Maturity Stages and Packaging Perforations Affect the Quality of Plum in Cold Storage

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ABSTRACT

The influence of maturity stages (pale green, yellow and purple) and package perforations (0, 5, 10, 15, 20 and 25) was investigated on the quality of plum fruit during storage (25 days) at low temperature (5±2 °C). The fruit quality was significantly affected by maturity stages (MS), packing perforation (PP) and storage duration (SD) as well as the MS x SD and PP x SD interactions. After 25 days storage, the fruits harvested at pale green stage had the lowest weight loss (1.81%) and disease incidence (3.71%), which increased to the highest 2.28% and 17.61%, respectively in fruits harvested at purple stage of maturity. In PP x SD interaction, the weight loss (5.23%) and disease incidence (18.58%), after 25 days storage were maximum in 0 package perforations and the least 1.24% and 1.86% respectively with 15 package perforations. The MS x SD interaction resulted in maximum fruit firmness (4.81 kg cm⁻²) and titratable acidity (0.735%), acidity (0.92%), Ascorbic acid (6.18 to 6.39 mg 100 g⁻¹) and disease incidence (3.71%), which increased to the highest 2.28% and 17.61%, respectively in fruits harvested at purple stage. Similarly, storage of fruits for 25 days resulted in significantly lower fruit firmness and titratable acidity as compared to corresponding values at each maturity stages. By contrast, the least TSS (7.58%), TSS/Acid ratio (6.18) and Ascorbic acid (5.78 mg 100 g⁻¹) was recorded at pale green stage increased to the maximum of 12.78%, 13.89 and 6.99 mg 100 g⁻¹, respectively at purple stage. In PP x SD interaction the range of fruit firmness (4.36-4.38 kg cm⁻²), acidity (1.001 to 1.005%) and Ascorbic acid (6.18 to 6.39 mg 100 g⁻¹) at day 0, decreased at each level of package perforations, with the highest fruit firmness (2.57 kg cm⁻²), acidity (0.735%) and Ascorbic acid (5.78 mg 100 g⁻¹) recorded in fruits stored with 15 packages perforation. Plum fruits harvested at pale green stage packed in 15 perforation packages proved the best in retaining most of the quality attributes during storage.

Key words: Fruit quality attributes maturity stages, perforation packages, plum, shelf life.

INTRODUCTION

Plum is a deciduous fruit of the family Rosaceae, mostly grown in temperate region, but some low chilling varieties can be grown in the mild subtropical region (Malik, 2005). In Pakistan, plum is second to peach in area and production (Shahzad et al., 2013). Plum is a climacteric and highly perishable fruit (Lee et al., 2013). The postharvest losses in the market channel of the plum are estimated at 21.51% and the major reasons for these losses are poor harvesting methods, harvesting over mature fruits, insufficient cold storage facility, poor grading, low-quality packaging materials and poor infrastructure (Shehzad et al., 2013). Thus, optimizing pre- harvest management practices such as application of gibberelic acid and harvesting the fruit at physiological maturity increase the storage life of plum fruit (Valero et al., 2008; Vandgal et al., 2012). Harvesting the fruit at proper maturity stage is a critical factor influencing fruit quality and storage performance (Crisostro et al., 2004).

Attempts have also been made to improve storage performance by optimizing temperature management (Lee et al., 2013) and application of edible coating (Bal, 2013; Seglina et al., 2013) and other chemicals such as 1-MCP (Erkan et al., 2012). Storage of fruits in modified atmosphere, characterized by elevated temperature and low oxygen concentration is one of the powerful techniques to delay senescence and retain fruit quality during storage (Kader, 2002; Vangdal et al., 2012). Modified atmosphere is generated by covering the packages with low density polyethylene films (Steffens et al., 2009; De-Santana et al., 2011) or covering with non-permeable film with specified perforations (Erkan et al., 2012). The number of perforations regulates the flow of respiratory gases in and out of the package and, thus, delays ripening and retains fruit quality during storage (Kader, 2002). The physical properties of the film and the respiration rate of the product are some of the factors that determine the success of modified atmosphere packaging (MAP) (Wargo et al., 2003). Since, metabolic processes such as respiration and ripening rates are sensitive to temperature (Sectar et al., 2010), MAP storage is more effective at lower temperatures (Crisosto et al., 2004; Guerra and Casquero, 2008). Keeping in view the importance of maturity stages and MAP, the current experiment was conducted to determine the storage life and quality of plum fruit harvested at different stages of maturity, and stored in packages covered with plastic film with different perforations.


MATERIALS AND METHODS

The experiment to evaluate the storage life of plum fruits stored in packages covered with perforated plastic films was conducted at the Postharvest Laboratory, Department of Horticulture, University of Agriculture, Peshawar. The plum fruits cv. Fazle Manani were harvested at pale green, yellow and purple stages of maturity and packed in packages covered by films having 0 (sealed), 5, 10, 15, 20 and 25 perforations of 2 mm diameter. At each maturity stage, the freshly harvested fruit were sorted and fruit of uniform maturity were selected as samples and divided into two groups. One group (day 0 of storage) containing 54 fruits were used for biochemical analysis. The other lot was packed in packages with specified perforations and shifted to cold storage (5±2 °C) and stored for 25 days. Data was recorded on the following parameters:

Weight loss of plum fruits was calculated by the difference between the initial and final weight for each treatment in each replication, expressed in percent (%) using the following equation:

\[ \text{Weight loss} = \frac{\text{Weight of fresh fruit} - \text{Weight after 25 days storage}}{\text{Weight of fresh fruit}} \times 100 \]

Disease incidence was calculated by visually examining the fruits after 25 days storage. Fruits with symptoms of disease were counted and converted to percent disease incidence (Mamatha and Rai, 2000).

\[ \text{Disease incidence} (%) = \frac{\text{Number of fruits stored}}{\text{Total number of fruits stored}} \times 100 \]

Fruit firmness was determined with hand held penetrometer (Effigi, FT-11) following the method used by Pocharski et al. (2000). A small portion of plum fruit was peeled and the flesh firmness was determined by penetrating the probe into the tissue. Five readings were taken and average was recorded for each treatment.

The total soluble solids (TSS) of the randomly selected plum fruit for each treatment were identified with the help of hand refractometer (Kernco Instruments Co Texas) (Ranganna, 1986). A drop of juice extracted from the selected fruit was placed on the clean glass of refractometer then readings were recorded. For every reading glass prism was washed with distilled water.

Titratable acidity (TA) (%) of the samples was determined by using recommended method of AOAC (2000). For this purpose, 10 ml of plum fruit juice was diluted to 100 ml with distilled water. From the solution, 10 ml was transferred to a conical flask and titrated against 0.1 N NaOH solution. Phenolphthealin was used as indicator by adding 2-3 drops. Reading was noted when pink color of sample persisted. The percent acidity was calculated by the following formula:

\[ \text{Ascorbic acid (mg /100 g)} = \frac{\text{F X T X 100}}{\text{D x S}} \]

Where F = Dye standardization factor
T = ml of dye used in titration.
D = ml of diluted sample used.
S = grams of plum juice used for dilution.

**Statistical Procedures:** The experiment was conducted under Completely Randomized Design (CRD) with three factors (maturity stages, package perforations and storage) and three repeats. The data on different parameters were analyzed through Analysis of Variance (ANOVA) technique to observe the differences between different treatments as well as their interactions. In cases where the differences were significant, the means were separated by Least Significant Difference (LSD) test (Steel et al., 1997).
RESULTS AND DISCUSSION

Weight Loss (%): Maturity stages (MS), storage duration (SD) and the number of perforations in packages (PP) significantly influenced the weight loss of plum fruits (Table 1). The interactions of MS×SD and SD×PP also significantly affected weight loss. The MS × SD interaction also significantly affected the weight loss during storage. The least weight loss (1.81%) in fruit harvested at pale green stage increased to 2.04% and 2.28% in yellow and purple stages of harvest and storage for 25 days. The PP×SD interaction revealed the highest weight loss (5.23%) was recorded with no perforations that declined to the least (1.24%) with 15 perforations in package but increased to 2.13 with 25 perforations in package. The weight loss of fruit is due to water loss through transpiration and loss of carbon in respiration process, which generally increases with delayed harvesting (Hardenburg et al., 1990). The greater weight loss in closed plastic packages might be due to high CO₂ and low O₂ levels in such packages that induce anaerobic respiration and increased the weight loss (Tariq et al., 2001). Similarly, the higher weight loss in fruits harvested at later stage of maturity could be attributed to higher respiration and transpiration losses (Ngebo et al., 2012). The present results are in close relation with Rashidi et al. (2014) who reported conservation of moisture content in nectarine with wrapping and packing material. Similarly, Sabir and Sabir (2013) also detected lower moisture loss when wrapping material was used during the storage of grapes. MAP, as a most common wrapping material, was reported to prevent water loss of minimally processed table grapes (Sabir et al., 2011).

Disease incidence (%): The disease incidence was significantly affected by maturity stages, package perforation and storage duration. The interactions of PP×SD and MS×SD also significantly affected the disease incidence of plum fruits. The interaction of MS×SD indicated that the fruits stored for 25 days had the highest disease incidence (17.61%) when harvested at purple stage, while the least disease incidence (3.71%) was recorded with harvesting the fruits at pale green stage of maturity (Table 1). The interaction of package perforations and storage duration revealed the highest (18.58%) disease incidence after 25 days storage in un-perforated packages and declined to 1.86% with increasing the number of perforation to 15 with the same storage duration. The highest disease incidence in packages with 0 perforations may be due to accumulation of moisture around the fruit that provide favorable environments for microbial growth and, thus, aggravate spoilage (Jawandha et al., 2012). The higher spoilage with fruit harvested at more mature stages may be due to the enhanced enzyme activities and disintegration of cell wall (Navjot and Sukhjit, 2010).

Fruit Firmness (kg cm⁻²): The fruit firmness was significantly affected by MS, PP and SD (Table 2). The interaction of MS and SD resulted in significant decrease in fruit firmness with advance in maturity from pale green (4.81 kg cm⁻²) through yellow (4.51 kg cm⁻²) to purple (3.78 kg cm⁻²) in fresh fruit; to 2.78, 1.19 and 1.09 kg cm⁻² in fruits stored for 25 days (Table 2). The interaction of PP x SD revealed that fruit firmness in freshly harvested (day 0) fruit ranged from 4.36 to 4.38 kg cm⁻² and decreased to 1.13, 1.39, 1.89, 2.57, 1.97, and 1.35 kg cm⁻² in fruit stored for 25 days in packages with 0, 5, 10, 15, 20 and 25 perforations, respectively. The firmness of the fruit depends on the texture of the flesh and changes in primary cell wall during ripening. During ripening, the primary cell wall and middle lamella are disassembled by enzymatic breakdown and pectin solubilization (Kov et al., 2003). Thus, the mechanical strength of cell walls is decreased with a concomitant decrease in the firmness of fruits (Kov et al., 2005). The decline in fruit firmness with maturation has been commonly observed in different fruits (Jan et al., 2012). Thus, the fruit harvested at physiological maturity (pale green stage) retains firmness during storage (Parker and Malleku, 2013). Package perforations are effective in increasing CO₂ concentrations and decreasing O₂ (Erkan et al., 2012), which retard the loss of firmness (Tariq et al., 2001). However, the least fruit firmness in packages with 0 perforations indicates high CO₂ or low O₂ levels that may result in fruit softening (Kader, 2002). Very low concentration may also induce anaerobic respiration that may accelerate the ripening and senescence (Saquet and Streif, 2008). Khan et al. (2013) reported a retained firmness in plum fruits with different packaging material. Similarly, Rashidi and Bahri (2014), reported a decrease in plum fruit firmness with increasing storage durations. Similar results were also reported by Zhou et al. (2011) and Tsegay et al. (2013).

Total Soluble Solids (%Brix): MS, PP and SD significantly affected the TSS of plum fruit (Table 2). The interactions of PP, SD and MS, also had significant effect on TSS of fruit juice. MS×SD interaction significantly influenced total soluble solids, with the minimum TSS (7.58°Brix) at pale green stage at day 0 of storage that increased significantly to 10.42 and 12.78°Brix in fruit harvested at yellow and purple stages of maturity. Storage for 25 days resulted in significant increase in TSS as compared to respective TSS content in fresh fruits. The highest TSS content (16.44°Brix) was in plum fruits harvested at purple stage and stored for 25 days. The interaction of package perforation and storage duration indicated that TSS ranged in fresh fruits (Day 0) ranged 9.91 to 10.87°Brix that increased at each perforation levels after 25 days storage at low temperature. The total soluble solids of plum fruits stored in sealed packages (15.41°Brix) declined significantly to
the least (11.56°Brix) in fruit with 15 package perforations. However, increasing the number perforation to 20 and 25 increased the TSS content to 12.69 and 12.92°Brix respectively. The total soluble solids content of the fruit generally increases during ripening and storage (Mohlra et al., 2000; Kader, 2002; Muftuoglu et al., 2012). However, the changes in TSS depend on the packing materials (Khan et al., 2007; Toivonen and Brummell, 2008). The increase in TSS during storage is attributed to the enzymatic conversion of the starches and pectins into simple sugars during ripening and storage (Jan et al., 2012; Bidyut et al., 2013). Since the package perforations modify the package environments by increasing CO₂ and decreasing O₂, which decrease the rate of respiration and ethylene production, thus, it delays the ripening of the fruits in the package (Saquet and Streif, 2008; Erkan et al., 2012). Results explain the greater efficiency of 15 package perforations as compared to higher (20 and 25) perforations in retaining the TSS content of the fruit. On the other hand, the highest TSS in sealed packages (0 perforations) could be due to the induction of anaerobic respiration due to very low levels of oxygen in the package atmosphere, as indicated by Saquet and Streif (2008).

Titratble acidity (%): The titratable acidity (TA) was significantly affected by the PP, MS and SD and the MSxS and PPxS interactions (Table 2). The interaction of maturity stages and storage duration showed that the TA of pale green plum fruits was the highest 1.11% at day 0 that decreased to 0.98 and 0.92% in fruits harvested at yellow and purple stage. TA declined with storage and was lower after 25 days storage as compared to top corresponding harvesting stage at day 0. The package perforations and storage interaction indicated, after 25 days storage, the highest TA (0.735%) was recorded in fruit stored in packages with 15 perforations that declined with both lower and higher number of perforations in package. Titratable acidity was 0.43 and 0.57% in fruits packed with 0 and 25 perforation respectively. Since the organic acid are consumed in respiratory metabolism (Beaudry et al., 1992), the acidity of the fruit generally decline during ripening and storage (Tariq et al., 2001; Shafique et al., 2006). The results are also in accordance with the findings of Jan et al. (2012). The modified atmosphere generated by package perforations helps in delaying the ripening and retain high levels of organic acid in the fruit (Beaudry et al., 1992). However, very low O₂, as occurred in the sealed packages, may actually induce the loss of organic acid due to high rate of respiration (Tariq et al., 2001). Pretel et al. (1999) and Khan et al. (2007) also recorded a decrease in TA of apricot and persimmon with storage duration. On the other hand, the results contradict with those of Muftuoglu et al. (2012) who recorded an increase in TA in apricot with different packaging material.

TSS/Acid Ratio: The TSS/Acid ratio of plum fruits was significantly affected by the interaction of maturity stages and storage duration as well as package perforations and storage duration (Table 2). The data related to the MS x SD interaction revealed that the TSS/Acid ratio was 6.18 in fresh fruits (day 0) and increased with advanced maturity to 10.63 and 13.89 in fruits harvested at yellow and purple stages of maturity, respectively. At each maturity levels, however, the TSS/Acid was significantly higher after 25 days storage at low temperature. The PP x SD interaction also altered the TSS/Acid ratio. The TSS/Acid ratio ranged from 9.89-10.86 in freshly harvested. After 25 days storage, the highest TSS/Acid ratio was (28.67) in sealed packages (0 perforations), that declined to the minimum (15.73) with 15 package perforations but increased to 22.59 with 25 package perforations. Since the TSS increased while acidity declined with harvesting at later stages of maturity, the TSS/Acid ratio increased accordingly with maturity stages or storage (Hussein et al., 2001; Tariq et al., 2001). These results are in agreement with Navjot and Sukhjit (2010). Similarly, the decrease in O₂ and elevated CO₂ due to package perforations delay the ripening (Zanella, 2003) and resulted in lower TSS/Acid ratio (Erkan et al., 2012). However, very low O₂ or very high CO₂ can also be detrimental to the fruit (Saquet and Streif, 2008).

Ascorbic Acid Content (mg.100g⁻¹): The ascorbic acid was significantly affected by the MS, PP and SD as well as the interactions of MS x SD (Figure 1) and PP x SD (Figure 2). The interaction of maturity stages and storage duration revealed that the Ascorbic acid content of freshly harvested plum fruit (day 0) was 5.78, 5.88 and 6.99 mg.100g⁻¹ with harvesting at pale green, yellow and purple stages, respectively. Storage for 25 days resulted in significant decrease in ascorbic acid content as compared to fresh fruits. The package perforations and storage interaction indicated that there was no significant difference at day 0 of storage. The ascorbic acid content of fruits stored in packages with 15 perforations had the highest ascorbic acid content (5.78 mg.100g⁻¹) after 25 days storage. The minimum ascorbic acid content (4.24 mg.100g⁻¹) was in fruits stored in closed packages (0 perforations) that were statistically non-significant with 4.33 mg.100g⁻¹ observed in fruit stored in packages with 25 perforations (Figure 2). The ascorbic acid content of the fruit increases as the fruit reaches optimum maturity but begin to decline with over ripening and senescence (Lee and Kader, 2000). The decline of ascorbic acid is triggered by exposure to light, high or low temperature and bruising or natural oxidation (Lee and Kader, 2000). It is also interesting to observe that while ascorbic acid content of plum fruit slightly increased at later stages of harvest, but the decline after 25 days storage was 19.72% in fruit harvested at pale green stage as compared to...
52.07% in fruit harvested at purple stage of maturity (Figure 1). The number of perforations in packaging also affected the ascorbic acid content of the plum fruits. The minimum ascorbic acid in closed packages indicates the sensitivity of this vitamin to low oxygen or high CO₂ atmosphere (Lee and Kader, 2000). However, at optimum air change as provided by 15 perforations in the package, the ascorbic acid is retained at high levels (Nasrin et al., 2008). Thus, at optimum air change, perforated packages may provide a decrease in oxidative loss of ascorbic acid during storage (Shafique et al., 2006).

Among various maturity stages, plum fruit harvested at pale green stage retained most of the quality attributes and hence resulted in an increased shelf life (25 days). Furthermore, plum fruits packed in 15 perforation packages proved the best in keeping the post-harvest life for longer period of time (25 days).

Table 1. The influence of maturity stages and package perforations on weight loss and disease incidence of plum fruit after 25 days storage at low temperature

<table>
<thead>
<tr>
<th>Maturity stages</th>
<th>Weight Loss (%)</th>
<th>Disease Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 0</td>
<td>Day 25</td>
</tr>
<tr>
<td>Pale Green</td>
<td>--</td>
<td>1.81 b</td>
</tr>
<tr>
<td>Yellow</td>
<td>--</td>
<td>2.04 ab</td>
</tr>
<tr>
<td>Purple</td>
<td>--</td>
<td>2.28 a</td>
</tr>
<tr>
<td>LSD</td>
<td>0.326</td>
<td>2.71</td>
</tr>
<tr>
<td>Package Perforations</td>
<td>Day 0</td>
<td>Day 25</td>
</tr>
<tr>
<td>0</td>
<td>--</td>
<td>5.23 a</td>
</tr>
<tr>
<td>5</td>
<td>--</td>
<td>4.34 b</td>
</tr>
<tr>
<td>10</td>
<td>--</td>
<td>3.41 c</td>
</tr>
<tr>
<td>15</td>
<td>--</td>
<td>1.24 e</td>
</tr>
<tr>
<td>20</td>
<td>--</td>
<td>2.08 d</td>
</tr>
<tr>
<td>25</td>
<td>--</td>
<td>2.13 d</td>
</tr>
<tr>
<td>LSD</td>
<td>0.532</td>
<td>1.764</td>
</tr>
</tbody>
</table>

Values in a group followed by different letters are significantly different at $p \leq 0.05$.

Table 2. The interactions of MS x SD and package perforations x storage durations on Fruit firmness, TSS, Acidity and TSS/ Acid Ratio of plum fruit.

<table>
<thead>
<tr>
<th>Maturity stages</th>
<th>Fruit Firmness (Kg.cm²)</th>
<th>TSS (°Brix)</th>
<th>Acidity (%)</th>
<th>TSS/Acid Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 0</td>
<td>Day 25</td>
<td>Day 0</td>
<td>Day 25</td>
</tr>
<tr>
<td>Pale Green</td>
<td>4.81 a</td>
<td>2.78 b</td>
<td>7.58 e</td>
<td>11.59 c</td>
</tr>
<tr>
<td>Yellow</td>
<td>4.51 a</td>
<td>1.19 c</td>
<td>10.42 d</td>
<td>13.89 b</td>
</tr>
<tr>
<td>Purple</td>
<td>3.78 ab</td>
<td>1.09 c</td>
<td>12.78 bc</td>
<td>16.44 a</td>
</tr>
<tr>
<td>LSD</td>
<td>1.351</td>
<td>1.35</td>
<td>0.21</td>
<td>2.37</td>
</tr>
<tr>
<td>Package Perforations</td>
<td>Day 0</td>
<td>Day 25</td>
<td>Day 0</td>
<td>Day 25</td>
</tr>
<tr>
<td>0</td>
<td>4.37a</td>
<td>1.13 d</td>
<td>9.91 c</td>
<td>15.41 a</td>
</tr>
<tr>
<td>5</td>
<td>4.36a</td>
<td>1.39 cd</td>
<td>10.38 c</td>
<td>14.67 a</td>
</tr>
<tr>
<td>10</td>
<td>4.38a</td>
<td>1.89 c</td>
<td>10.87 c</td>
<td>12.59 b</td>
</tr>
<tr>
<td>15</td>
<td>4.38a</td>
<td>2.57 b</td>
<td>10.37 c</td>
<td>11.56 bc</td>
</tr>
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<td>4.37a</td>
<td>1.97 bc</td>
<td>10.27 c</td>
<td>12.69 b</td>
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<tr>
<td>25</td>
<td>4.37a</td>
<td>1.35 cd</td>
<td>10.49 c</td>
<td>12.92 b</td>
</tr>
<tr>
<td>LSD</td>
<td>0.63</td>
<td>1.57</td>
<td>0.23</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Values in a group followed by different letters are significantly different at $p \leq 0.05$. 

Figure 1. The influence of maturity stages on the ascorbic acid content of plum fruit. The vertical error bars represent LSD at $p \leq 0.05$.

Figure 2. The influence of package perforation on the ascorbic acid content of plum fruit. The vertical error bars represent LSD at $p \leq 0.05$.

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