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SHORT COMMUNICATION

Edible coatings influence the cold-storage life and quality of 'Santa Rosa' plum (*Prunus salicina* Lindell)

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Abstract Plum is a perishable fruit with a very short shelf life of 3–4 days. Several studies have suggested the possible use of edible coatings on maintaining quality and prolonging storage life of fresh horticultural produce. Hence, different edible coatings, namely, lac-based (2:3), Semperfresh™ (1:3) and Niprofresh® (1:5) were selected to observe their efficacy on quality retention of 'Santa Rosa' plums. The effects of these coatings on the physical, physiological and biochemical attributes were studied under cold storage conditions (2 ± 1 °C and 85–90% relative humidity). Our results revealed that all the coatings, especially the lac-based significantly reduced the weight loss and maintained higher firmness throughout the storage period. These surface coatings modified the respiration and ethylene rates of the plums and slowed down their metabolism as shown by the retention of texture of the tissue and delayed colour development. At the end of 35 days of cold storage, lac-based coating helped to retain nearly 55% higher fruit firmness and 21% higher antioxidant activity in fruits as compared to uncoated ones. However, the changes in total anthocyanin content were found to be suppressed by 13% in lac-based coated fruits. Overall, the results suggested that lac-based coating of plum fruits was most effective to extend the storage life of 'Santa Rosa' plums over other coatings and uncoated fruits under low temperature storage conditions.

Keywords Plum · Edible coating · Quality · Anthocyanin · Antioxidant activity

Abbreviations

1-MCP	1-Methylcyclopropene
MAP	Modified atmospheric packaging
WL	Weight loss
AOX	Antioxidant
CUPRAC	Cupric reducing antioxidant capacity
FID	Flame ionization detector

Introduction

Plum is considered as one of the most important stone fruits of temperate origin. Among different varieties of Japanese plum cultivated in India, 'Santa Rosa' is grown commercially and on a large scale (Chattopadhyay 2009). Plum has a short shelf life with rapid deterioration in quality after harvesting. However, owing to its high market value, there is a need to increase its shelf life. Several postharvest treatments such as application of 1-MCP (Sharma et al. 2013), MAP (Mare et al. 2005) and edible coatings (Valero et al. 2013; Eum et al. 2009) have been used for prolonging its shelf life. However, none of these is being practiced on a commercial scale in India because the information on these practices is sporadic, inconclusive and there is need to develop a farmer-friendly, cheap and easy-

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to-use alternative. However, scanning of literature revealed that several coatings are available in India for commercial use; these are easy-to-apply and satisfactorily extend the storage life of fresh horticultural produce (Singh 2010). These edible coatings are composed of polysaccharides, proteins, lipids or a blend of such compounds and have been applied successfully for prolonging the shelf life and maintaining quality of fresh horticultural produce (Dhall 2012). In addition, they also act as moisture and gas barriers and control microbial growth, preserve the colour and texture. The coatings are applied directly on the surface by dipping, spraying or brushing to create modified atmospheres (McHugh and Senesi 2000).

In India, several types of edible coatings are used on fruits, of which, Semperfesh™, Niprofresh®, Citrashine™ are commercially used in apples, strawberries and citrus. However, in the recent years, the Indian Institute of Natural Resins and Gums, Ranchi, Jharkhand, India has developed a lac-based coating that is an excellent film former with good barrier properties (Luangtana-anan et al. 2007). It has been widely used in the food and agro products and prolongs their shelf life (Valencia-Chamorro et al. 2009). Considering the potential of this newly developed lac-based coating vis-à-vis existing coatings, we planned to investigate the influence of the commercially available edible coatings for extending the storage life and also on the physical, physiological and biochemical attributes of 'Santa Rosa' plums, which is the most favourite plum variety among Indians.

Materials and methods

Experimental material and treatments

The fruits of 'Santa Rosa' plum were procured from a private orchard at Kullu, Himachal Pradesh (India) during 2013–2014. The harvested plums were sorted and graded and then divided into four lots of 30 kg each, having three replications of 10 kg each. The fruits of first three lots were dipped for 5 min in the solution of edible coatings such as Semperfresh™ (1:3), Niprofresh® (1:5), lac-based coating (2:3), respectively. The fruits of 4th lot (control) were dipped in distilled water for 5 min. After treatment, the plums were air-dried for 15 min., packed and transported to Delhi and stored at 2 ± 1° C and 85–90% RH for 35 days. During storage period, observations on physical, physiological and biochemical attributes were recorded at weekly interval.

Determination of fruit firmness and weight loss (WL)

Fruit firmness was determined using a texture analyzer (model: TA + Di, Stable micro systems, UK) using compression test and expressed in Newtons (N) (Sharma et al. 2013). WL was determined by subtracting the final fruit weight from the initial weight and expressed as percentage (%).

Changes in peel colour

Peel colour of coated and uncoated plums was determined using Hunter Lab Colour Meter (model: Miniscan XE PLUS). The colour value was expressed as chroma index and hue angle and calculated by using corresponding a* and b* values (McGuire 1992) as shown below.

$$\mathrm{chroma} = \left(a^2 + b^2\right)^{1/2}$$

$$\mathrm{hue} = \tan^{-1}(b/a)$$

Determination of rates of respiration and ethylene evolution

Respiration rate in the in coated and uncoated plums was measured using auto gas analyzer (Model: Checkmate 9900 O_2/CO_2, PBI Dansensor, Denmark) and expressed as ml CO_2 kg^{-1} h^{-1} FW. The rate of ethylene evolution was measured by Hewlett Packard gas chromatograph (model 5890 Series II) equipped with a FID, Porapack-N 80/100 mesh packed stainless steel column and expressed as μl C_2H_4 kg^{-1} h^{-1} FW.

Determination of total anthocyanin content and total antioxidant (AOX) activity

The anthocyanin content (mg kg^{-1} FW) in coated and uncoated was determined on a UV–visible spectrophotometer (Perkin-Elmer) by the pH differential method (Wrolstad et al. 2005). The AOX activity was determined by following the CUPRAC method (Apak et al. 2004) and represented as μmol Trolox g^{-1} FW.

Sensory evaluation

The uncoated and coated fruits were subjected to sensory evaluation by a panel of 15 semi-trained judges during storage for appearance, colour, texture, odour, taste and overall acceptability at weekly interval on a 9 point hedonic scale (1: dislike extremely; 5: neither like nor dislike; and 9: like extremely) (Amerine et al. 1965).

Statistical design and analysis of data

Two way analysis of variance (ANOVA) was performed on the data sets using SAS 9.3 software and significant effects ($P < 0.05$) were noted. Significant difference amongst the means was determined by Tukey's HSD.

Results and discussion

Fruit firmness and weight loss (WL)

Softening of fruits is considered as one of the important quality changes associated with fruit ripening, which is generally caused by the degradation of pectin in the fruit cell wall (Bal 2013). The loss of texture affects the acceptability of the fruits by the consumers that determines its marketability (Eum et al. 2009). In the present study, firmness of plum fruits declined gradually with the advancement in storage period in all the treatments. A 86.9% decrease in firmness was observed in control fruits (water dipped) after 35 days of storage. Owing to the increased softness and loss of texture, the control fruits were found to be acceptable only till 28 days of storage as judged by the sensory panelists. In contrast, fruits coated with different coatings displayed a slower rate of decrease in fruit firmness. Further, coated fruits showed higher retention of firmness till 35 days of storage, the maximum being in lac-based coated fruits (9.57 N) followed by those coated with Semperfresh™ (9.16 N) (Table 1). At the end of storage period, lac-based coated fruits showed about 55% higher fruit firmness than uncoated fruits, followed by those coated with Semperfresh™ (~ 53%). Higher retention of firmness by the coated fruits indicated that coatings were effective in retarding the water loss, metabolic and enzymatic activities in plums and also degradation of cell wall components (Yaman and Bayoundurlc 2002). Further, lac-based coating was observed to be best in retaining firmness primarily because of better control of this coating on moisture loss from the fruits. Some previous studies have also reported similar results of delaying fruit softening by shellac coatings in apples (Bai et al. 2002), Semperfresh™ coatings in quinces (Yaman and Bayoundurlc 2002) and cherries (Yurdugul 2005). These effects of edible coatings on fruit firmness are primarily due to the fact that coatings act as an extra layer on the fruit surface, which coats the stomata and pores, leading to a decrease in transpiration, and thereby the moisture loss, which is ultimately responsible for maintaining the firmness of the fruits (Bai et al. 2002).

Plum fruits are susceptible to rapid loss of water due to their very thin peel which results in fruit shrinkage. Therefore, the weight loss was monitored over the storage

Table 1 Effect of different edible coatings on weight loss and firmness in plum cv. 'Santa Rosa' stored under low temperature (2 ± 1 °C and 85–90% RH) conditions

Treatments	Weight loss (%)					Firmness (N)					
	Storage period (days)					Storage period (days)					
	7	14	21	28	35	0	7	14	21	28	35
Uncoated	2.09 ± 0.41^{hg}	6.74 ± 0.01^{ebdac}	7.51 ± 0.78^{bac}	7.93 ± 0.65^{ba}	8.84 ± 0.24^{a}	13.50 ± 0.49^{ba}	11.50 ± 0.23^{bac}	9.10 ± 0.19^{dc}	5.20 ± 0.11^{egf}	4.98 ± 0.06^{egf}	1.76 ± 0.04^{h}
Niprofresh®	1.84 ± 0.27^{hg}	5.65 ± 0.10^{ebdcf}	6.23 ± 0.11^{ebdacf}	6.86 ± 0.25^{bdac}	7.26 ± 0.09^{bac}	13.70 ± 0.42^{ba}	11.80 ± 0.25^{bac}	10.70 ± 0.09^{bc}	6.02 ± 0.12^{egdf}	5.50 ± 0.13^{egf}	2.96 ± 0.02^{gh}
Lac-based	1.21 ± 0.01^{h}	3.65 ± 0.23^{ehg}	3.82 ± 0.18^{ehggf}	4.15 ± 0.05^{ehdg}	4.53 ± 0.18^{edgcf}	14.20 ± 0.19^{a}	13.20 ± 0.20^{ba}	11.50 ± 0.36^{bac}	8.41 ± 0.21^{edc}	6.22 ± 0.20^{edf}	3.92 ± 0.10^{ghf}
Semperfresh™	1.11 ± 0.22^{h}	3.32 ± 0.10^{hgf}	3.86 ± 0.04^{ehdgf}	5.40 ± 0.11^{ebdef}	6.74 ± 0.44^{ebdac}	14.10 ± 0.30^{a}	12.90 ± 0.42^{ba}	11.20 ± 0.14^{bac}	7.13 ± 0.08^{ed}	5.91 ± 0.18^{egf}	3.75 ± 0.09^{ghf}

Means with same superscript are not significantly different

period to evaluate the effect of the coatings. The coated as well as uncoated fruits exhibited a continuous decline in weight over the storage period. However, the uncoated fruits showed maximum (8.84%) and rapid WL than the coated fruits. In contrast, lac-based coated plums showed a WL of 4.53% on 35 days of storage (Table 1). At termination of the experiment, lac-based and Semprefresh™ coated plums showed ~ 49 and 24% lower WL than uncoated plums. Increase in WL with the increase in storage period may be due to increase in transpiration rate from the fruits. In this study, lac-based coating displayed better efficacy in reducing WL in plums over other coatings and uncoated fruits. This may be as a result of the differences in moisture permeability of the applied coatings. In addition, edible coatings act as an extra layer, which also covers the stomata, leading to a decrease in transpiration and in turn, reduction in the WL. Our results were consistent with previous studies of Zhou et al. (2008) and Yaman and Bayoundurlc (2002) who reported a significantly reduced WL during storage of coated pear and cherry, respectively. A reduction in WL of chitosan coated guava has also been reported by Hong et al. (2012).

Peel colour

Changes in the peel colour of the uncoated and coated plums were evaluated by measuring the chroma and hue values during storage (Table 2). In general, chroma index showed an inconsistent trend while hue angle decreased significantly ($P \leq 0.05$) with the advancement in storage under all treatments and the fruits attained a deep purple colour with increase in storage time. Among the coatings, lac-based coated fruits resulted in the slowest decrease in hue angle which continued till 35 days of storage (48.87). Peel colour changed during storage in all plum samples to dark purple as could be inferred from the decrease in the values of chroma and hue angle. This can be ascribed to the synthesis of anthocyanins, the pigment contributing to the purple colour of plums (Valero et al. 2013). The colour changes in plums were delayed by all the edible coatings, suggesting a delay in the maturation/ripening of the fruits and suppression of the metabolic activities as reported earlier by Eum et al. (2009) and Valero et al. (2013) in coated plums. A decreasing trend in hue angle was also reported earlier by Liu et al. (2014) during storage for the ascorbic acid + chitosan coated plum fruits with the corresponding highest chroma index for the coated fruits.

The rates of respiration and ethylene production

The changes in the respiration rate of uncoated as well as coated plums were monitored during storage period. It was observed that irrespective of treatment, the rate of

Table 2 Effect of application of different edible coatings on chroma and hue values in plum cv. 'Santa Rosa' stored under low temperature (2 ± 1 °C and 85–90% RH) conditions

Treatments	Chroma					
	Storage period (days)					
	0	7	14	21	28	35
Uncoated	26.85 ± 0.86^{ba}	21.57 ± 0.32^{ba}	21.20 ± 0.26^{ba}	16.16 ± 0.31^{b}	19.38 ± 0.45^{b}	17.90 ± 0.15^{b}
Niprofresh®	22.08 ± 0.09^{ba}	22.58 ± 0.42^{ba}	26.75 ± 0.37^{b}	20.88 ± 0.46^{ba}	18.97 ± 0.47^{ba}	19.07 ± 0.41^{b}
Lac-based	32.35 ± 0.51^{ba}	33.05 ± 0.77^{ba}	41.91 ± 0.40^{a}	26.13 ± 0.52^{ba}	26.78 ± 0.84^{ba}	25.37 ± 0.56^{ba}
Semperfresh™	27.38 ± 0.50^{ba}	24.63 ± 0.45^{ba}	31.38 ± 0.82^{ba}	26.94 ± 0.47^{ba}	20.18 ± 0.41^{ba}	17.46 ± 0.64^{b}
Treatments	**Hue**					
	Storage period (days)					
	0	7	14	21	28	35
Uncoated	56.18 ± 0.85^{bdac}	50.98 ± 1.04^{ebdac}	47.02 ± 0.36^{ebdc}	40.74 ± 0.25^{edc}	37.62 ± 0.58^{ed}	33.66 ± 0.41^{e}
Niprofresh®	53.93 ± 1.85^{ebdac}	50.99 ± 1.04^{ebdac}	49.45 ± 0.74^{ebdac}	46.27 ± 0.73^{ebdc}	44.37 ± 1.34^{ebdc}	39.32 ± 1.44^{edc}
Lac-based	70.42 ± 0.35^{a}	62.75 ± 0.41^{ba}	60.40 ± 0.24^{bac}	53.31 ± 1.43^{ebdac}	53.19 ± 0.70^{ebdac}	48.87 ± 1.08^{ebdac}
Semperfresh™	70.70 ± 2.16^{a}	56.24 ± 0.96^{bdac}	49.04 ± 0.98^{ebdac}	47.64 ± 0.81^{ebdc}	46.26 ± 0.61^{ebdc}	39.69 ± 0.93^{edc}

Means with same superscript are not significantly different

respiration steadily increased initially, followed by a gradual decline in all the fruits. In general, the uncoated fruits recorded higher respiration rate than the coated fruits. The rate of CO_2 production increased in control (water-dipped) fruits and the climacteric peak was observed on 28 days of storage (26.52 ml CO_2 kg^{-1} h^{-1}). In all treatments, the attainment of respiratory peak was followed by a decline in the rate of respiration rate. Among the coatings applied, lac-based coated fruits (17.03 ml CO_2 kg^{-1} h−1) had a significantly ($P < 0.05$) lower respiration rate at the end of storage period followed by Semperfresh™ coated (18.15 ml CO_2 kg^{-1} h^{-1}) ones. At end of 35 days of storage, the respiration rate of control (water-dipped) samples was quite high (24.23 ml CO_2 kg^{-1} h^{-1}) than those coated with either of the coatings. Of the treatments, lac-based coating was found to be more effective in reducing the respiration rates of fruit because of the fact that it is more efficient in restricting the gas exchange between fruit and the atmosphere during storage (Bai et al. 2002). Similar effects of coatings on respiration rates have also been reported by Eum et al. (2009) and Zhou et al. (2008) on plums and pears, respectively.

The pattern of ethylene evolution in coated and uncoated 'Santa Rosa' plums was almost similar to the pattern of respiration rate. Uncoated plums (water-dipped) exhibited a drastic increase in the ethylene evolution rate from 14.23 to 36.56 µl kg^{-1} h^{-1} by the 14 days, followed by a steady decline up to the 35 days (23.98 µl kg^{-1} h^{-1}). Nevertheless, coated fruits recorded significantly lower rates of ethylene evolution than the uncoated plums, indicating the slowing down of the ripening process by the applied coatings. Among the coatings, lac-based coated plums exhibited a lower rate of ethylene evolution, which may be ascribed to better barrier properties of the lac-based coating over other coatings. Similar pattern of ethylene evolution rate has earlier been observed by Eum et al. (2009) and Valero et al. (2013) in versasheen and alginate coated plums, respectively. Similarly, a delayed ethylene production in hydroxypropyl methylcellulose coated plum has also been reported (Choi et al. 2016).

Total anthocyanin content and AOX activity

Our results revealed that there was an increase in the total anthocyanin content throughout the storage period both in coated and uncoated fruits (Table 3). However, the coated plums displayed a significant delay in the rate of increase in anthocyanin content. Fruits treated with lac-based coating showed the slowest rise in anthocyanins until the termination of experiment. During the course of the experiment, lac-based coated fruits showed ∼ 59% rise in anthocyanins as against ∼ 72% in uncoated (water-dipped) plums. The increasing trend in the concentration of

Table 3 Total anthocyanin content (mg/kg) and AOX activity (µmol Trolox g^{-1}) in plum cv. 'Santa Rosa' and stored under low temperature (2 ± 1 °C and 85–90% RH) conditions as influenced by edible coatings

Treatments	Total anthocyanin content (mg kg^{-1}FW)					
	Storage period (days)					
	0	7	14	21	28	35
Uncoated	112.25 ± 2.47^{n}	118.98 ± 3.22^{lk}	126.85 ± 1.72^{j}	160.56 ± 3.46^{e}	165.48 ± 3.54^{d}	192.65 ± 2.44^{a}
Niprofresh®	112.35 ± 1.12^{n}	114.25 ± 2.47^{nm}	120.65 ± 2.45^{k}	155.65 ± 5.50^{f}	160.25 ± 3.68^{e}	185.62 ± 5.13^{b}
Lac-based	112.52 ± 1.85^{n}	112.52 ± 1.52^{n}	116.41 ± 1.28^{lm}	140.65 ± 3.44^{i}	151.24 ± 4.56^{g}	178.65 ± 2.73^{c}
Semperfresh™	112.56 ± 1.70^{n}	113.52 ± 1.99^{nm}	118.56 ± 3.42^{lk}	145.26 ± 3.51^{h}	155.48 ± 2.61^{f}	180.25 ± 2.66^{c}
Treatments	**Total antioxidant activity (µmol Trolox g^{-1}FW)**					
	Storage period (days)					
	0	7	14	21	28	35
Uncoated	14.20 ± 0.28^{de}	16.00 ± 0.24^{bdac}	15.98 ± 0.36^{bdac}	15.02 ± 0.26^{bdec}	14.89 ± 0.27^{bdec}	12.69 ± 0.05^{e}
Niprofresh®	14.50 ± 0.32^{dec}	16.50 ± 0.34^{bdac}	16.56 ± 0.36^{bdac}	16.45 ± 0.29^{bdac}	16.39 ± 0.36^{bdac}	14.91 ± 0.10^{bdec}
Lac-based	15.30 ± 0.50^{bdec}	16.14 ± 0.38^{bdac}	18.96 ± 0.48^{a}	18.86 ± 0.28^{a}	18.46 ± 0.48^{a}	16.21 ± 0.48^{bdac}
Semperfresh™	15.20 ± 0.33^{bdec}	17.60 ± 0.29^{bac}	17.86 ± 0.74^{ba}	18.26 ± 0.03^{ba}	17.38 ± 0.37^{bac}	14.95 ± 0.53^{bdac}

Means with same superscript are not significantly different

anthocyanins in plums with the advancement in storage period may primarily be because of a progressive increase in ripening process leading to colour development. Further, the reduced rate of anthocyanin development in treated fruits may be due to reduction of respiratory activity and suppression of anthocyanin synthesis associated with postharvest ripening as reported by Diaz-Mula et al. (2012) in alginate-coated plums. Liu et al. (2014) have also reported that ascorbic acid and chitosan coated plums developed much lower anthocyanin content than uncoated fruits.

Plum fruits contain several important secondary metabolites such as flavonoids and phenolic acids, with a strong AOX activity. In this study, we observed that irrespective of the coating applied, the AOX activity was significantly higher in fruits coated with edible coatings than uncoated fruits (Table 3). In general, the antioxidant activity increased initially, followed by a progressive decline with the increase in storage duration. However, the maximum AOX activity after 35 days of storage was recorded in lac-based coated fruits (17.32 μmol Trolox g^{-1}). This indicated that edible coatings were able to maintain higher AOX activity in plums by delaying the senescence and decay in fruits, as also reported by Sánchez-González et al. (2011) in hydroxypropyl methylcellulose and chitosan coated grapes. Wang and Gao (2013) have also reported higher levels of antioxidant activity in strawberries coated with chitosan.

Sensory evaluation

Sensory evaluation was conducted to check the effect of coatings on the organoleptic acceptability of the plum fruits. As per results, the coated 'Santa Rosa' plums were

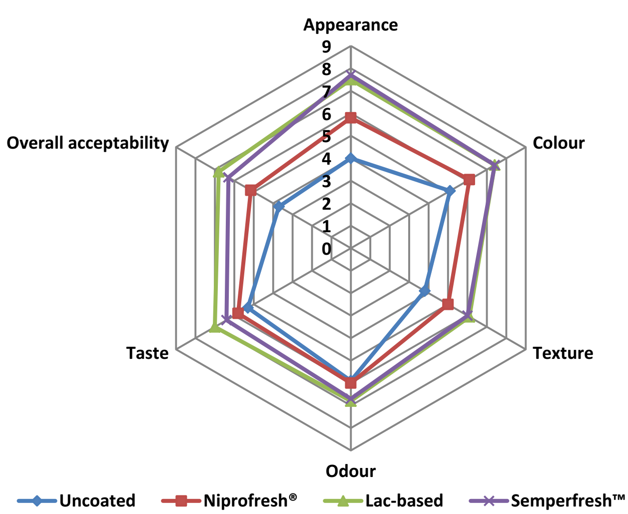

Fig. 1 Sensory scores of uncoated and coated plums at 35th day of storage at low temperature (2 ± 1 °C and 85–90% RH)

more acceptable than the uncoated ones at 35 days of storage and the coatings did not have a negative impact on consumer perception (Fig. 1). Further, the uncoated plum fruits became unacceptable at 28 days of storage due to enhanced softening (Table 1) as compared to the coated ones. The lac-based and Semprefresh^{TM} coatings on plums, enhanced the visual appearance of the fruits by imparting a glossy finish which resulted in higher sensory scores for appearance. Earlier, Reinoso et al. (2008) have also reported improved acceptability of the coated produce as consumers tend to buy products with good visual attributes.

Conclusion

It can be concluded from the study that the coatings evaluated in this study showed different effects on prolonging the storage life of the plums with lac-based coating showing the most promising effects. This coating extended the storage life of 'Santa Rosa' plums by about 7 days as compared to uncoated fruits by reducing weight loss, flesh softening and maintaining the quality and sensory acceptability.

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