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THE USE OF LIQUID COATING COMPOUNDS AS POSTHARVEST APPLICATION TO PLUM FRUITS

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Abstract. **Four liquid coating compounds; NatureSeal 2020, Nu Film 17, Nu-Coat-Flo, and chitosan at concentration of 100%, 10%, 10.3%, and 1%, respectively; and one aqueous polyamine treatment, 5mM putrescine, were applied to freshly harvested plum fruit (*Prunus salicina* cv. 'Blue goose') to study their effects on fruit storage and quality. After dipping for five minutes in solutions of these compounds, the fruits were air dried and stored in ventilated bags at 3 ± 2°C and 90-95% RH for 4 weeks. The treatment compounds benefited fruit storage and quality with variable effects. Fruits treated with NatureSeal 2020 or Nu-Film 17 were attractive, marketably acceptable and of better quality than fruits from other treatments.**

Postharvest losses of produce is a serious problem and usually ranges from 15 to 25% or more (Priser et al., 1981). Among the different methods used to reduce these losses are cooling, waxing, controlled atmosphere, modified atmosphere packaging and other methods. The use of polymeric coating or waxing has gained popularity in this respect because of its convenience and low cost (Ben-Yehoshua, 1978; Ben-Yehoshua et al., 1979). Waxing or applying polymeric coating substances to the surfaces of fruits and vegetables has been a useful practice to reduce moisture and postharvest quality losses of various fresh commodities (Baldwin, 1994). Weight loss, due to transpiration along with respiration, contributes to physiological deterioration of the fruit after harvest and during storage. The use of liquid coatings dates back to 1924 when Magness and Diehl (1924) studied the effects of oil and paraffin coatings on apples. Subsequent studies have provided evidence that such materials retained firmness, retarded softening, preserved quality, improved appearance and prolonged shelf-life of many fruits (Drake et al., 1987; Erbil and Muftugil, 1986; Hagenmaier and Shaw, 1991; Kramer et al., 1989; Lowings and Cutts, 1982; Meheriuk and Lau, 1988; Paull and Chen, 1989). The beneficial effects of waxing or polymeric coatings are directly related to gas and water vapor exchange between the fruit and its environment. The principal disadvantage, however, is the development of off-flavors which are attributed to the inhibition of O_2 and CO_2 exchange, thus resulting in anaerobic respiration and the accompanying elevated levels of ethanol and acetaldehyde (Ahmed and Khan, 1987; Dhalla and Hanson, 1988; Cohen et al., 1990). Currently, there are several coating substances available for commercial use for postharvest prestorage treatment of fresh fruits and vegetables. They generally contain shellac, natural waxes or sucrose esters of edible fatty acids as active components incorporated with other materials as well as various polysaccharide-based coatings. These materials, despite of their compositional differences, form an elastic film around the fruit which reduces the effect of environmental degrading factors.

Polyamines appear to be potent inhibitors of senescence-related processes in plant tissues (Galston and Kaur-Sawhney, 1987). The anti-senescent activity may be related to their antioxidant properties (Drolet et al., 1986), their ability to stabilize and protect cell membranes (Ballas et al., 1983; Roberts et al., 1986) and their inhibition of degradative enzymes such as protease (EC 3.4.24.4), RNase (EC 3.1.27.5) (Galston and Kaur-Sawhney, 1987) and peroxidase (EC 1.11.1.7) (Srivestava and Rajbau, 1983).

The purpose of this study was to investigate the effect of different coating compounds on the storage ability and quality of plum fruit.

Materials and Methods

'Blue goose' plum (*Prunus salicina* Lindel) were handpicked at a fruit firmness ranging from 35 to 39 Newton (N), and with soluble solid content (SSC) between 12 to 14 percent. Immediately after harvest, the fruits were put in cold storage overnight before being taken to the laboratory where they were sorted and treated with five treatment compounds. Uniform fruits were randomly assigned to five dipping solutions in a completely randomized design with three replications of ten fruits each. The dipping solutions consisted of NatureSeal 2020 (NS, a cellulose-based coating) (EcoScience, Orlando, FL) at a concentration of 100%, Nu Film 17 (NF17, a β-pinene polymer-based coating) (Miller Chemical & Fertilizer Co., Hanover, PA) at 10%, chitosan (CSN, a deacetylated form of chitin) (ICN Pharmaceuticals Inc., Costa Mesa, CA) at 1%, Nu-Coat Flo (NCF, a sucrose ester/cellulose-based coating) (United Agricultural Products, Greeley, CO.) at 10.3%, the polyamine, putrescine (PUT) (Sigma Chemical Company, St. Louis, MO) at 5 mM, and tap water as a control. An additional sample of 25 fruit was used to assess fruit initial (INIT) quality parameters at harvest. The fruits were submersed for about five minutes in the dipping solutions and dried at room temperature using a portable fan. After drying, the fruits were transferred to ventilated boxes and stored at 3 ± 2°C with 90% to 95% RH for four weeks. At the end of 2 and 4 week periods in storage, comparable samples of 25 fruits from each treatment were taken and immediately analyzed.

Fruit volume was determined by water displacement. firmness was determined using an Effegi penetrometer Model Ft 011 with an 8 mm plunger. The SSC was measured by means of a temperature compensated Atago refractometer. Titratable acidity (T.ac) was determined as previously reported (Graddick et al., 1986). Anthocyanins (T.Acy) were extracted by high speed blending of plum juice with 95% ethanol:1.5 M HCl (85:15,v/v). The concentration was then determined by

Table 1. Effects of liquid coating compounds on quality parameters of plum fruits after 2 weeks in cold storage.

	NC F	NS	NF 17	PUT	CSN	CONT	INIT[z]
Wt (g/fw)	49.2a[y]	43.8c	44.6b	43.7c	43.2c	38.4d	52.3
Vol. (cc/f.)	48.7a	42.9c	44.2b	42.0c	40.3d	34.5e	53.4
Firmness (N)	39.3a	34.5c	36.2b	32.1d	32.0d	29.6e	37.1
SSC (%)	12.6bc	12.8c	12.4bc	13.9b	13.2b	13.7a	12.1
T.ac (%)	0.92b	0.99a	1.04a	0.84c	0.91bc	0.82a	1.14
SSC/Acid (ratio)	13.69d	11.92e	10.76f	15.36b	14.51c	16.71a	10.61
pH	03.3a	03.3a	03.2a	03.3b	03.4a	03.4a	03.0
T. Acy	38.6b	34.3c	33.2c	37.6b	37.8b	40.1a	29.7
Deterioration (%)	8	8	8	12	16	33	

[z]NCF = Nu-Coat Flo, NS = NatureSeal, NF17 = Nu-Film 17, PUT = Putresine, CSN = Chitosan, CONT = Control, INIT = Initial sample.
[y]Average of 3 replications. Mean separation within rows using Duncan Multiple Range Test (5% level).

spectrophotometric analysis at 533 nm (Sapers et al., 1983, 1985) and was expressed as absorbance units (A.U.) per gram (Absorbance × dilution factor/sample weight).

Results and Discussion

The data obtained in this study indicate that the use of coating compounds on plum fruits resulted in less weight and volume losses and significant reduction in fruit deterioration over a four week period in cold storage.

Cold storage of treated, as well as control plum fruits resulted in a reduction in fruit weight, volume, firmness and titratable acidity and an increase in total anthocyanin and soluble solid contents (Tables 1, 2 and 3). Losses in fruit weight and volume were faster and more obvious in control than treated fruit and probably resulted from moisture loss due to fruit transpiration and weight loss due to respiration. Control fruit lost 27 and 35% weight and volume, respectively, after two weeks; 40 and 43%, respectively, after four weeks (Table 3). In contrast, regardless of the type of the treatment compound, weight and volume losses were much less for treated fruit: between 6 and 17 percent after two weeks and 23 and 31percent after four weeks in cold storage for weight and volume, respectively (Table 3). There were wide differences in fruit weight loss and volume among the different coating compounds used. Fruits treated with NCF retained the highest weight and volume during two weeks in cold storage (Table 1). However, fruits coated with NS or NF17 exhibited the least loss in weight and volume after four weeks in cold storage when compared with other coating compounds (Tables 2 and 3). The PUT and CNS treatments consistently resulted in rapid and significant fruit weight and volume losses particularly after four weeks in storage (Tables 2 and 3). However, since most of the water is lost from the outer layer of the fruit (exocarp), moisture loss primarily affects the appearance of the fruit. The consequence of moisture loss are shrinkage, softening, shriveling and deterioration of the fruit. While no data were obtained on the fruit juice content, it is believed that the inner portion of the fruit (mesocarp) is usually not affected depending on the type of the fruit (Purvis, 1983).

Retention of firmness was better in coated fruit than in non-coated fruit (Tables 1, 2 and 3). This agreed with data obtained by Meheriuk and Lau (1988) using Pro-Long (a sucrose ester/cellulose coating) and Nutri-Save (a chitosan coating) on pears. With the exception of the CSN treatment, treated fruits were significantly firmer (34.2- 29.7 N) than non-coated fruits (27.6 N) after four weeks in cold storage (Table 2). The apparent increase in firmness after two weeks in fruits treated with NCF was due to the solidification effect of this coating compound on the surface of the fruit, which evidently diminished after four weeks in cold storage. Fruits coated with NS or NF17 were the most firm (Table 2) and had the lowest firmness loss (Table 3) after four weeks compared to fruits from other treatments with the exception of the apparent high firmness values recorded for fruits treated with NCF. On the other hand, both PUT and CSN treatments were less effective in inducing firmer plum fruits than the other treatment compounds.

Soluble solids content generally showed an increases in both treated and non-treated fruit as the storage period increased (Tables 1, 2 and 3). This can be expected since the fruit ripens during storage. However, the percent increases in SSC were generally slower in treated fruits after two and four weeks in cold storage than in control fruits which received water treatment only (Tables 1, 2 and 3). This was probably due to a retardation of ripening induced by the coatings (Baldwin, 1994) and antisenescent putrescine. The differences in

Table 2. Effects of liquid coating compounds on quality parameters of plum fruits after 4 weeks in cold storage.

	NC F	NS	NF 17	PUT	CSN	CONT	INIT[z]
Wt (g/f.)	38.7b[y]	40.0a	40.3a	37.8c	36.1d	31.2e	52.3
Vol. (cc/f.)	39.3b	41.3a	41.4a	38.2c	36.7d	30.6e	53.4
Firmness (N)	34.2a	30.4c	32.1b	29.7c	27.4b	27.6d	37.1
SSC (%)	13.3c	13.2c	13.0c	13.6c	14.2b	15.5a	12.1
T.ac (%)	0.82b	0.89a	0.92a	0.80b	0.72c	0.62d	1.14
SSC/Acid (ratio)	15.8d	13.7e	12.45f	17.00c	19.72b	25.0a	10.61
pH	3.5b	3.4b	3.2bc	3.5b	3.9a	4.1a	3.0
T. Acy	39.4b	36.1d	37.3c	33.2e	40.6a	39.3b	29.7
Deterioration (%)	33	21	21	25	33	54	

[z]N-C F = Nu-Coat Flo, NS = NatureSeal, N-F 17 = Nu-Film 17, PUT = Putresine, CSN = Chitosan, CONT = Control, INIT. = Initial sample.
[y]Average of three replications. Mean separation within rows using Duncan Multiple Range Test (5% level).

Table 3. Percent increase or decrease in quality parameters on plum fruits during 4 weeks in cold storage as induced by liquid coating compounds.

	NC F		NS		NF 17		PUT		CSN		CONT'	
	Weeks in storage											
	2	4	2	4	2	4	2	4	2	4	2	4
Wt (g/f.)	6	24	16	29	15	23	16	28	17	31	27	40
Vol. (cc/f.)	8	26	20	23	17	22	21	28	25	31	35	43
Firmness (N)	30'	8	7	8	2	13	13	20	11	26	20	26
SSC(%)	4	10	6	10	2	7	7	13	9	17	13	28
T.ac (%)	27	19	13	22	11	19	26	30	20	37	28	46
T. Acy	30	33	15	22	12	26	27	29	27	37	35	32
Deterioration (%)	8	33	8	21	8	21	12	25	16	32	33	54

'N-C F = Nu-Coat Flo, NS = NatureSeal, N-F 17 = Nu-Film 17, PUT = Putresine, CSN = Chitosan, CONT = Control.

SSC increase among fruits treated with NCF, NS and NF17, however, were not statistically significant after two or four weeks of storage (Tables 1 and 2).

The increase in SSC is usually accompanied by a decrease in percent T.ac as fruit ripen. The decrease in concentration of organic acids during fruit maturity and ripening is presumably a consequence of the respiratory activities in the fruit. Sugars and organic acids can be utilized as respiratory substances. Coating compounds induced variable results on percent T.ac. There was, however, significant decreases in percent T.ac in non-treated fruits after four weeks compared to treated fruits (Table 2). Fruit juice pH was also higher in control fruit after four weeks of storage, reflecting the lower acidity (Table 2). This could be the result of ripening, senescence and deterioration of the fruit. The differences in the degree of acidity reduction in the juice obtained from plum fruits treated with different treatment compounds could not be explained.

The SSC/T.ac ratios for control fruit were considerably higher than for treated fruit, especially after four weeks of storage (Tables 1 and 2). Perhaps the slow increase in SSC and decrease in titratable resulted in lower SSC/T.ac ratios. This, however, does not imply that a high ratio necessarily means better quality. In fact, fruit with a low SSC/T.ac ratio may sometimes be preferable to those with high ratios which can have a bland flavor.

The characteristic color of 'Blue goose' plum is due to the presence of glycosides of pelargonium and cyanidin as well as other molecules. It was observed that there was a gradual increase in total anthocyanin as fruit was maintained in storage over a four-week period (Tables 1, 2 and 3). A similar trend was previously reported in blueberry fruit. (Basiouny, 1995). After two weeks in cold storage, the development of anthocyanins was significantly less in treated fruits than in controls (Table 1). Anthocyanin development seems to have been completed in plum fruits between the second and fourth week, a matter which attributed to less significant differences among treated and non-treated fruits analyzed after four weeks in cold storage. The increase in anthocyanin contents in fruits coated with NS or NF17 was slow and significantly less than in control fruits at two and four weeks in cold storage. No correlation between SSC/T.ac. ratio and T.Acy could be established in this study.

Coating compounds affected fruit quality parameters differently. It was obvious that NatureSeal 2020 and Nu-Film 17 were superior in their effects on fruit quality, storability and presumably consumer acceptance than the other compounds since these treatments resulted in the lowest percentage of deteriorated fruit at the end of the storage period (Table 2). This could be due to the permeability characteristics of these coatings. On the other hand, NCF when used as a 10.3% coating material for plum was more effective in reducing moisture and weight losses. However, percent deterioration, in addition to the off-flavor of fruit coated with this material was the highest among other treatment compounds tested after four weeks of storage (Table 2). In coating treatments, levels of CO_2, O_2, and ethylene during storage can be viewed as the result of interaction of the gas production/uptake and gas diffusion characteristics of the fruit and coating materials, respectively (Baldwin et al., 1995; Elkashif et al., 1983; Henig and Gilbert, 1975). The deterioration of NCF-coated fruits, was more than likely due to inadequate permeation characteristics, allowing anaerobic respiration and subsequent fruit deterioration. Polyamines appear to be potent inhibitors of senescence-related processes in plant tissue (Galston and Kaur-Sawhney, 1987). They were, in fact, found to inhibit the activity of the degradative enzymes RNase (EC 3.1.27.5), pectinase (EC 3. 4. 24. 4) (13) and polygalacturanase (EC 3. 2. 1. 15) (Kader, 1986; Wang, 1989). The results of this study, however, were in contrast with those obtained by Kramer et al. (1989). This could be due to the difference in commodity or due to the fact that the divalent PUT is much less effective than the trivalent spermidine, another polyamine (Kramer et al., 1989). The lack of effectiveness of chitosan as a coating compound for plum agreed with the conclusion reached by Al-Zaemy et al. (1994) who studied the effects of polymers and organic acids on the postharvest control of anthracnose on mango fruit.

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ASYMMETRIC DISTRIBUTION OF SUGARS IN CITRUS FRUITS: POSSIBLE PHYSIOLOGICAL CAUSES

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Abstract. **Sugars and related enzymes were determined at three stages of development in the stem and the blossom halves of 'Valencia' oranges (*Citrus sinensis* [L] Osbeck). The blossom half contained significantly higher concentrations of sugars at later stages of development. Neither the enzyme marker for sucrose synthesis (sucrose-phosphate synthase, SPS) nor enzymes of CO_2 fixation (NADP-malic enzyme, PEP carboxylase and PEP carboxykinase) were significantly different between the halves. Sucrose synthase (SS), a marker of sink strength, had significantly higher activity in the blossom half during later stages of fruit development when rapid sugar accumulation takes place. The data suggest that differential distribution of sugars between the stem and the blossom halves of citrus fruits is, in part, the result of differential sink strength.**

Soluble solids in citrus fruits are distributed unevenly both at the tree level (Syvertsen and Albrigo, 1980), and within the individual fruit as well (Bartholomew and Sinclair, 1946; Ting, 1969). Inside the fruit, soluble solids and total sugars are found in an increasing gradient towards the blossom end (Bartholomew and Sinclair, 1946; Ting, 1969), and on a outwardly radial direction. Bartholomew and Sinclair (1946) reported that mature oranges and grapefruits had considerably higher concentrations of soluble solids in the blossom halves than in the stem halves. Ting (1969) also observed an increase in the concentration of non-reducing sugars and total sugars along the axis of the mature fruit from the stem end to the blossom end. Unequal sugar distribution has also been reported for other mature fruits (Martin, 1954).

In citrus fruits, sugar content increases rapidly during development (Lowell et al., 1989) resulting from an increase in

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