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RESEARCH ARTICLE

Effects of harvesting time on fruit quality and internal browning of 'Wonhuwang' pear during cold storage

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Abstract **Average fruit weight, seed browning, flesh firmness, total soluble solids, internal browning, and skin blackening were used to determine the optimum harvesting time of 'Wonhuwang' pear. Pears for storage were picked three times at 5-day intervals before, during, and after estimated optimum harvesting date. Average fruit weight and seed browning degree were calculated at each picking time. Quality changes, internal browning, and skin blackening were employed to estimate the optimum harvest date. It was found that fruit quality parameters both at harvest and after storage depended on the stage of ripeness at which the pears were picked. Pears harvested earliest (H1) had the highest firmness both before and after storage and lost less percentage of their firmness during storage. The latest picked pears (H3) showed higher total soluble solids value and serious internal browning and skin blackening due to their over ripeness. Pears picked on the 15th of August (H2) had higher firmness and total soluble solids, lower extent of internal browning, and no skin blackening. Based on the changes in fruit firmness and physiologic disorder during ripening and storage, the optimal harvesting time for 'Wonhuwang' pear in Shijiazhuang area is around the 15th of August.**

Keywords harvesting time, flesh firmness, total soluble solids, internal browning, 'Wonhuwang' pear, cold storage

Introduction

Researches on harvesting time have focused on fruit quality of 'Sebri' pear (Rahemi and Baghbani, 2002), Asian pear (Arzani et al., 2009), Cuiguan pear (Yan et al., 2005), Jingbai pear (Jia et al., 2008), Concorde pear (Mielke et al., 2005), and European pears (Li et al., 2007), including flesh firmness, total soluble solids, nutrient content, internal browning, and taste. Inferior quality and lower output are obtained when fruits are harvested early; at the same time, flesh firmness is lower at harvesting time and decreases quickly when harvested late, which leads to aggravation of fruit quality. Therefore, harvesting time has close relation with fruit quality. 'Wonhuwang' pear (*Pyrus pyrifolia* Nakai. cv. Wonhuwang) is a new cultivar introduced to China several years ago, and studies on harvesting time on fruit quality have rarely been reported. The only reports (Chen et al., 2007; Ding et al., 2008; Li et al., 2009; Wang et al., 2009) were mainly focused on the effect of 1-MCP. Therefore, it is important to study the effect of harvesting time on the fruit quality of 'Wonhuwang' pear in order to obtain high consumer acceptance at the end of storage period. In our test, fruits were picked at different harvesting time and packed in polyethylene film to analyze the effect of harvesting time on fruit quality.

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Materials and methods

Materials

The fruits of 'Wonhuwang' cultivar of pear were harvested on the 11th (125 d after full bloom), 15th (129 d after full bloom), and 20th (134 d after full bloom) of August in 2009 at the orchard of ZhaoXian County, Hebei Province, China. They were marked as H1, H2, and H3, respectively. The fruits were transported on the same day to the Postharvest Research Center at the Institute of Genetics and Physiology. After prompt precooling, those healthy and intact fruits with uniform size were packed in polyethylene film bags with the thickness of 0.015mm made by Farm Product Storage and Freshening Institute, Shanxi Academy of Agricultural

Sciences, China (No.16 Nongke North Road in Taiyuan City), with 15 fruits in each bag. All fruits were stored at 0± 0.5ºC and 90%±5% RH. The average fruit weight, firmness, and total soluble solids (TSS) of 30 fruits were determined immediately at each picking, and the seed browning index was calculated. A sample was collected for analysis at 30-day intervals from each replication in all treatments during the storage, with data recorded.

Methods

Flesh firmness
Flesh firmness was determined by peeling the fruits at four equatorial sites and measuring the firmness by means of a Fruit Firmness Tester, model GY-1 (the Institute of Machine Research of Mudanjiang City, China), equipped with a 4 mm plunger tip, using 15 fruits from each treatment. Values were expressed in kilogram force per square centimeter (kg/cm^2).

Total soluble solids
Total soluble solids (TSS) in Birx % were measured using FORLI refractometer model 53020 (Trsnc Com, Italy) by collecting four samples from each fruit of 15 fruits in each treatment and out-squeezing juice from each sample.

Seed browning index
Seed browning index was assessed immediately after picking by measuring the extent of blackening area described by Yan et al. (2009) but using 30 fruits on the following scale: 0 = no blackening; 1 = less than 1/4 blackening; 2 = 1/4 to 1/2 blackening; 3 = 1/2 to 3/4; and 4 = more than 3/4 blackening. The seed browning index was calculated using the following formula:

Seed browning index = $[(1 \times N_1 + 2 \times N_2 + 3 \times N_3 + 4 \times N_4)/4/N] \times 100$,

where N is the total number of seeds observed and N_1, N_2, N_3, and N_4 are the number of seeds showing the different degrees of blackening.

Internal browning index
Internal browning index was assessed at the end of the storage period by measuring the extent of internal browning area using the same method mentioned above based on the brown areas with no browning = 0, < 25% = 1, 25%–50% = 2, and > 50% = 3. The browning index was calculated using the following formula:

Internal browning index = $[(1 \times N_1 + 2 \times N_2 + 3 \times N_3)/3/N] \times 100$,

where N is the total number of fruits observed, and N_1, N_2, and N_3 are the number of fruits showing the different degrees of browning.

Skin browning index
Skin browning index was assessed at the end of the storage period by measuring the extent of skin browning area with that above method.

CO_2 and O_2 concentration
CO_2 and O_2 concentration in each bag was measured at the end of the storage period using OXBABY V analyzer (Witt-gasetechnik, Germany).

Statistical analyses

A randomized plot factorial experimental design was used with three replicates, consisting of 30 fruits per replicate. Variance analysis was used for data processing with means compared using the least significant difference (LSD) test ($P < 0.05$).

Results and discussion

Average fruit weight and seed browning

Similar to Jingbai pear and some European pears, the average fruit weight of ‘Wonhuwang’ pear slightly increased with the delay of harvest time, but with no significant difference, which indicated that the development of fruits had already stopped when picked. The deferring of harvest time did not bring obvious economic return. The browning of seed was accelerated with the postponing of harvest time, with the browning index of H3 quickly increased up to more than 50%, as compared to H1 and H2 whose browning indexes were about 40% without a significant difference (Fig. 1). This result was in line with that of Jia et al. (2008).

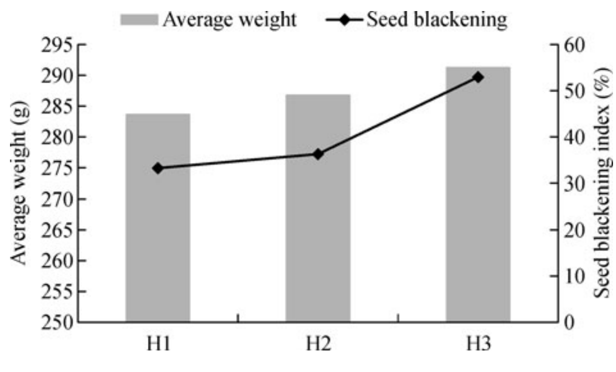

Figure 1 Effect of harvesting time on the average weight and seed browning of ‘Wonhuwang’ pear at picking. H1, H2, and H3 represent fruits of ‘Wonhuwang’ cultivar harvested on the 11th, 15th, and 20th of August, respectively.

Firmness

Flesh firmness immediately at picking decreased with the retarding of harvesting time, and it also decreased with the prolonging of the storage period. However, the tendency and extent differentiated in harvesting time. The flesh firmness of

H1 was stable during 0–190 d, and it quickly decreased after that, while that of H2 and H3 continuously decreased during the whole storage period but that of H3 was the smallest among all the treatments. Up to the end of storage period, the decreased firmness of H1, H2, and H3 was 28.2%, 38.0%, and 36.0% less than initial values, respectively (Table 1). The data also revealed that there was less decrease of fruit firmness during the whole storage period when fruit were harvested early, and higher one when harvested late, which was in line with Cuiguan pear (Yan et al., 2005), Jingbai pear (Jia et al., 2008), and some European pears (Li et al., 2007). However, there was no significant difference in the decrease between H2 and H3.

Table 1 Effect of harvesting time on quality of ‘Wonhuwang’ pear

Storage time (d)	Quality	H1	H2	H3
0	Firmness	7.97a	7.57b	7.23c
	TSS	10.87c	13.56b	14.69a
130	Firmness	6.91a	6.50b	5.99b
	TSS	12.97c	14.08b	15.33a
160	Firmness	6.91a	6.17b	5.75c
	TSS	13.42c	13.70b	14.47a
190	Firmness	6.57a	5.67b	5.20c
	TSS	12.92c	15.26a	13.95b
220	Firmness	5.97a	5.57b	4.83c
	TSS	13.05c	14.39a	13.39b
250	Firmness	5.73a	4.69b	4.63b
	TSS	12.91c	14.04b	14.44a

Different letters in the same column indicate significant differences (LSD) at 0.05 level. H1, H2, and H3 represent the fruits of ‘Wonhuwang’ cultivar harvested on the 11th, 15th, and 20th of August, respectively.

Total soluble solid (TSS)

Total soluble solids at harvesting time increased with the delay of harvesting time. TSS of all treatments showed a tendency of continuous increase or initial increase then decrease. Though TSS of H1 increased much more than that of H2 or H3, it was still the lowest, indicating that early harvesting was not propitious to accumulation of sugar (Table 1). The observation of TSS of H3 that decreased the most in all the treatments meant higher metabolism, and more nutrients were expended in fruits that were harvested late. The changes of TSS was directly related to the harvesting time and coincided with the report of Yan et al. (2005), Jia et al. (2008), and Mielke et al. (2005), which revealed that early harvesting was not in favor of the accumulation of sugar but resulted in lower TSS, while late harvesting brought higher TSS and more stable change of TSS in fruit.

Concentration of CO_2 and O_2

The concentration of CO_2 showed an initial-increase-then-decrease tendency in all treatments, whereas the concentration of O_2 maintained steadiness during the whole storage period. The CO_2 concentration of H1, H2, and H3 reached the maximum at 190 d, 160 d, and 160 d after storage, respectively, and the former was twice as high as the two latter, which indicated that thriving metabolism existed in early harvested fruits. The concentration of CO_2 decreased right after the maximum occurred due to the high permeability of package material (Table 2).

Browning and decay

Browning and decay were common problems in fruit storage. In this study, internal browning and decay increased with the retarding of harvesting time (Table 3). Skin browning appeared in H3 (fruits harvested late), which indicated that late harvesting may induce skin browning. Similar results were reported in Cuiguan pear (Yan et al., 2005) and another Japanese pear (*Pyrus pyrifolia* cv. Shinsetsu) by Kuo et al. (2007) who suggested that skin browning development of pear fruits after low temperatures storage was highly correlated to the response of phenylalanin ammo-nialyase (PAL) and polyphenol oxidase (PPO) activities to chilling.

It was believed that internal browning (IB) was due to the factors of chilling injury, physiologic senescence, and CO_2 injury (Larrigaudière et al., 2001; Pintó et al., 2001). Late harvesting made internal browning and decay more serious, which was in accordance with the findings of Khoshghalb et al. (2008) and Arzani et al. (2009), revealing that internal browning incidence was higher in fruit harvested late than that harvested early, because the lower incidence of IB in earlier harvested fruits than in later harvested fruits was a result of the presence of a higher level of ascorbic acid and a lower level of PPO activity. A similar result was reported in European plum (Guerra et al., 2009), but it was not in agreement with that of Li et al. (2009), which may be due to the effect of 1-MCP. ‘Wonhuwang’ pear was found to be susceptible to low temperature, water logging flesh and skin browning. Moreover, skin browning was related to internal browning, which indicated that the latter may have some relations with low temperature. It was reported that visible

Table 2 Effect of harvesting time on CO_2, O_2 concentration inside the packaging film of ‘Wonhuwang’ pear

Treatment	130 d		160 d		190 d		220 d		250 d	
	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2
H1	0.1a	19.9a	0.1c	19.8ab	1.7a	19.9a	0.1a	19.9ab	0	19.5a
H2	0.1a	19.9a	0.7b	20a	0.2b	19.7ab	0a	20ab	0	19.5a
H3	0.1a	19.8a	0.9a	19.7ab	0.2b	20.0a	0a	20.3a	0	19.5a

Different letters in the same column indicate significant differences (LSD) at 0.05 level. H1, H2, and H3 represent the fruits of ‘Wonhuwang’ cultivar harvested on the11th, 15th, and 20th of August, respectively.

Table 3 Effect of harvesting time on internal browning, decay, and skin browning of 'Wonhuwang' pear at 250 d storage

Treatment	Internal browning index (%)	Skin blackening index (%)	Decay index (%)
H1	56.67 c	0 b	2.22 bc
H2	70.00 b	0 b	3.33 b
H3	81.11 a	52.22 a	7.78 a

Different letters in the same column indicate significant differences (LSD) at 0.05 level. H1, H2, and H3 represent the fruit of 'Wonhuwang' cultivar harvested on the 11th, 15th, and 20th of August, respectively.

chilling injuries (CI) mainly resulted in serious skin browning of Japanese pear (*Pyrus pyrifolia* cv. Shinsetsu) stored at 1°C, and an increase in PAL and PPO activities was related to the incidence of skin blackening symptoms (Kuo et al., 2007). Therefore, internal browning was a compositive question that includes many factors.

Conclusion

Fruit quality was directly related to the harvesting time. Though harvesting time in present study had no effect on average fruit weight of 'Wonhuwang', it influenced seed browning, flesh firmness, TSS, internal browning, and decay. In this paper, we suggested that H1 had higher firmness, less internal browning, and no skin browning; however, its TSS was the lowest among H1, H2, and H3. The firmness and TSS of H3 decreased quickly, with more serious internal browning than any one of the other two. Therefore, both H1 and H3 were not suitable for long-term storage.

In terms of H2, it maintained relatively higher firmness and TSS, with less internal browning and decay index; therefore, H2 could be stored for a long time with acceptable quality and assumed to be the optimum for 'Wonhuwang' pear storage in Shijiazhuang area.

'Wonhuwang' pear is susceptible to low temperature. As internal browning may be attributed to low temperature, physiologic senescence, and CO_2 injury, some measures should be taken, such as aptly increasing storage temperature and harvesting in proper time, in order to alleviate browning and obtain better consumer acceptance and good fruit quality.

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