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Research Article

EFFECT OF PAPER BAG TYPES ON FRUIT PHYSIOLOGY AND QUALITY OF PEAR CULTIVAR "PACKHAM'S TRIUMPH" DURING HARVEST AND STORAGE PERIOD

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Summary: In the present study, the effects of bagging on growth and fruit quality of pear cv. "Packham's Triumph" before harvesting and during the fruit storage period were investigated. Five fruit bagging treatments were used: 1) control, non-bagged fruits 2) double layer white paper bags (WPB) 3) double layer yellow paper bags (YPB) 4) double layer black paper bags (BPB) and 5) double layer black and red paper bags (RPB). Results showed that pre-harvest pear bagging affected fruit biochemical and technological quality and decreased fruit size in comparison to control non-bagged fruits, but it did not significantly change fruit acidity. Sucrose content in non-bagged control pear fruits significantly increased during the 1-month period of storage. A slightly lower content of sucrose was accumulated in all bagging variants compared to the control. It should be noted that within the first 15 days of fruit bagging, sucrose content increased significantly in all treatments followed by a subsequent decrease at the end of the storage. Almost the same pattern of changes was revealed in fructose, glucose and sorbitol concentrations where during harvesting minimal contents were detected, then in mid storage period they reached maximal values and were again reduced afterwards till the end of the storage period. The skin of control and WPB fruits was characterized with higher concentration of total chlorophyll. The highest fruit starch status - lightness color was measured in control and WPB variants during harvesting, whereas the highest dark staining was found in fruits coated with YPB, BPB and RPB bags. On the other hand, at the end of storage in a refrigerator, the flesh lightness index significantly increased especially in fruits coated with YPB, BPB and RPB bags, compared to control and WPB variants. During the storage period all bagged fruits were characterized with higher loss of weight as compared to non-bagged fruits. During harvest and subsequent storage period in a refrigerator, fruit firmness showed higher values in bagged fruits compared to control.

Keywords: Pear fruits; fruit bagging; fruit firmness; chlorophyll; glucose; fructose; sucrose; sorbitol.

Abbreviations: BPB – double layer black paper bags; RPB – double layer black and red paper bags; WPB – double layer white paper bags; YPB – double layer yellow paper bags.

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NTRODUCTION

Nowadays, modern fruit agriculture is impossible without appropriate physical protection techniques such as pre-harvest bagging of fruits. Some of them have found their rightful place and have been successfully used in agricultural production, but some of them are still under pilot study. The use of fruit bagging pursues many positive objectives: increased fruit yield and quality of cultivated products, accelerated maturation, improved fruit-setting, mechanical harvesting, prolongation of postharvest storage life, etc. (Hong et al., 1999; Amarante et al. 2002a; Choi et al. 2013).

The effect of bagging on growth and morphogenesis of plants has long been not only the subject of research, but also widely used in the practice of different sectors of crop production (Berrill 1956; Arakawa 1988; Husein et al., 1994; Joyce et al., 1997; Hofman et al., 1997; Li et al., 1998; Hasan et al., 2001).

Literature data show that the practice of pre-harvest bagging in pear crop is used to improve different fruit characteristics like size, maturity, skin, hardness, chemical contents as well as to decrease mechanical and biotic damage on fruit physiological, agrochemical residues in the fruit etc. (Kitagawa et al., 1992; Dussi et al., 1995; Hong et al., 1999; Amarante et al., 2002a-b; Huang et al., 2007; Huang et al., 2009; Ahn et al., 2009; Kim et al., 2010; Hudina et al., 2011; Choi et al.. 2013).

Moreover, nowadays under-expressed in bagged fruit skins there were identified protein spots which were classified into functional classes. These proteins were mainly involved in photosynthesis, signal transduction, energy pathways, carbohydrate and acidity metabolisms (Feng et al., 2011).

At present, fruit bagging is a conventional practice in pear cultivation worldwide aimed to improve the visual quality of the fruits. However, the bagging practice should be examined for its effect on fruit coloring, the effect of bag types and bag removal during fruit maturation and also their effect in the postharvest storage period. The main objective of this work was to investigate the effectiveness of different types of paper fruit bagging on fruit growth and ripening, fruit skin firmness, chemical composition of fruits, the process of fruit maturation and fruit storage.

MATERIALS AND METHODS

Plants, bagging materials, pre and post-harvest fruit storage conditions

The study was conducted with pear trees of cv. "Packham's Triumph" during 2013 growing season at the Pear Research Station of NIHHS, RDA (Republic of Korea). Pear fruits were coated with different paper bags to follow five treatments in fastened 18 randomly selected fruits on the 05th of June: 1) control non-bagged fruits; 2) fruits coated with double layer white paper bags (S.I-№6); 3) fruits coated with double layer yellow paper bags (No 126); 4) fruits coated with double layer black paper bags (PB4-B- HJ06); and 5) fruits coated with double layer black and red paper bags (No 126).

The inner and outer layers of the white paper bags were white in color while the yellow paper bags had a yellow layer both in the inner and outer parts. The first outside part of the outer layer of the black paper bags had a gray color and the inner part was entirely black while the second inside layers had a dark blue color on both sides. The first outside the outer layer of the black-red paper bags had a gray color and the inner part was black while the second inside paper bag layers had a red color on both sides. Pear fruits were harvested on the 25^{th} of September before full fruit physiological maturing stage, as it is well known that over matured fruits cannot be stored for a longer period of time. Fruits were investigated in the harvest period and after storage for 15 and 30 days in a refrigerator under +1-2°C and humidity of 65-70%, where fruits were stored with their own paper bags inside a polyethylene bag.

Evaluation of fruit quality parameters

Growth of the bagged and non-bagged control fruits were measured every 10 days until harvest, by measuring length and equatorial diameter (with digital caliper) of 18 fruits for each treatment. The same fruits were assessed at harvest for maturity, weight volume, flesh firmness, skin background color, etc.

Pear fruit color was measured by using a Minolta Chroma Meter CR-400 (Japan) with C illuminant. Fruit chromaticity was expressed in L^*, a^*, and b^* color space coordinates (CIELAB). L^* represents the relative lightness of colors on a scale from 0 to 100, being low for dark colors and high for light colors. The a^* and b^* scales extend from -60 to +60, where a^* is negative for green and positive for red and b^* is negative for blue and positive for yellow. Soluble solids concentration was determined for the juice of each fruit, using a digital refractometer (model Palette, Atago, Japan) at 20°C. Fruit starch content was estimated experimentally by applying iodine to slices of fresh pear fruits and the color was measured by Minolta Chroma Meter CR- 400 (Japan) using the following scale: full starch stain indicating immature and no starch stain indicating mature stage of ripeness.

Fruit firmness was measured with a fruit pressure tester FT 327 (Italy) with an 8 mm diameter plunger and hardness tester (5 kg- Japan). The springiness, gumminess, fracturability, chewiness, adhesiveness, hardeness and cohensiveness of fruits were analyzed by a Texture analyzer Stable Micro System GB/TA-XT2-25. The sugars content (glucose, sucrose, fructose and sorbitol) were measured by HPLC (Differential Refractometer Waters 410 and Waters 717 plus Autosampler USA) and total acids with a Titrette class A precision 50 ml (Germany). Chlorophyll content was analyzed using an Eon Microplate Spectrophotometer USA (mg g^{-1} fresh weight).

RESULTS AND DISCUSSION

Effects of bagging on fruit's size parameters

Our results showed that bagging of pear fruits cv. "Packham's Triumph" had a significant impact on fruit quality parameters. Fruit size and weight are an important attribute to evaluate advantages of a cultivar. According to our results, pre-harvest bagging resulted in decreased size and weight of fruits in comparison with control (Table 1). Seasonal growth rate of bagged fruits started to decrease later on in the period of bagging with relatively slow development than control (data not presented). Similar results were reported for the size and weight of pomegranate fruit (Husein et al., 1994), apple (Witney et al., 1991), pear (Zhang et al., 2006; Hudina et al., 2011), banana (Hasan et al., 2001). However, together with considering that bagging increased the fruit size of banana (Johns and Scott, 1989b), other studies reported contradictory results showing that bagging had no influence on the size of mango (Joyce et al., 1997) as well as on pear fruit size and weight (Amarante et al., 2002a). Summarizing the literature data, it can be concluded that the impact of bagging on the size and weight of fruits is different depending on plant features, cultivation technology, etc.

Effects of bagging on fruit quality and storage parameters

To give a decent economic assessment of the pear cultivar we carried out a study on the influence of bagging on the biochemical and technological fruit quality after harvest and during a period of fruit storage in controlled refrigerator conditions. Our results showed that bagging might significantly affect the fruit quality and storage ability. Fruit bagging affected the biochemical composition of fruits indicating that during the harvest period control and WPB fruits accumulated higher soluble solid in comparison with YPB, BPB and RPB fruits. However, subsequently during the fruit storage a different rate of soluble solid concentration was determined. In YPB, BPB and RPB fruits increasing rates were detected till October 10 with 0.6 and 1.0% respectively, in comparison with the control and WPB fruits (Table 1) while control rate remained almost unchanged (14.0 and 14.01%, respectively) at the end of the experiment on 25 October. It was found that the soluble solid in WPB and YPB fruits continued to increase (13.3 - 13.9 and 13.4 - 13.9%, respectively), whereas in the BPB and RPB coated fruits it decreased. However, according to Hussein et al., (1994) and Xu et al., (2010), the soluble solid in bagged fruits significantly increased compared to non-bagged fruits.

Variable results have been reported related to different types of bagging technique including a decrease in pear fruit soluble solid concentration (Hong et al., 1999; Amarante et al., 2002b; Zhang et al., 2006; Huang et al., 2007) as well as such showing no effect (Huang et al. 2009; Hudina, Stampa,r 2011).

Compared to soluble solid content, acidity was high in pear fruits in the harvesting period and it was not significantly decreased thereafter in all bagging treatments. We were not able to detect great differences between the variants where its rate being kept at about 2.0%.

Fruit bagging made the fruit skin brighter and promoted a considerable degradation of the existing total chlorophyll in the fruit peel, especially in the fruits coated with YPB, BPB and RPB. In these bagging treatments the total chlorophyll content was much lower than in the control and WPB fruits - 0.019, 0.008 and 0.008 mg g^{-1} FW, respectively (Fig. 1), whereas WPB and control fruits were characterized with the ability to accumulate and sustain significantly higher total chlorophyll (0.038 and 0.043 mg g^{-1} FW, respectively). The same pattern was revealed in a study on apples (Li et al., 1998) or pears (Huanga et al., 2009; Hudina et al., 2011).

Table 1. Effect of different types of pear fruit bagging on fruit size, fruit weight, soluble solid and acidity content during harvest and storage period.

Treatment/ date	Fruit parameters								
	height [mm]^{y}	width [mm]	weight [g]	soluble solid [ºBrix]			acidity [%]		
				09.25^{y}	10.10^{x}	10.25^{x}	09.25	10.10	10.25
Control	92.1±2.4^{az}	88.2±1.8^{a}	342.8±22.2^{a}	13.6±0.4^{a}	14.0±0.7^{a}	14.1±0.3^{a}	2.1±0.1^{a}	2.2±0.2^{a}	1.9±0.0^{a}
WPB	89.2±1.8^{ab}	87.2± 2.0^{ab}	328.3±18.2^{ab}	13.2±0.5^{ab}	13.3±0.2^{a}	13.9±0.3^{a}	2.3±0.1^{a}	2.1±0.1^{a}	2.2±0.0^{a}
YPB	85.2±1.5^{bc}	83.7±1.3^{bc}	290.8±11.1^{bc}	12.8±0.4^{ab}	13.4±0.6^{a}	13.9±0.7^{a}	2.3±0.2^{a}	2.2±0.2^{a}	2.0±0.1^{a}
BPB	85.3±1.8^{bc}	82.0±1.3^{c}	266.9±10.8^{c}	12.5±0.2^{b}	13.5±0.6^{a}	13.1±0.3^{a}	2.3±0.1^{a}	2.1±0.1^{a}	2.1±0.0^{a}
RPB	81.0±1.4^{c}	83.0±1.3^{bc}	267.7±10.5^{c}	12.8±0.3^{ab}	13.8±0.3^{a}	13.5±0.4^{a}	2.4±0.1^{a}	2.3±0.1^{a}	2.3±0.1^{a}

^{y}harvest time and data represent means± SD (n = 18).
^{x}investigation date during storage period with interval of 15 days and data represent means± SD (n = 3).
^{z}mean separation within columns by LSD test, $P \leq 0.05$.

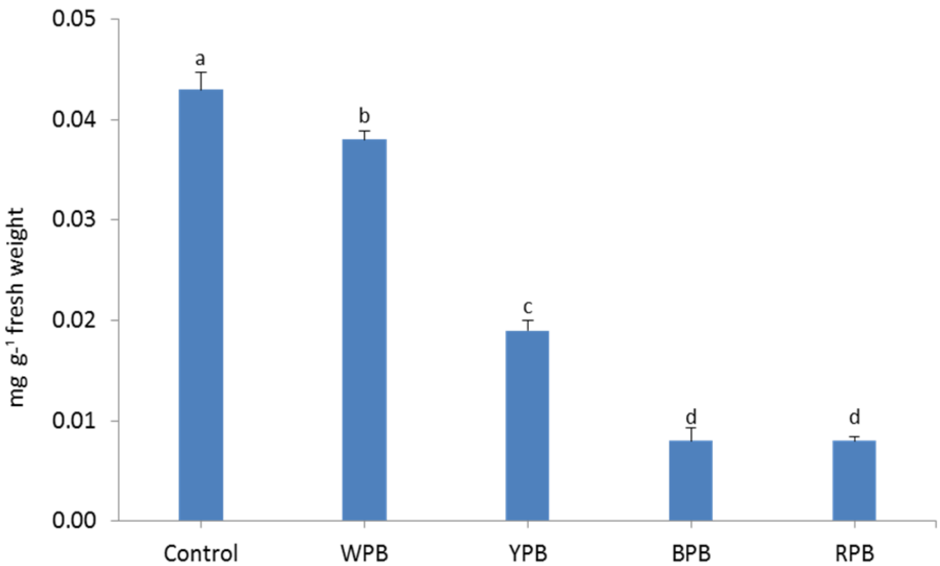

Figure 1. Effect of paper bag types on fruit skin chlorophyll content. Data are means ± SD (n = 10). Different letters indicate the significant difference at the 5% level by LSD multiple range test.

Since high concentrations of chlorophyll are known to contribute to an increased photosynthetic efficiency in plants (Rotondi and Predieri, 2002), our results indicated that pear fruits in the control and WPB bagging treatment were able to receive enough light to sustain photosynthesis, whereas in the fruits bagged with YPB, BPB, and RPB the photosynthetic function was obviously disturbed due to a relatively low light permeability rate through the bags and higher fruit temperatures during the day. Similar pattern of chlorophyll content was observed by Amarante et al. (2002b), Huanga et al. (2009), Hudina et al. (2011). They reported that the changes in chlorophyll content were related to fruit breakdown physiology, due to lower light permeability to the inner side of the bag, thus affecting also the fruit skin thickness (Homutova, Blazek, 2006) and epidermis structure (Qin et al., 2012). In addition, lower CO_2 uptake and O_2 exchange rate in paper bagged fruits were also reported (Amarante, Banks, 2001; Amarante et al., 2002b).

Fruit weight loss ability due to different types of bagging is a very important factor especially during the storage period. In our case control fruits were characterized with significantly low weight loss compared with the bagged fruits although all fruits were kept inside a polyethylene bag with their own paper bags. Regardless of the paper bag treatment, all fruits were characterized with high ability of weight reduction (about 0.4 - 0.5%) in the first five days of storage (Fig. 2). Further on, all bagged fruits demonstrated a loss of fruit weight regardless of the low temperature and well humidified environment in the refrigerator during treatment. It can be assumed that storage of fruits without bags in a refrigerator could provoke higher rates of weight loss in comparison with the bag coated fruits.

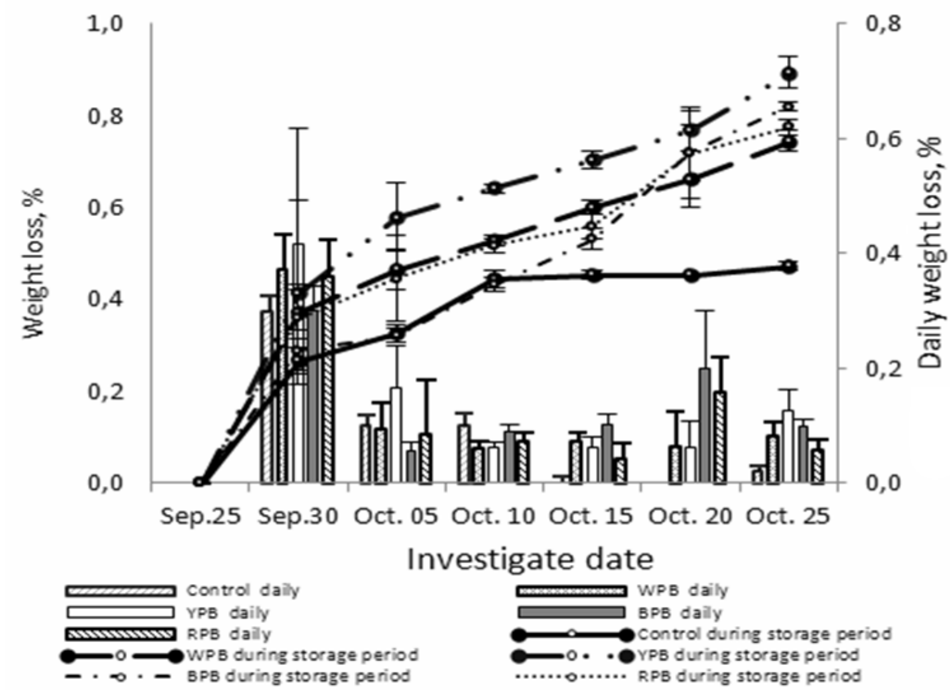

Figure 2. Effect of paper bag types on fruit weight loss ability in the storage period. Data are means ± SD (n = 3).

Iodine processing of fruit flesh demonstrated that bagging might also affect the fruit starch status, as revealed by the high lightness in color of the control fruits and WPB fruits in contrast to the deeper dark stain of fruits from the YPB, BPB and RPB treatments. In the latter variants full starch stain indicated immature stage of fruits (Table 2). Amarante et al., (2002b) reported a similar pattern of starch changes showing that the starch index was higher in bagged fruits than in non-bagged ones. Several authors have reported contradictory results on the effects of pre-harvest bagging on fruit crop maturity and flesh mineral content at harvest time (Bruinsma et al., 1975; Witney et al., 1991; Wang et al., 2002; Zhang et al., 2006; Huanga et al., 2009; Hudina et al., 2011; Shin et al., 2012).

Subsequently, during storage in cold conditions, the changes in starch index also ranged especially in fruits which were coated with YPB, BPB and RPB where the index of lightness significantly increased at the end of the storage period in comparison with the control and WPB fruits.

Bagging of pear fruits resulted in a decrease of sucrose content as compared to the control fruits which had high sucrose content - 0.36% (Fig. 3). However, within 15 days of storage the sucrose content increased significantly in all treatments due to starch hydrolysis in contrast to non-bagged control fruits which preserved high sucrose content.

Almost the same pattern of changes was found for fructose, glucose and sorbitol content. The minimal values were detected in mid storage period, followed by maximal values and a reduction

Table 2. Effect of different types of pear fruit bagging on fruit flesh starch status during harvest and storage period.

Treatments/ date	Starch status (Hunter color value)								
	*L**			*a**			*b**		
	25.09.13[y]	10.10.13[x]	25.10.13[x]	25.09.13	10.10.13	25.10.13	25.09.13	10.10.13	25.10.13
Control	54.11[az]	56.17[a]	58.08[a]	-1.35[b]	-3.02[a]	-2.48[b]	12.76[a]	26.37[a]	21.10[a]
WPB	51.36[a]	52.36[a]	55.18[a]	-0.54[ab]	-2.88[a]	-0.89[a]	7.69[a]	19.97[a]	17.28[a]
YPB	45.88[a]	49.20[a]	54.13[a]	-0.28[a]	-1.81[a]	-1.82[ab]	4.57[a]	20.27[a]	16.06[a]
BPB	48.93[a]	55.40[a]	56.04[a]	-0.25[ab]	-2.51[a]	-1.44[ab]	8.22[a]	22.07[a]	19.65[a]
RPB	39.06[a]	53.10[a]	54.58[a]	-0.21[ab]	-2.35[a]	-1.94[ab]	6.74[a]	19.85[a]	18.77[a]

[y]harvest time.

[x]investigation time during storage period with interval of 15 days.

[z]mean separation within columns by LSD test, $P \leq 0.05$.

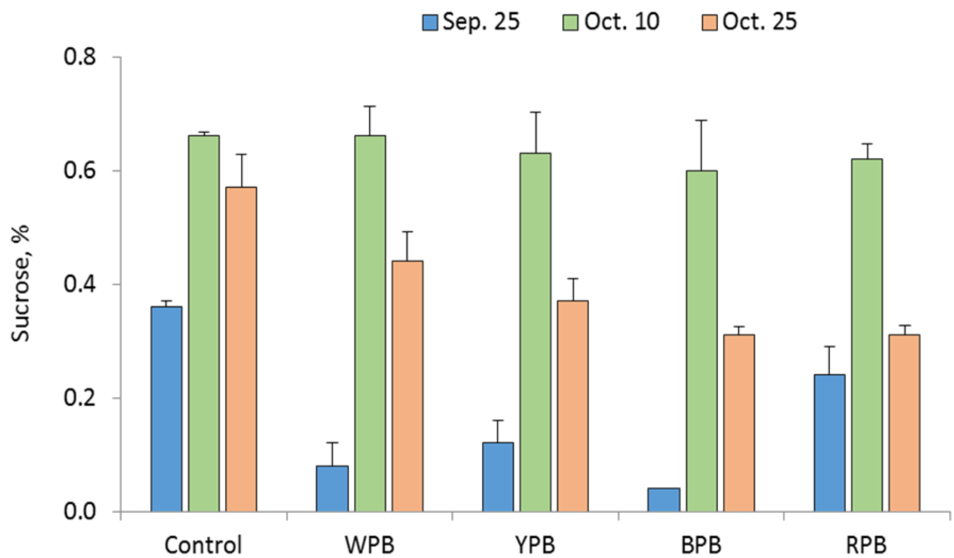

Figure 3. Changes in fruit sucrose content during harvest and storage period. Data are means ± SD (n = 3).

thereafter (Figs. 4, 5, 6). It should be noted that in the RPB fruits relatively higher contents of fructose, glucose and sorbitol were measured during harvest as well as in the storage period. In the harvesting period RPB fruits showed relatively high accumulation capacity for total sugar and then in mid storage period it increased in RPB and BPB fruits (Fig. 7).

Data on fruit firmness showed that the bagged fruits versus control fruits had a higher level of hardness in both plunger tester (5 mm Ø 5kg and kg/Ø 8 mm) during the harvest time and the storage period in a refrigerator (Figs. 8, 9). Fruit firmness ability was reduced regardless of the treatment under a longer storage period.

Amarante et al., (2002b) reported that differences in fruit softening may reflect differences in skin composition and structure after different treatments thus being responsible for the loss of cell wall integrity. In addition, these authors noted that bagged fruits showed a stronger decrease in fruit firmness compared with non-bagged ones, the same pattern being maintained during the storage of fruits. In contrast to these results, in our case we found an opposite pattern of changes with the lowest value of fruit firmness in control fruits (non-bagged fruits). It might be assumed that these changes in fruit firmness could be accompanied with density of fruit stone cells, their size and weight (Lee and Kim, 2001).

The impact of treatment on the texture data showed that springiness of fruits in all treatments including control was identical during harvest and then during the storage period a non-significant increase was noted (Table 3). Control fruits were characterized with low values of gumminess, chewiness, adhesiveness and hardness in comparison with the bagged fruits. No significant differences were detected in the cohesiveness test between treatments.

Pre-harvest bagging of pear fruits significantly contributed to the

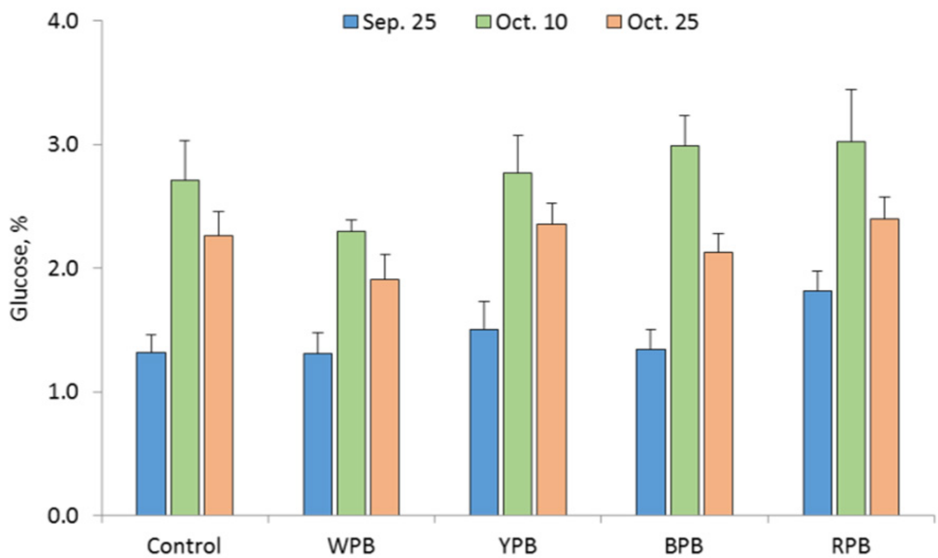

Figure 4. Changes in fruit glucose content during harvest and storage period. Data are means ± SD (n = 3).

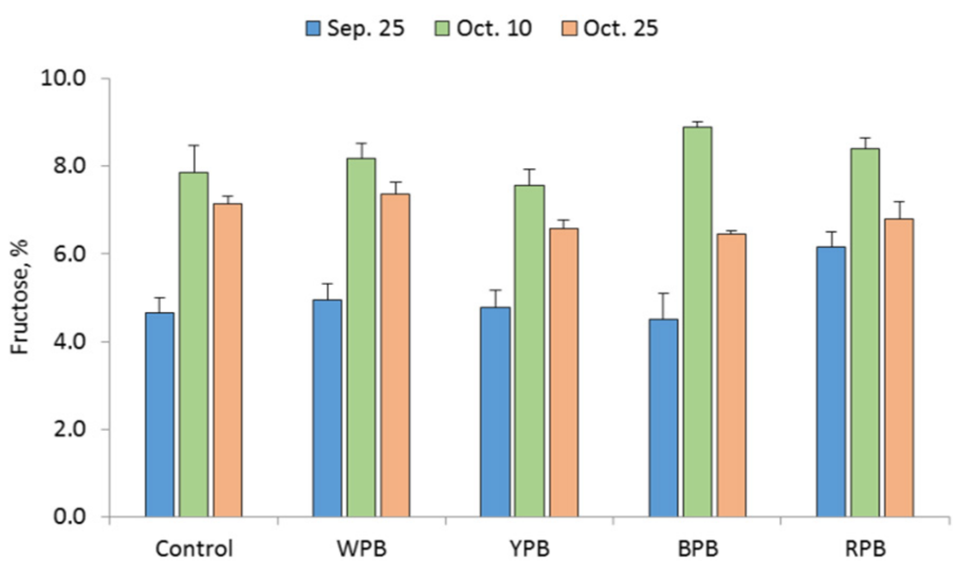

Figure 5. Changes in fruit fructose content during harvest and storage period. Data are means ± SD (n = 3).

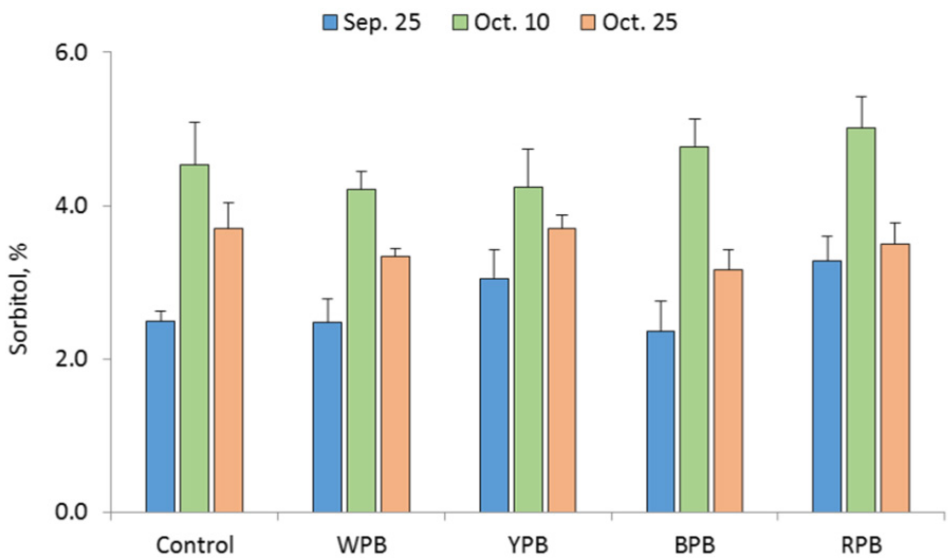

Figure 6. Changes in fruit sorbitol content during harvest and storage period. Data are means ± SD (n = 3).

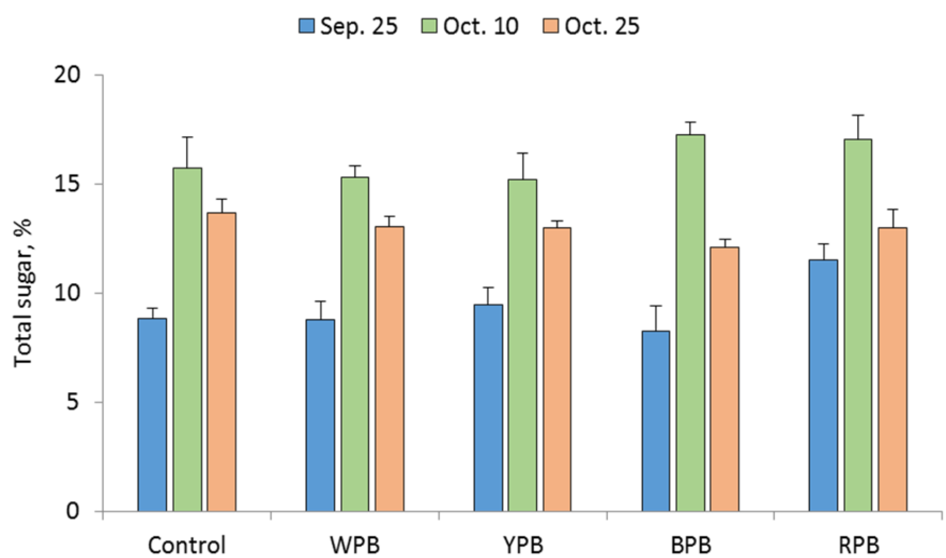

Figure 7. Changes in fruit total sugar content during harvest and storage period. Data are means ± SD (n = 3).

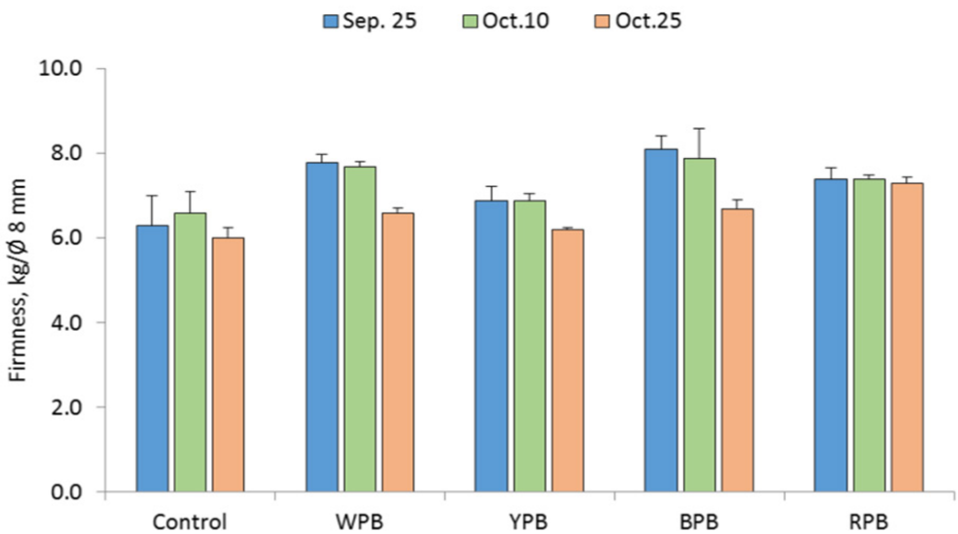

Figure 8. Changes in fruit firmness (kg Ø/0.8mm) during harvest and storage period. Data are means ± SD (n = 3).

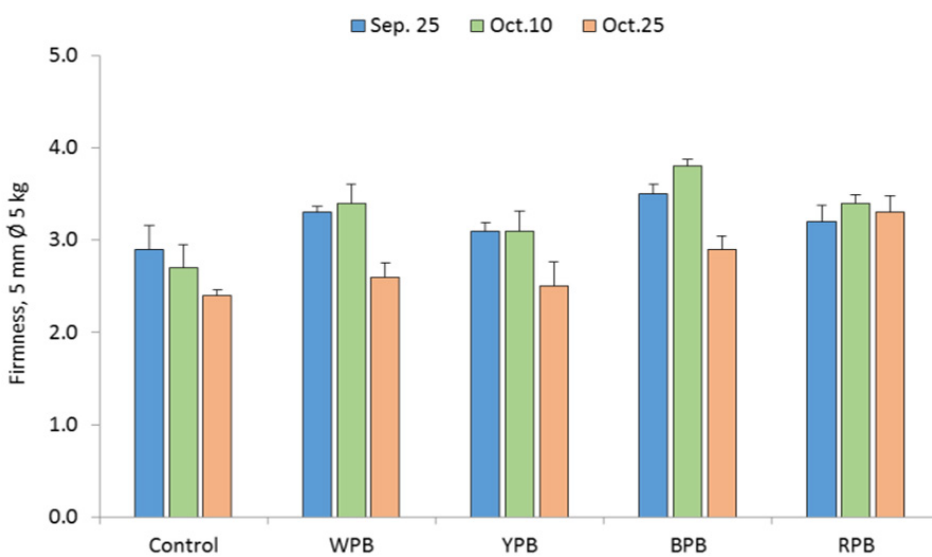

Figure 9. Changes in fruit firmness (5 mm Ø/5 kg) during harvest and storage period. Data are means ± SD (n = 3).

Table 3. Effect of different types of pear fruit bagging on fruit texture data during harvest and storage period in a refrigerator.

State	Fruit texture value[z]																	
	Springiness			Gumminess			Chewiness			Adhesiveness			Hardiness			Cohesiveness		
	09.25[y]	10.10[x]	10.25[x]	09.25	10.10	10.25	09.25	10.10	10.25	09.25	10.10	10.25	09.25	10.10	10.25	09.25	10.10	10.25
Control	0.96[a]	0.98[b]	0.99[a]	5.69[b]	6.35[b]	6.02[ab]	5.45[b]	6.20[b]	5.95[b]	-15.96[a]	-22.84[a]	-21.49[a]	26.70[b]	26.45[c]	26.17[c]	0.21[a]	0.24[a]	0.23[a]
WPB	0.95[a]	1.01[a]	1.00[a]	6.42[ab]	7.05[ab]	4.67[b]	6.15[ab]	7.10[ab]	7.10[ab]	-18.02[ab]	-23.65[ab]	-23.88[a]	31.10[ab]	29.94[bc]	30.95[ab]	0.20[a]	0.23[a]	0.22[a]
YPB	0.96[a]	0.99[ab]	0.99[a]	6.73[ab]	6.30[b]	7.36[ab]	6.45[ab]	6.27[b]	7.27[ab]	-22.91[bc]	-25.07[ab]	-23.95[a]	30.41[ab]	28.48[bc]	28.32[bc]	0.22[a]	0.22[a]	0.26[a]
BPB	0.96[a]	1.00[a]	0.98[a]	8.06[a]	9.15[a]	8.32[a]	7.77[a]	9.11[a]	8.16[a]	-25.69[c]	-30.40[b]	-31.90[b]	32.84[a]	34.97[a]	31.28[ab]	0.25[a]	0.26[a]	0.27[a]
RPB	0.96[a]	1.00[a]	0.98[a]	7.55[ab]	8.00[ab]	8.90[a]	7.27[ab]	7.98[ab]	8.75[a]	-24.30[bc]	-25.81[ab]	-32.97[b]	32.60[a]	32.40[ab]	33.54[a]	0.23[a]	0.25[a]	0.27[a]

[y]harvest time.

[x]investigation time during storage period with interval of 15 days.

[z]mean separation within columns by LSD test, $P \leq 0.05$.

improvement of fruit skin brightness, promoted degradation of existing chlorophyll in fruit peel and as a result fruits acquired more attractive light yellow color. Presumably an optimal period for harvest is late September when fruits are in immature stage. For getting the best fruit quality, the duration of fruit storage in a refrigerator should be 2-3 weeks. And as well-known if the temperature during the storage period is kept low, fruits storability will also be longer. Fruit storage in paper bags contribute to saving fruits from weight loss, strong blackening and damages due to fungal diseases.

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