvested at mature green stage, turning red stage and dark red stage. Ten uniform-sized fruits were selected from each stage, kept in small plastic crates and stored in both conditions separately. The experiment was set to an RCBD with 7 replications and 3 treatments in both conditions. Observations were recorded for 14 days in ambient condition and 28 days in refrigerated condition. The results revealed that the fruit stages differed for total soluble solids, titratable acidity and juice content at harvesting. Before storage, TSS for mature green, turning red and dark red stages ranged 8.2-8.4, 10.1-10.3 and 12-12.3-^{0}Brix respectively; while it was 11.2, 12.8 and 12.7^{0}Brix respectively after storage in ambient condition and 11.4, 11.9 and 12.8^{0}Brix respectively after storage in refrigerated condition. Titratable acidity for mature green, turning red and dark red stages ranged 1.83-1.92, 0.95-0.98- and 0.6-0.65 percent respectively before storage while it was 0.62, 0.49 and 0.4 percent respectively after storage in ambient condition and 1.10, 0.75 and 0.50 percent respectively after storage in refrigerated condition. Refrigerated (5.6-8.2^{0}C/59 - 65% RH) fruits had minimum weight loss (3.62% in 28th days of data recording) while in ambient condition (12.9 -23.8^{0}C/ 49-60 % RH) the loss was 34.5%. The fruit stages were significantly different for post-harvest loss indicating the mature green stage fruits had the minimum loss and the longest post-harvest life. These results showed an indication of possibility of early harvesting (8.2-8.4^{0}Brix TSS and 1.83-1.92 percent TA) to enhance post-harvest life with minimum loss of fruits.

Keywords: plum, TSS, TA, storage, fruit color

Introduction

Plum (*Prunus domestica* L.; family: Rosaceae) is one of the important temperate fruits in the world. China (68,01,187 metric tons), Romania (8,42,132 metric tons) and India (2,51,389 metric tons) are some leading producers of plum (www. atlasbig.com/en-gb/country-by-plum-production, 2021). Among the temperate fruits, it occupies 5th position in priority after apple, pear, walnut and apricot in Nepal. Its productive area, production and productivity are 1585 ha, 10284 metric tons and 6.49 t/ha, respectively (MoALD, 2022). However, its productivity is comparable to the above-mentioned leading producers China (3.53 t/ha), India (8.4 t/ha) and Romania (12.77 t/ha) (atlasbig.com/en-gb/country-by-plum-production, 2021). Besides increasing its production, it is easy way to save production by minimizing post-harvest losses. Little is known about post-harvest losses of plum in Nepal. However, it was estimated about 20-35% of losses of fruits during different stages of post-harvest handling and storage (Gautam and Bhattarai, 2012; Bhattarai, 2021). In a previous work, it was estimated about 21-51% losses of plum fruits in the marketing channel of which, 5.12% measured in farm level, 1.44% at wholesale, 6.3% at retail and 8.64% at consumer level (Sahzad et al., 2013). Due to its rapid perishable nature (Menniti et al., 2004), post-harvest losses of plum fruit is considerable research issue in Nepalese condition. Containing climacteric nature of ripening, it shows a high rate of respiration during ripening process which is concomitant with an enhancement of ethylene synthesis (Kays and Paull, 2004). Therefore, the shelf-life after harvesting of plum fruits is very important for its storage and sale. However, plums constitute diverse group of fruit species traded internationally (Blazek, 2007). Obviously, ethylene hormone is responsible for coordinating and initiating ripening events in climecteric fruits (Alexander and Grierson, 2002; Bapat et al., 2010). The influence of ethylene on ripening and senescence results in reduced shelf-life and quality (Giovannoni, 2001; Trainotti et al., 2007). The senescence is critical for the plum to reduce fruit shelf life and quality (Valero et al., 2007). However, data for different European plum varieties are lacking (Usenik et al., 2008), which is also true to varieties grown in different parts of Nepal. Plums are very susceptible to low temperature and develop physiological disorders such as internal browning, gel breakdown, reddening or bleeding, retarded softening after prolonged cold storage and/or after ripening at room temperature (Abdi et al., 1998; Fanning et al., 2014). This study explains the results of a study in which we assessed post-harvest shelf-life of plum fruits by measuring quality parameters and post-harvest losses of a plum variety 'Methley' in ambient and refrigerated condition.

Materials and Methods

The experiment was conducted in ambient and refrigerated condition in cool environment of Directorate of Agricultural Research (DoAR) Lumle, Nepal during June-July in 2022. Lumle lies between 28°18' N latitude and 83°48' E longitude with an elevation of 1740 m above sea level (VDC profile, 2008). Agro-ecologically, it represents the high hill environment with cool climate in the winter and moderate warm in the summer. It is the place of the highest rainfall (up to 5500 mm per annum; DoAR Lumle, 2022) in Nepal. DoAR, Lumle is located 35 km north-west from the provincial capital Pokhara city.

During the study period from 5^{th} june to 5^{th} july 2022, the fruits of variety 'Methley' at fully mature green stage (<5% color change), turning red stage (20-40% color change) and dark red stage (100% color change) (Plate 1) were harvested from the plum orchard at DoAR Lumle, Nepal at an altitude of 1750 meters above sea level. The trees were more than 25 years old. Fruits were well-known for their mild, sweet taste and dark red to purple skin. The flesh was red and juicy at full ripe stage. The trees were still heavy bearer unless the dame of hailstones occurred during flowering and bud break stage. These plums are characterized as clingstone, meaning the skin and flesh are tightly held.

Ten uniform-sized fruits of variety 'Methley' were selected from each stage, kept in small plastic crates in ambient room condition and stored in plastic bags in refrigerated condition. The experiment was set to an RCBD with 7 replications and 3 treatments in both conditions. Immediately after the harvesting, the fruits were washed with clean water and allowed to dry in shade until fruit surface became free from water.

***Plate 1.** Fruits showing peel and pulp color at different maturity stages*

Fruits were weighed in a digital balance for fresh fruit weight and weighing was continued to 14 days for the experiment in ambient condition and was remained for 28 days in refrigerated condition. Fruit juice was squeezed from fruit pulp and collected in a in a measuring cylinder before and after storage. Juice content (mean of 5 fruits) was calculated using the following formula:

$$\%\ \text{Juice content} = \frac{\text{Weight of fruit} - \text{Weight of juice extracted}}{\text{Weight of fruits}} \times 100$$

From the sampled fruits, total soluble solids (TSS) of the fruit juice was determined with the help of hand held refractometer which was calibrated using the distilled water and measured in (^{0}Brix). Titratable acidity (TA) of the juice extracted from the fruits was estimated by titration with 0.1 N NaOH solutions using the following formula:

$$\text{Titratable Acidity (\%)} = \frac{\text{weight of acid (maleic acid 0.0067 g) x volume of 0.1N NaOH}}{\text{Volume of sample}} \times 100$$

Similarly, the TSS: TA ratio was calculated by using the following formula:

$$\text{TSS:TA ratio} = \frac{\text{TSS (°Brix) value}}{\text{TA value}}$$

Post-harvest shelf-life was evaluated as the fruits started deterioration from their original texture, flavour and physical appearance.

Data were managed and calculated in Microsoft Office Excel (Microsoft corporation, 2018) and analyzed by Genstat version 18 (VSN International, 2015) software for windows. Analysis of variance was used to determine statistically significant differences between means. Multiple comparisons between treatments were done by Duncan's Multiple Range Test. Least significant differences were determined for all significant data. Coefficient of variation was calculated for the extent of variability in relation to the mean of the population.

Results and Discussion

Temperature and relative humidity

Maximum temperatures of DoAR, Lumle ranged 19.6 - 22.8^{0}C while minimum temperatures varied from 12.9 to 14.8^{0}C (Table 1) at ambient condition. For plum storage, room temperatures should be between 15 and 20^{0}C (Kock & Taylor, no date) while the majority of maximum and minimum temperatures of the DoAR, Lumle were beyond the ranges. Similarly, Maximum temperatures at refrigerator storage condition ranged 8.0 - 8.2^{0}C while minimum temperatures varied from 5.6 to 6.8 degrees. The ambient temperature 18^{0}C and cold temperatures 2-4^{0}C are appropriate to maintain quality of consumption (Alvarez-Herrera et al., 2021). Similarly, Relative humidity ranged from 49-60% in ambient condition and 59-65% in refrigerated condition. The ideal relative humidity for storing plum is 90-95% (Emongor and Ramagonono, 2019). Relative humidity figures were lower indicating the dry spell during the experimental period. The weather of DoAR, Lumle was dry summer during the experimental period.

Table 1. Temperatures and relative humidity in ambient and refrigerated condition

Day of storage	Ambient condition			Refrigerated condition		
	Temp. (^{0}C)		RH (%)	Temp. (^{0}C)		RH (%)
	Max.	Min.		Max.	Min.	
1	19.6	12.9	49.0	8.2	5.6	59.0
2	19.0	13.4	52.0	8.2	6.0	62.0
4	20.4	13.6	51.0	8.0	6.0	62.0
6	21.2	14.0	55.0	8.0	6.2	45.0
8	21.1	14.4	54.0	8.0	6.8	65.0
10	22.0	14.6	56.0	8.2	6.7	65.0
12	22.4	14.8	59.0	8.2	6.4	65.0
14	22.8	14.2	60.0	8.2	6.8	65.0
16				8.1	5.8	60.0
18				8.0	6.0	59.0
20				8.1	6.2	60.0
22				8.1	6.2	62.0
24				8.1	6.2	62.0
26				8.2	6.0	60.0
28				8.0	6.2	60.0

Weight loss

In ambient room condition, the weight loss of fruit was gradually increased until the end of storage (Fig. 1). The trend of increasing loss was high from 2 to 6 days of storage. The weight loss per cent was significantly (p=<0.005) lower (25.2 %) in mature green fruits than the loss in turning red (32.78%) and dark red (45.43%) fruits. We kept the fruits in open small plastic crates in room condition from which the transpiration would be high. In a previous experiment, the highest mean value of weight loss (5.79%) was observed when the fruits were kept in polyethylene bags in a room temperature (±25^{0}C) (Khan et al., 2013). In our results, the variation in weight loss between the maturity stages might be linked with the chemical changes during ripening process and varied responses of peels to the effect of temperatures and relative humidity. In another experiment, weight loss was dependent on the storage temperatures and increased from 0 to 15^{0}C (Emongor and Ramagonono, 2019). In the present study, the variation in weight loss between maturity stages was significantly higher after 4 days of storage indicating the loss of strength of ripe fruits to retain moisture and to control transpiration after 4 days of storage.

Similar trend of weight loss of plum fruits was observed in refrigerated condition (Fig. 2). The weight loss of fruits was gradually increased until 28 days of storage. The trend of increasing loss was high in initial 6 days of storage. The weight loss per cent was significantly ($p=<0.005$) lower (1.99%) in mature green fruits than the loss in turning red (3.22%) and dark red (5.66%) fruits. We kept the fruits in small plastic bags in a refrigerator which should have delayed the rate of respiration and transpiration. In refrigeration, fruits could be stored for 28 days however; their quality started reducing after 22 days showing softness in fruit peels. After 28 days, the fruits completely loose their quality and discarded from the experiment. Similar results of weight loss in refrigerated condition were observed by Khan et al. (2013). There are other reports on minimizing weight loss by coating fruits with beet pulp (Togrul and Arslan, 2004) and lac-based coatings (Kumar et al., 2018). The latter researchers reported that the lac-based coatings significantly reduced the weight loss by modifying the respiration and ethylene rates of the plums and slowed down their metabolism and delayed color development. Previous studies of Zhou et al. (2008) and Yaman and Bayoundurlc (2002) also reported a reduced weight of coated pear and cherry in storage and Hong et al. (2012) explained positive effect of chitosan coating in reduced weight loss of Guava. In the present study, the average weight loss in refrigerated condition was 3.62% which was considerably lower than the average weight loss in ambient condition (34.5%).

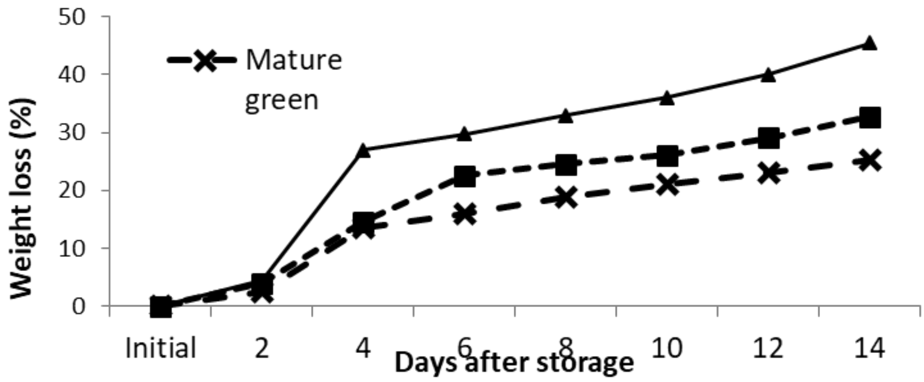

Fig. 1. *Weight loss per cent of plum fruits at different maturity stages in ambient condition*

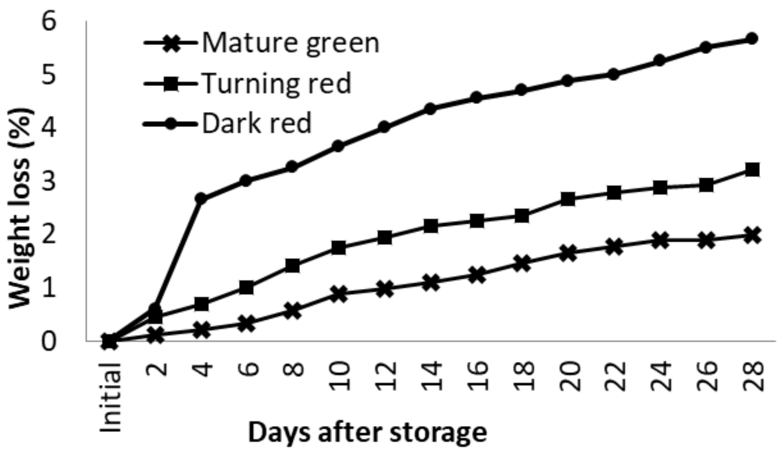

Fig. 2. *Weight loss per cent of plum fruits at different maturity stages in refrigerated condition*

Juice content

The color of juice of fruits at different maturity stages was different (Plate 2). Fruits at different maturity stages significantly differed for percent of juice content in the plum fruit before and after storage in both storage conditions (Table 2). After storage, the juice content of turning red fruits was similar to the juice content of dark red fruits in refrigerated condition. In a previous experiment, maximum content of juice (63.4%) was observed in plums covered by castor oil whereas the minimum content of juice (57.6%) was in control plums (Shah et al., 2021). The same authors also explained that the content of juice declined with prolonging storing intervals containing juice about 82.6% at 0 day, 73.46% at 7 days and 32.73% at 28 days. We used the fruits of different maturity stages and slight increase in juice content might have occurred during post-harvest ripening process in the storage.

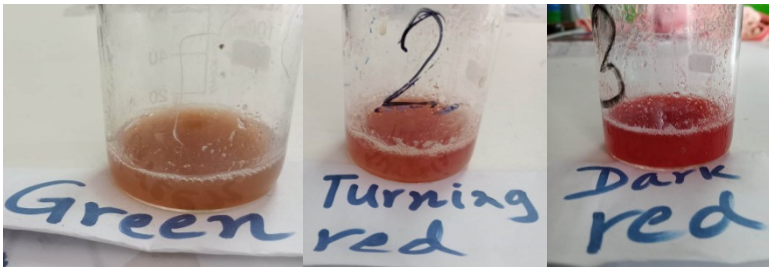

Plate 2. *Colors of juice of plum fruits at different maturity stages*

Table 2. Juice content of plum fruits at different maturity stages in two storage conditions

Maturity stage	Juice content (%)			
	Ambient condition		Refrigerated condition	
	Before storage	After storage	Before storage	After storage
Mature green	64.0c	71.6c	64.3c	70c
Turning red	73.0b	75.3b	73.3b	74a
Dark red	77.0a	77.1a	74.9a	75a
Mean	71.3	74.7	70.8	73.0
CV (%)	5.0	2.1	5.1	2.4
P-value	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	2.53	1.30	2.51	1.55

Total soluble solids

The results revealed that the total soluble solids (TSS) were increased after storage in both storage conditions (Table 3). In ambient condition, mature green green fruits had lower TSS than turning red and dark red fruits before storage indicating the significant differences ($p = <0.05$) between the maturity stages whereas there was no difference in TSS between turning red and dark red fruits after storage. There were no differences in maturity stages for TSS after refrigerated storage. Before storage TSS ranged from 8.2 -8.4 in mature green, 10.1 to 10.3 in turning red and 12.0 to 12.3 in dark red stage. Similarly, it was 11.2, 12.7 and 12.8 in mature green, turning red and dark stages, respectively in ambient condition. In an experiment, the TSS (11.97 $\pm$ 0.17 of 'Sanhua' plum fruit did not change before and after storage (Chang et al., 2019). In the case of the fruits with same maturity stage, it might be obvious; but in our experiment, the fruits were of different maturity stages. In a previous experiment, the TSS varied from 11.9 in 'Souffriau' to 15.8 in 'Avalon' cultivars (Vangdale et al., 2007) but they were not significantly different. Vangdale (1981; In: Vangdale 2007) also found that the soluble solids content increased in Mallard plums during storage. In our case, there was no difference in TSS after storage in refrigerated condition and ambient condition.

Table 3. Total soluble solids of plum fruits at different maturity stages in two storage conditions

Maturity stage	Total soluble solids (^{0}Brix)			
	Ambient condition		Refrigerated condition	
	Before storage	After storage	Before storage	After storage
Mature green	8.2c	11.2b	8.4c	11.4
Turning red	10.1b	12.8a	10.3b	11.9
Dark red	12.3a	12.7a	12.0a	12.2
Mean	10.22	12.23	10.23	11.82
CV (%)	8	6.8	8.3	7.5
P-value	<.001	0.003	<.001	0.261
LSD (0.05)	0.92	0.936	0.956	0.991

Titratable acidity

The results revealed that the titratable acidity (TA) was decreased after storage in both storage conditions (Table 4). In ambient condition, mature green green fruits had higher TA than turning red and dark red fruits before storage indicating the significant differences (p = <0.05) between the maturity stages before and after storage in both conditions. Before storage, TA ranged 1.83% -1.92 in mature green, 0.95% - 0.98% in turning red and 0.60% - 0.65% in dark red stage. Similarly, it was 0.62%, 0.49% and 0.40% in mature green, turning red and dark stages, respectively in ambient condition whereas it was 1.5%, 0.75% and 0.5% in mature green, turning red and dark stages, respectively in refrigerated condition. In a previous experiment, the TA varied from 0.9% in 'Reevs' to 2.3% in 'Avalon' cultivars (Vangdal et al., 2007), however; they were not significantly different. The decrease in titratable acidity was in the range of 15–20% from slightly ripe to well ripe plums (Vangdal et al., 2007). In a recent experiment, it was found that the TA varied in 12 tested accessions from 0.62% to 2.47% (Kitzberger et al., 2017). Fruit acidity is influenced by fertilization, climatic conditions, degree of ripeness, location and genetic diversity of each cultivar (Kitzberger et al., 2017).

Table 4. Titratable acidity of plum fruits at different maturity stages in two storage conditions

Maturity stage	Titratable acidity (%)			
	Ambient condition		Refrigerated condition	
	Before storage	After storage	Before storage	After storage
Mature green	1.92a	0.62a	1.83a	1.50a
Turning red	0.98b	0.49b	0.95b	0.75b
Dark red	0.60c	0.40c	0.65c	0.50b
Mean	1.17	0.5014	1.15	0.918
CV (%)	21.7	8.4	20.3	25.4
P-value	<.001	<.001	<.001	<.001
LSD (0.05)	0.285	0.04754	0.2614	0.2614

Total soluble solids: Titratable acidity ratio

The ratio of TSS to TA is an important indicator of ripeness. In the present study, properly ripe fruits had values more than 7.89 showing great variability for this characteristic among the maturity stages (Table 5). It also significantly differed from the beginning to the end of storage in both storage conditions. Similar variability (4.67-19.40) was also observed in a study of Brazilian plum genotypes (Queiroz, 2014, In: Kitzberger et al., 2017) When the titratable acidity value is less than 0.6% and the soluble sugars content value varied between 10 and 12%, the fruits are perceived as sweet % (Kitzberger et al., 2017). If the TA value is greater than 1%, the soluble sugars content values must be above 15% for the consumers to perceive (Crisosto et al., 2004). In the present study, mature green fruits showed high TA value associated with TSS values below 10^{0}Birx.

Table 5. TSS: TA ratio of plum fruits at different maturity stages in two storage conditions

Maturity stage	TSS : TA ratio			
	Ambient condition		Refrigerated condition	
	Before storage	After storage	Before storage	After storage
Mature green	4.36c	18.19c	4.68c	7.89c
Turning red	10.95b	26.18b	11.53b	17.32b
Dark red	21.32a	32.67a	19.37a	26.41a
Mean	12.21	25.68	11.86	17.21
CV (%)	27	16.1	31	37.2
P-value	<.001	<.001	<.001	<.001
LSD (0.05)	3.698	4.634	4.131	7.179

Post-harvest shelf-life

In ambient condition, fruit were normal for 14 days of storage. However, there were some changes like softening of peel and pulp, aroma and taste were observed after 12 days. In refrigeration, fruits were stored for 28 days but their above-mentioned qualities started reducing after 22 days showing softness in fruit peel. After 14 days in ambient condition and after 28 days in refrigeration the fruits completely loose their quality and they were discarded from the experiment. In the refrigeration, symptoms of chilling injury were observed after 22 days. There are many treatment factors responsible for extending post-harvest life of plum fruits. For instance, application of CMC (carboxymethylcellulose) - based edible coatings was a promising method for increasing fruit quality and shelf-life (Panahirad et al., 2019). Similarly, post-harvest application of $CaCl_2$ (4%) was the most effective treatment in improving the shelf-life and quality of fruits up to four weeks against control fruits (Mahazam and Dhatt (2004). Other important factors are temperature and relative humidity. Storage temperatures less than 15^0C increased chilling injury and its severity while temperatures increased from 0 to 15^0C juice pH, TSS and weight loss increased (Emonger and Ramagonono, 2019). Similar 85-90% RH was appropriate for storing plums (Yahaha, 2019). The 100% red fruits stored at 2^0C maintained the best quality during storage while the fruits without refrigeration and stored at 18^0C only reached 10 days and refrigerated fruits at 4^0C and 2^0C continued for 24 and 31 days respectively (Alvarez-Herrera et al., 2021). Another limiting factor of storage life is disease. Fruits coated with the extract of an algae *Ascophyllum nodusum* @ 0.4 ml/L reduced the incidence and severity of brown rot disease (Viencz et al., 2020). In the present study, rotting of some fruits was started after 12 days in ambient condition and after 22 days in refrigerated condition. However, its cause was unknown.

Conclusion

Plum fruits were suited to harvest when fruits were at mature green stage (<5% color change). Fruits could be stored for 12 days with proper quality in ambient room condition whereas they could be stored for 22 days with proper quality in refrigerated condition. Post-harvest shelf-life could be extended for 14 days in ambient condition and for 28 days in refrigerated condition if the appropriate combination of temperatures and relative humidity could be maintained. Several other physico-chemical parameters should be considered to determine appropriate time of harvesting and duration of storage.

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Declaration of Conflict of Interest and Author's Contribution

We declare that we do not have any type of competing interest related to the manuscript. Among the authors, Kalika Prasad Upadhyay designed the experiment, set up the experiment and wrote the manuscript. Shyam Prasad Paudel assisted in data management and preliminary review of manuscript. Chandra Kanta Timilsena and Resham Bahadur Basnet assisted in collecting experimental materials, arranging in the laboratory and recording data.

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