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Effect of bagging and time of harvest on fruit quality of 'Red Fuji' apple in high altitude area in China

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Summary

Introduction – **The appearance quality of horticultural produce including fruits is a major factor influencing consumer acceptability. Two-year field experiments were conducted from May to September in 2013 and 2014 to determine the effect of bagging and number of days at harvest on apple fruit quality.** *Materials and methods* – **'Red Fuji' (*Malus domestica* Borkh. 'Nagafu No. 2') apple was used. Two levels of bagging (*i.e.*, bagged fruits and un-bagged fruits) and five levels of time of harvest including 170, 175, 180, 185 and 190 days after full bloom (DAFB) were studied in a randomized complete block design with three replications. The bags were applied at 35 days when most of the flowers were observed to have opened and then removed at 131 days after the bagging. The external and internal qualities of the fruits were assessed by physical and chemical analysis.** *Results and discussion* – **Bagging improved most of the appearance quality parameters including longitudinal and vertical lengths, skin color, cleanness and firmness of fruits. Spot sizes and spot densities decreased in bagged fruits. Soluble solids, soluble sugar, titratable acidity and vitamin C content were, however, high in the un-bagged fruits. The soluble solids and soluble sugar in both bagged and un-bagged fruits increased after 100 days storage. Titratable acidity in both bagged and un-bagged fruits, however, decreased after storage. Harvesting either 185 or 190 DAFB was more appropriate for maintaining the quality of both bagged and un-bagged fruits.** *Conclusion* – **In the high altitude area of China, bagging improved the appearance quality of the 'Red Fuji' apples. Better internal quality was, however, obtained from the un-bagged fruits. Harvesting 185 or 190 DAFB was most appropriate for improved quality of the apples in this area.**

Keywords
China, apple, *Malus domestica*, fruit bagging, quality management, time of harvest

Résumé

Effet de l'ensachage et de la date de récolte sur la qualité des pommes 'Red Fuji' cultivées en zone d'altitude en Chine.

Introduction – **La qualité des produits horticoles, y-compris l'apparence des fruits, est un facteur qui influence l'acceptabilité des consommateurs. Une expérience a été conduite sur le terrain pendant deux ans (2013 et 2014) de mai à septembre afin de déterminer l'effet de l'ensachage et de l'âge des fruits avant récolte sur la qualité des pommes.** *Matériel et méthodes* – **La variété de pommes 'Red Fuji' (*Malus domestica* Borkh. 'Nagafu n° 2') a été utilisée. Deux types d'ensachage (fruits ensachés ou fruits non-ensachés) et cinq dates de récolte, 170, 175, 180, 185 et 190 jours après pleine floraison (AFB) ont été étudiés dans un dispositif en blocs randomisés à trois répétitions. Les sachets ont été posés 35 jours AFB alors que la plupart des fleurs avaient éclos, puis ont été retirés 131 jours plus tard. Les paramètres de qualité interne et externe des fruits ont été évalués par analyses physique et chimique.** *Résultats et discussion* – **L'ensachage a amélioré la plupart des paramètres de qualité liés à l'aspect du fruit, y-compris les dimensions longitudinales et verticales, la couleur de la peau, la propreté et la fermeté. La taille et la densité des tâches ont diminué sur les fruits ensachés. Les teneurs en matières solubles, sucres solubles, l'acidité titrable et la teneur en vitamine C étaient toutefois élevées pour les fruits non-ensachés. Les teneurs en matières solubles et sucres solubles des fruits ensachés ou pas ont augmenté après 100 jours de conservation. L'acidité titrable des fruits ensachés ou non, quand-à elle, a diminué après stockage. La récolte à 185 ou 190 jours AFB était la plus appropriée au maintien de la qualité des fruits ensachés ou pas.** *Conclusion* – **En zone de haute altitude de Chine, l'ensachage a nettement amélioré la qualité externe des pommes 'Red Fuji'. La qualité interne des fruits est toutefois meilleure chez les fruits non-ensachés. Une date de récolte 185 ou 190 jours AFB s'est révélée la plus appropriée pour une qualité optimale des pommes dans cette région.**

Significance of this study

What is already known on this subject?
- The positive impact of bagging apple during its development on the appearance quality of the fruit has been extensively published.

What are the new findings?
- Bagging 'Fuji' fruits during their development reduced the nutritional quality attributes measured.

What is the expected impact on horticulture?
- Our findings provide a basis for strategies to improve the nutritional quality attributes of bagged 'Fuji' apples in order to maintain both the appearance and nutritional qualities.

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Mots-clés
Chine, pomme, *Malus domestica*, ensachage des fruits, gestion de la qualité, date de récolte

Introduction

Apple (*Malus domestica* Borkh.) is one of the most popular fruit crops cultivated worldwide and its consumption has been increasing over the past years. Apples have thin skin, various skin color and sweet flavor and these attributes makes apples one of the most preferred fruits among consumers with increased marketability (Sharma *et al*., 2014; Liu *et al*., 2013). Previous studies have shown that the quality of apple fruit is influenced by the genetic make-up of the species and the environment within which it is being cultivated (Stern, 2015; Bentley and Viveros, 1992).

Fruit bagging can protect fruits against pathogens and insects, prevent them from sunburn, keep the fruit surface clean, decrease the use of pesticides and thus pesticide residues, promote anthocyanin synthesis, and other external quality. It can also affect the levels of chlorophylls, carotenoids, sugars, organic acids and many other secondary metabolites (Amarante *et al*., 2002; Chonhenchob *et al*., 2011; Hofman *et al*., 1997; Xu *et al*., 2010; Zhang *et al*., 2013). Feng *et al.* (2014) indicated that bagging and de-bagging did not affect the level of total non-structural carbohydrates or total organic acids, but bagging decreased the concentrations of total phenolics in the peel and flesh while de-bagging increased them in ‘Jonagold’ apple. Sharma *et al.* (2013) found that bagged fruits had better color than the control fruits at harvest. Chen *et al.* (2012) reported that fruit bagging decreased phenolic compound concentrations in both the peel and the flesh of ‘Golden Delicious’, ‘Red Delicious’, and ‘Royal Gala’ apples. Hao *et al*. (2011) also reported that bagged fruits had cleaner surfaces, glossy skin and were scattered with few light-color lenticel pits. The cuticles of the fruits were thin and developed uniformly with shallow cracks. Since fruit bagging affects the external and internal qualities of fruits, it has been extensively studied and utilized in China, Japan, Australia and many other countries. However, the interaction effect of bagging and time of harvest on fruit quality of apples cultivated at high altitude area has rarely been reported particularly in China.

The duration of bagging developing fruits in the field play a vital role in fruit quality and this has been reported by many research scientists (Vielma *et al*., 2008; Kviklienė *et al*., 2008; Echeverría *et al*., 2002). Vielma *et al.* (2008) used eight apple species to study the effect of environment on harvest time, and the result showed that different apple species grown under various climates require different harvest time. Kviklienė *et al.* (2008) studied the changes in fruit quality parameters during ripening and storage as influenced by time of harvest and found that the optimal harvest time for ‘Alva’ was about 131 DAFB. Echeverría *et al.* (2002) studied the effect of harvest date and storage conditions on quality and aroma production of ‘Fuji’ apples. After 3.5 and 7.0 months of storage (plus 1.5 and 10 days at 20°C, resp.) fruit firmness, titratable acidity, soluble solids, skin color, physiological disorders and aroma changed. These studies conducted on the apple tree were carried out at lower altitudes. Since the environment also greatly influences fruit quality, we conducted our experiment at a high altitude area to determine how bagging and number of days at harvest will influence the external and internal characteristic of fruits of ‘Red Fuji’ apples.

The Loess Plateau is located in the middle of northern China (34–40°N, 103–114°E) and it is the world’s largest loess deposition zone. The altitude is more than 1,300 m and annual mean rainfall is about 362.5 mm. Apple growers are in the rush to harvest in order to attract early market at the beginning of the apple season. This has significant implications on quality and marketability of the fruits which in the long run can affect the incomes of the farmers. We have reported the effect of bagging and time of harvest on the quality of ‘Red Fuji’ apple cultivated in the Loess Plateau, a high altitude with low rainfall amount, and our findings provides some recommendations and bases for future research to improve the production of apples in the area.

Materials and methods

Profile of the experimental orchard

The experimental orchard is located in the Pan’an Village, Gangu County, Gansu Province, China (34.717N, 105.067E, 1,360 m elevation). The area is a warm temperate continental region. The annual mean rainfall is about 362.5 mm, and the mean annual temperature is about 11.2°C. The soil properties are uniform and deep, the organic matter content of the soil in the orchard was 1.17%. The rainfall in the area is usually unevenly distributed, with about 70% concentrated in July to September, but with very little showers from January to May. There is usually a well pronounced drought during spring. The region which is noted for low rainfall also lacks irrigation facilities. In order to establish a suitable soil water condition for apple trees in the area, plastic mulching is practiced in autumn. Based on this situation, we adopted the black plastic mulching in autumn in the experimental orchard. Data on average daily temperature, relative humidity and rainfall for the periods of the field experiments are presented in Table 1.

Experimental materials

‘Red Fuji’ apple (*Malus domestica* Borkh. ‘Nagafu No. 2’) was used as the test crop. The trees were 15 years old grafted on *Malus baccata* Borkh. rootstocks. Rows were oriented in a south–north direction, with in-row and between-row spacing of 3 m and 4 m, respectively. The full blooming occurred on April 10, 2013 and April 12, 2014. The bags used were double-layer (the outer layer was gray outside and black inside, and the inner layer was red) paper bags.

Experimental design and sampling for data collection

Flowers were thinned during inflorescence period, leaving 7–8 inflorescences per branch. Young fruits were thinned within 28 days after bloom, and the space between fruits was kept 20 to 25 cm eventually. Bags were used at 35 days and removed at 166 days after full bloom (DAFB). Fruits from each tree were randomly selected for bagging treatment, with un-bagged fruits as control. In all, thirty (30) trees were used in the experiment with ten (10) trees in each of the three replications. The experiment was a 2 × 5 factorial in a completely randomized design. Factor A was two levels of bag application (*i.e.*, bagging and no bagging). Factor B was five levels of time of harvest (*i.e.*, harvesting 170, 175, 180, 185 and 190 DAFB). On each tree, the fruits were tagged and either bagged or not bagged by using random numbers. Fifty percent of the fruits on each tree were bagged while the other 50% were not bagged. The harvesting times were then randomly assigned to the bagged and un-bagged fruits.

Ten fruits, five bagged and five un-bagged ones, were used per tree per harvest for data collection on the various

TABLE 1. Evaluation standard for fruit coloring index and cleanness of the 'Red Fuji' apple.

Grades	Scores	Grading standards for fruit coloring index	Grading standards for fruit cleanness
Level 1	5	Fruit coloring area >90%	No rust-spotting and crack were observed on fruit surface, and fruit necrosis was not shown.
Level 2	4	75% < Fruit coloring area ≤ 90%	Little rust-spotting was observed on fruit stems in hollow cavities. No fruit crack was observed on fruit surface, and fruit necrosis was not obvious.
Level 3	3	65% < Fruit coloring area ≤ 75%	Pieces of rust-spotting were observed in fruit stems in hollow cavities. Little fruit crack was observed on fruit surface, and fruit necrosis was relatively obvious.
Level 4	2	50% < Fruit coloring area ≤ 65%	Fruit rust-spotting and crack were observed on less than 30% of fruit surface, and fruit necrosis was obviously observed.
Level 5	1	Fruit coloring area ≤ 50%	Fruit rust-spotting and crack were observed on more than 30% of fruit surface, and fruit necrosis was obviously convex.

variables studied. The harvested fruits were packaged separately and taken to the laboratory for the physical and chemical analyses. The fruits were stored at 4 °C in a refrigerator.

Fruit quality assessment

The fruit quality at harvest was evaluated according to standard methods described by Jha *et al.* (2012), and 5 fruit sets per treatment, 3 replications per treatment. Fruit vertical and horizontal diameters were measured using an electronic caliper. Fruit fresh weight was determined using an electronic balance. The volume of fruits was determined using water displacement method.

Flesh firmness was measured on four opposite sides of a peel-removed apple with a hand-held penetrometer (Top Instrument, Zhejiang, China), and the average firmness recorded. The penetration force to the depth of the sample was expressed as kg cm^{-2}.

The fruit coloring index was calculated as follows:

$$\text{Fruit coloring index } = \frac{\sum(fi \times Ei)}{Emax \times \sum fi} \times 100\%$$

where $\sum(fi \times Ei)$ is the sum of the fruit number of corresponding grade level in each treatment multiplied by the corresponding score, and $Emax \times \sum fi$ indicates the total number of fruit multiplied by the score of the highest grade level of each treatment. The classification standard for the fruit coloring is shown in Table 2. The fruit cleanness was calculated similarly

$$\text{Fruit cleanness } = \frac{\sum(fi \times Ei)}{Emax \times \sum fi} \times 100\%$$

The soluble solid content was measured with a digital refractometer (Top Instrument, Zhejiang, China), with reading taken from the combined juice extracted from the two opposite sides (green and red) of the apples. Refractometer values were expressed as °Brix at 20 °C.

Titratable acidity was measured with approximately 5 g fruit pulp and reported in percentages, by fruit fresh weight, in terms of the malic acid equivalent. The tissue was macerated and the juice filtered from the homogenate, was titrated by 0.1 N NaOH (pH = 8.1) to an end point when the phenolphthalein indicator became pink. Titrations were undertaken using an automatic burette.

The vitamin C content was determined by 2.6-dichloroindophenol titration. After it was put into the tissue blending machine and mixed with 50 mL 2% oxalic acid, 10 g fruit pulp was churned into homogenate. Then, 18.0 mL of homogenate was extracted and diluted to 50 mL volumetric flask with 2% oxalic acid solution, left for 10 min, the filtrate was reserved next. Two shares of 10.0 mL filtrate were added and filled into 100 mL conical flask and titrated with the method mentioned above. The content of ascorbic acid (in mg 100 g^{-1} fresh weight – FW) was calculated as:

$$Vc = V \times T / W \times 100$$

where V is the amount of dye titrated (in mL), T is the amount of ascorbic acid (in mg mL^{-1} dye), and W is the amount of sample (in g) in 10 mL liquid.

The solution was slightly modified. Anthocyanin was extracted from 1 g skin disks with ethanol containing 1.5 mol L^{-1} HCl, and absorbency was measured at 530 nm by spectrophotometer (UV- 2450 UV-Visible Spectrophotometer, Shimadzu, Japan) (Wang *et al.*, 2000). The anthocyanin content was calculated as described previously(Arakawa, 1991).

Soluble sugar was extracted from 5 g fruit pulp, and measured by using the method of anthrone colorimetric determination and expressed as mg soluble sugar g^{-1} FW of fruit pulp (Gao, 2006). Density was computed by dividing the weight of apple by its determined volume.

TABLE 2. Climate data in 2013 and 2014 in Tianshui, Gansu Province, China.

Years	Months	Rainfall (mm)	Average temperature (°C)	Relative humidity (%)
2013	April	39	13.0	68.2
	May	54	20.7	68.8
	June	71	21.6	71.7
	July	92	22.8	76.0
	August	85	25.3	80.2
	September	86	25.7	73.2
	October	49	17.3	68.3
2014	April	41	14.5	67.5
	May	57	20.5	66.5
	June	74	24.3	73.2
	July	94	23.7	78.6
	August	83	26.6	82.3
	September	88	27.4	74.4
	October	49	17.3	71.4

Scanning electron microscopy

According to Hao *et al.* (2011) with minor modifications, the surface of apples was gently wiped with a soft brush. Fragments of fruits with peel (5 × 5 × 2 mm) from the equatorial part of the fruit red side were sampled from each treatment immediately after the fruits reached the laboratory. The samples (freshly cut sections) were put into 2.5% glutaraldehyde solution containing 0.2 M dipotassium phosphate (buffer) to fixing for 24 h at 4 °C, washing by 0.2 M dipotassium phosphate (buffer) for three times. Samples were dehydrated in an ethanol series, then replaced by the tertiary butyl alcohol series, dried using freeze-drying apparatus, were mounted directly on stubs using double-side adhesive tape, sputter-coated with gold and examined under a S-3400N scanning electron microscope at an accelerating voltage of 5 kV (peel longitudinal section) and 3 kV (peel surface). Peel thickness and the area of micro cracks were quantified by image analysis (Adobe Photoshop CS3; Soft Imaging System, Thomas Knoll, America).

Data analysis

Data were expressed as means ± standard errors (SE) of three replicate determinations using Microsoft Excel 2003. Statistical analysis was conducted with the SPSS 19.0. Mean comparisons were performed using the Duncan's New Multiple Range Test to examine the differences among all treatments for statistical significance ($P < 0.05$). Plots in this paper were made by Origin 8.5.

Results and discussion

Climate records

The climate data for the location of the experiment for the 2013 and 2014 seasons are shown in Table 2. The average daily temperature, relative humidity and rainfall for the two years were very similar in figures and in trend. The lowest and highest average daily temperature for 2013 and 2014 seasons were recorded in April and September respectively. The lowest and highest relative humidity for 2013 was recorded in April and August respectively. The lowest and highest relative humidity for 2014 was recorded in May and August. Rainfall amount for 2013 was lowest in April and highest in July while the lowest and highest rainfall in 2014 occurred in April and July respectively. There were no marked differences in the climate data for the two seasons. Therefore, the differences in most of the quality parameters observed could not be attributed to differences in climatic conditions for the two seasons.

Effect of bagging and time of harvest on external fruit quality

Vertical and horizontal fruit diameter

From September to October in each of the seasons, vertical fruit diameter increased steadily regardless of treatment as the fruits mature on the tress (Table 3). The longest vertical diameter occurred in bagged fruits which were harvested 190 DAFB while the least occurred in bagged fruits harvested 170 DAFB. The vertical diameter of fruits harvested 190 DAFB was similar to the one of fruits harvested 185, 180 and 175 DAFB. The results on vertical fruit diameter for 2013 were similar to what occurred in 2014. The effect of the treatments on horizontal fruit diameter is also shown in Table 3. The horizontal fruit diameter increased steadily with time. The longest horizontal diameter in 2013 occurred in bagged fruits which were harvested 190 DAFB, and the least was found in the bagged fruits harvested 170 DAFB. The 2013 results on horizontal fruit diameter were similar to those of 2014. The growth rate for both the vertical and horizontal fruit diameters in both seasons decreased with time.

Fresh fruit weight

The fresh fruit weight of bagged and un-bagged fruits and the average daily increase in fruit weight for 2013 season is presented in Figure 1A–B. The greatest fruit weights regardless of whether bagged or not, were obtained at 190 DAFB. Although not significant, the un-bagged fruits were heavier than the bagged fruits at 190 DAFB. The average daily increase in fruit weight decreased with time and reached the least at 190 DAFB for both bagged and un-bagged fruits. The 2013 results on fruit weight and average daily increase in fruit were similar with those for the 2014 (Figure 1C–D).

Table 3. Changes of vertical and horizontal diameters (in mm) of bagged and un-bagged fruits harvested in 2013 and 2014 at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Vertical diameter (mm)		Growth rate of vertical diameter		Horizontal diameter (mm)		Growth rate of horizontal diameter	
		Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged
2013	170	71.07±0.82b*	72.04±0.45ab	–	–	80.05±0.59c	81.08±0.38bc	–	–
	175	71.98±0.81ab	72.57±0.44ab	0.91	0.53	80.99±0.71bc	81.68±0.43abc	0.94	0.60
	180	72.68±0.82ab	73.08±0.43ab	0.70	0.51	81.79±0.59abc	82.16±0.39ab	0.80	0.48
	185	73.25±0.91ab	73.52±0.50a	0.56	0.44	82.35±0.63ab	82.56±0.59ab	0.56	0.40
	190	73.65±0.82a	73.95±0.41a	0.40	0.43	82.70±0.58ab	82.95±0.15a	0.36	0.39
2014	170	72.92±0.36b	73.14±0.12abc	–	–	80.33±0.22e	80.28±0.32de	–	–
	175	73.97±0.10ab	73.74±0.22ab	0.94	0.53	80.59±0.37de	80.97±0.16cd	0.95	0.59
	180	74.18±0.06ab	73.72±0.15ab	0.72	0.52	81.38±0.37bcd	81.69±0.36abc	0.79	0.47
	185	74.05±0.03ab	74.47±0.04a	0.57	0.45	81.87±0.15ab	82.17±0.26ab	0.55	0.40
	190	74.90±0.08a	74.91±0.13a	0.42	0.44	82.11±0.16ab	82.35±0.18a	0.34	0.38

* The different lower letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

There have been various findings on the effect of bagging on fruit weight. For instance, bagging reduced fruit weight in apples at harvest (Witney *et al.*, 1991), did not affect fruit weight in mangoes (Joyce *et al.*, 1997) while banana fruits which were bagged increased in weight at harvest (Johns and Scott, 1989). The decrease in average daily weight at 190 DAFB was lowest in 2014 probably due to the relatively higher average daily temperature (27.4 °C) recorded at that time compared with 25.7 °C recorded around the same time in 2013.

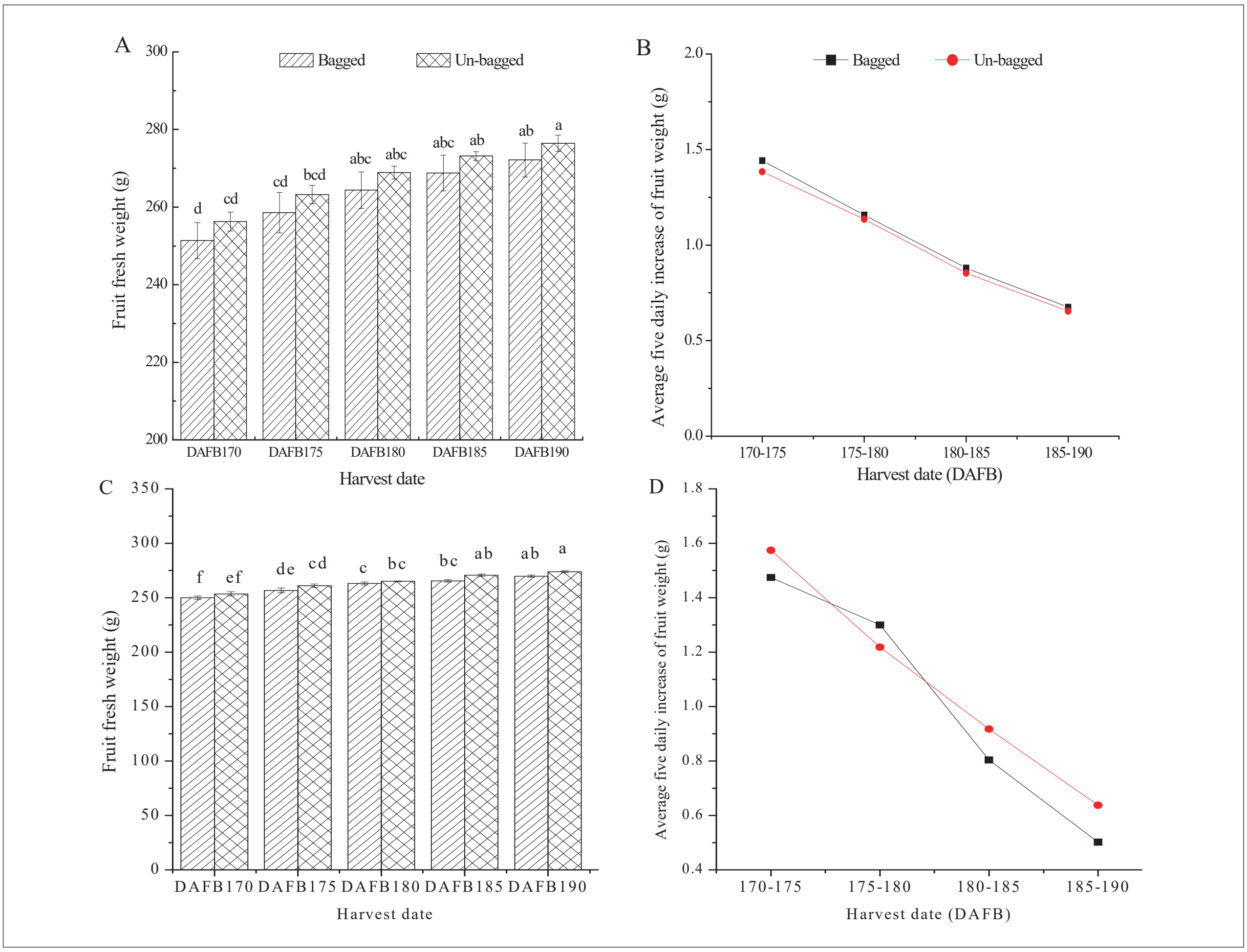

FIGURE 1. Changes in weight of bagged and un-bagged 'Red Fuji' apple fruits harvested at different dates (DAFB: days after full bloom). A: Fruit fresh weight; B: Average five daily increase of fruit weight. Each bar is the mean ± SE ($n = 3$). Different lower letters above the bar indicate the significant difference among all of treatments at $P < 0.05$.

TABLE 4. Changes of fruit shape index, volume and peel aspect of bagged and un-bagged 'Red Fuji' apple fruits harvested at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Fruit shape index		Fruit volume (cm³)		Surface red (%)		Brightness (%)	
		Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged
2013	170	0.89±0.01a*	0.89±0.01a	275.57±9.09e	290.51±4.91de	33.33	52.50	100	95.00
	175	0.89±0.02a	0.89±0.01a	290.66±3.07de	304.75±4.81cd	60.00	64.17	100	90.00
	180	0.89±0.01a	0.89±0.01a	304.36±6.57cd	317.81±6.59bc	75.00	73.33	100	87.50
	185	0.89±0.02a	0.89±0.01a	315.52±3.19bc	328.01±5.88ab	80.83	78.33	95.83	84.17
	190	0.89±0.02a	0.89±0.01a	325.95±4.40ab	337.44±3.76a	85.00	81.67	89.17	80.83
2014	170	0.88±0.01a	0.88±0.01a	278.94±5.33d	291.87±5.44cd	33.03	52.10	100	93.00
	175	0.88±0.01a	0.88±0.02a	289.46±3.15cd	302.93±10.5bc	61.00	66.17	100	92.00
	180	0.88±0.02a	0.88±0.01a	295.70±4.51bc	313.08±6.92ab	75.00	73.23	99.86	88.10
	185	0.88±0.01a	0.88±0.01a	303.18±3.85abc	318.47±9.13a	81.83	77.33	96.83	86.24
	190	0.88±0.01a	0.88±0.02a	305.45±1.25abc	320.57±6.20a	86.00	81.31	88.97	79.83

* The different letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

Fruit shape index, volume, surface color, cleanness and firmness

Bagging and number of days at harvest had no significant ($P>0.05$) effect on fruit shape index for both 2013 and 2014 seasons (Table 4). Fruit shape is probably influenced most by genetic traits than environmental factors. Webster (1976) indicated that the fruit shape of Mcintosh apple was influenced by strain or cultivar among other factors. Fruit volume increased steadily with time and was significantly ($P<0.05$) affected by the treatments (Table 4). Greater fruit volume was found in un-bagged fruits which were harvested at 190 DAFB for both 2013 and 2014 seasons while the bagged fruits harvested at 170 DAFB had the least volume. The reddening of the fruit skin also progressed with time but was more pronounced in the bagged fruits (Table 4). Our results is consistent with Sharma *et al*. (2013) who also found that bagged apple fruits had better color development. Fan and Mattheis (1998), however, found that bagging 'Fuji' apples did not only delay color development but also reduced red color development of the fruits. The cleanness of the skin was also more pronounced in the bagged fruits but it decreased with time (Table 4). Fruits which were harvested 170, 175 and 180 DAFB in 2013 and those harvested 170 and 175 DAFB in 2014 were the brightest. The most firm fruits were obtained when bagged fruits were harvested at 170 DAFB in both 2013 and 2014 seasons (Figure 2). The bagged fruits which were harvested 190 DAFB were the softest in both seasons. After 100 days storage, the bagged fruits which were harvested 170 DAFB were still the most firm in both seasons. The softest fruits after storage were the bagged fruits that were harvested late. Generally, bagging maintained fruit firmness while delay harvesting resulted in softening of fruits especially of the bagged fruits. It was likely that the bags lowered the ambient temperature around the fruits and reduced respiration rate and thus maintained fruit firmness. According to Kader (2013), at temperatures below optimum, the rate of carbohydrate breakdown decreases by 2 to 3 fold for every 10°C decrease in temperature. Some previous studies made similar observations and reported that bagged apples had higher firmness than the un-bagged fruits (Sharma *et al*., 2013; Feng *et al*., 2012; Witney *et al*., 1991).

Peel longitudinal section and peel surface

Fruit peel longitudinal section was observed only in 2013 by SEM (Figure 3). The layers of epidermal cell of both bagged and un-bagged fruits increased with maturity. The peel of bagged fruits harvested 170 DAFB was composed of a single layer of cells, which were uniform in size and arranged neatly and closely. Fruit cuticle can repair microcracks. Cuticle thickness increased rapidly during the spring as tempera-

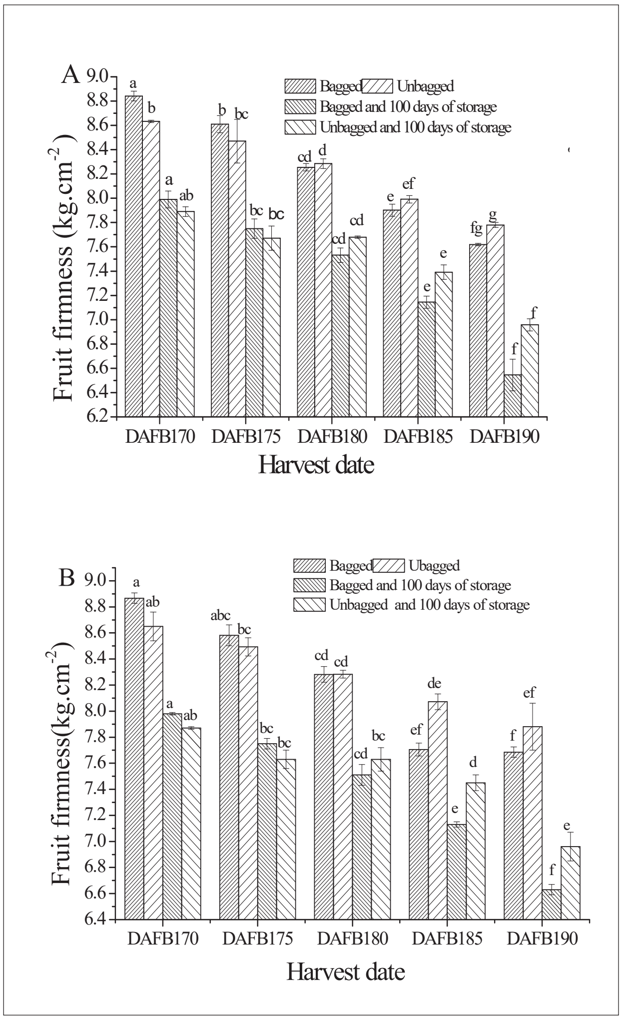

Figure 2. Fruit firmness of 'Red Fuji' apples at different harvest dates, A: in 2013; B: in 2014. Each bar is the mean ± SE ($n=3$). Different lower letters above the bar indicate significant difference among all of treatments at $P<0.05$.

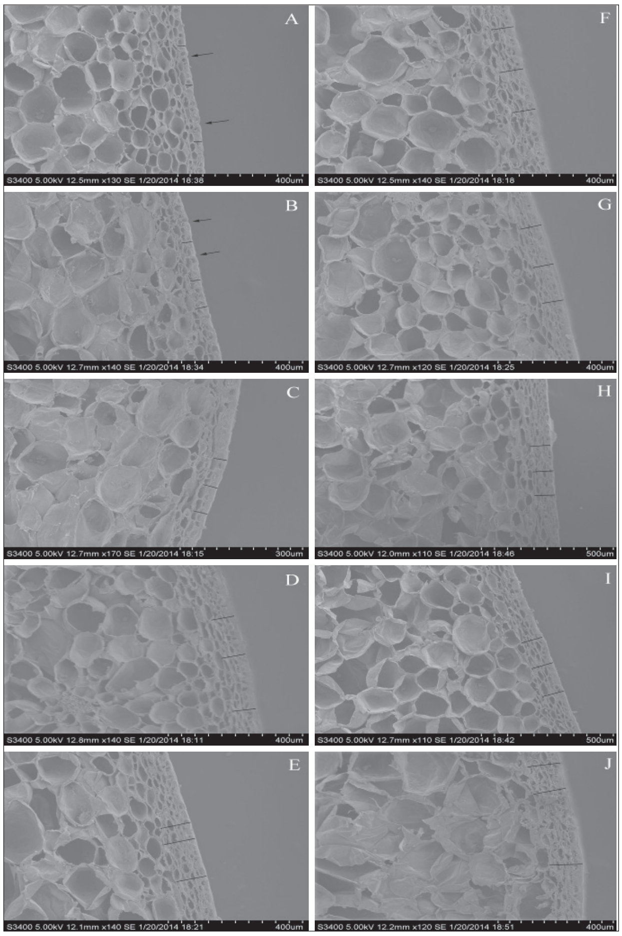

Figure 3. Scanning images of peel longitudinal section of 'Red Fuji' apples harvested at different dates. A-E and F-J are scanned images of peel longitudinal section of bagged and control fruits, respectively, picked at 170, 175, 180, 185 and 190 days after full bloom, from top to bottom, respectively. Arrows represent microcracks in the cuticle. Length of the line represents the thickness of pericarp.

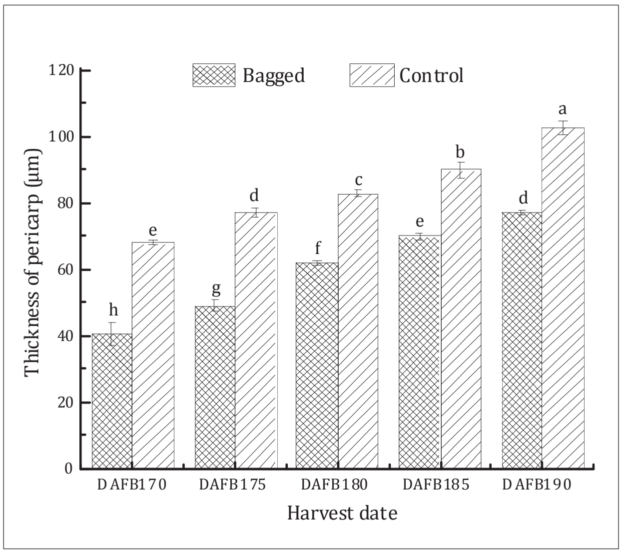

FIGURE 4. Changes of pericarp thickness of bagged and un-bagged 'Red Fuji' apples harvested at different dates (DAFB: days after full bloom). Each bar is the mean ± SE ($n = 3$). Different lower letters above the bar indicate significant difference among all of treatments at $P < 0.05$.

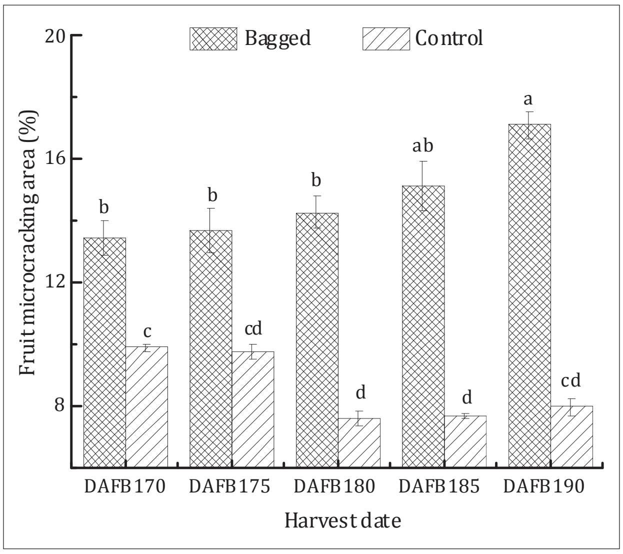

FIGURE 6. Microcracking area of 'Red Fuji' apple peel surface harvested at different dates (DAFB: days after full bloom). Each bar is the mean ± SE ($n = 3$). Different lower letters above the bar indicate significant difference among all of treatments ($P < 0.05$).

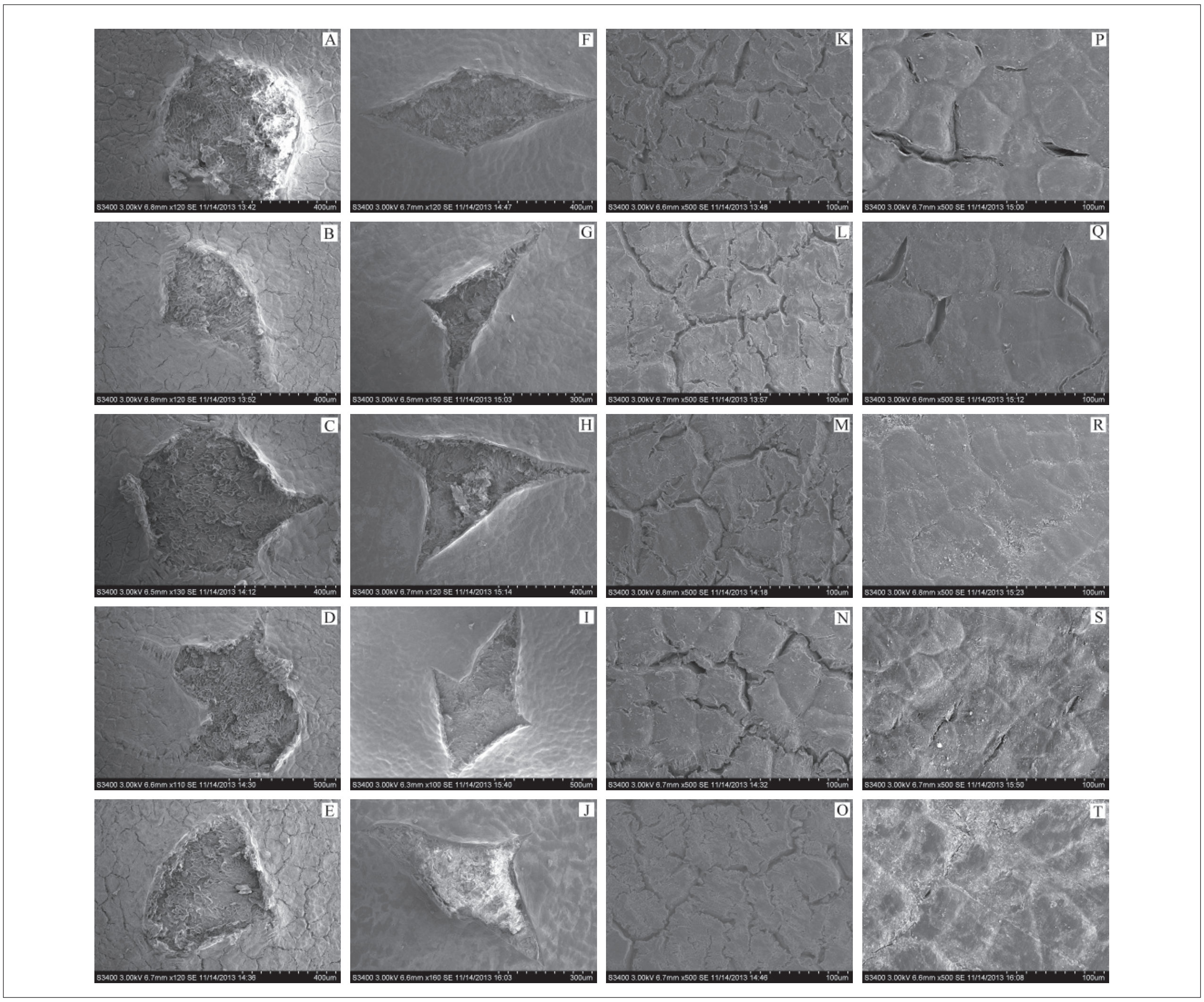

FIGURE 5. Scanning images of peel surface of 'Red Fuji' apple fruits harvested in different harvest time. A-E and F-J are scanned images of spot of bagged and un-bagged apples picked at 170, 175, 180, 185 and 190 days after full bloom, respectively. K-O and P-T are scanned images of peel surface microcracks of bagged and control fruits picked at 170, 175, 180, 185 and 190 days after full bloom, respectively.

ture increases and water vapor pressure decreases (Zhang *et al*., 2006). From this study, it can be concluded that due to changes that probably occurred within the modified environment of the bagged fruits, more microcracks occurred. The change also enhanced moisture evaporation and slowed the accumulation of cutin and wax. Therefore, the healing of microcracks became retarded.

The peel of the bagged fruits harvested 175 DAFB was composed of two layers of cells, with uniform size, arranged in neat rows. The first layer cells were oval in shape and the second layer ones were nearly round. The peel of the bagged fruits harvested 180 DAFB was composed of two layers of cells, the second layer had bigger and oval cells. The peel of the bagged fruits harvested 185 DAFB was composed of four layers of cells which were long and oval in shape. The second, third and fourth cell layers were arranged loosely with bigger intercellular spaces. The peel of the bagged fruits harvested 190 DAFB was composed of five layers of cells. The layers of epidermal cells of the bagged fruits were less than those of the un-bagged fruits at the same time of harvest. The volume of epidermal cells of the bagged fruits was bigger than those of the un-bagged fruits.

The pericarp thickness of bagged and un-bagged fruits increased significantly with fruit maturity (Figure 4). The pericarp thickness of bagged fruits was less than that of the un-bagged fruits at the same time of harvest. The pericarp thickness of the bagged and un-bagged fruits harvested during the third and fourth harvest was 61.83 and 82.69 µm, respectively, and 69.85 and 89.88 µm, respectively.

Peel surface was observed using SEM during the 2013 experiment only (Figure 5). The picture showed that the shape of apple lenticels was opened. The shape of lenticels of bagged fruit harvested early was sub-rounded, and that of those harvested late was polygonal. The edge of lenticels of bagged fruit harvested late was curled (Figure 5A-E). The shape of lenticels of the un-bagged fruits harvested at different harvest times was always polygonal (Figure 5F-J). The surface of lenticels of the control fruits harvested at later time was covered by dead cells. The peel surface of bagged fruits harvested at different times had micro cracks. The micro cracks of bagged fruits harvested early were shallow, and with the progress of fruit maturity on the tree, they became wider and deeper (Figure 5K-O). The microcracks along the direction of epidermal cell wall in cuticle of the un-bagged fruits harvested early were few and shallow (Figure 5P-Q). As the fruits mature on the trees, the microcracks of the un-bagged fruits were replenished by wax until the third harvest (Figure 5R). During the last two harvest, random direction microcracks in old wax layer of the control occurred and gradually increased (Figure 5S-T). Konarska (2012) reported that at the harvest maturity stage, the fruit surface was characterized by a great number of microcracks, which formed a specific reticulate network often aligned along the epidermal cell walls.

The microcrack area of the bagged fruits increased with the progress of fruit maturity on the tree (Figure 6). The microcrack area of the un-bagged fruits were initially few and then increased later. The microcrack areas of the bagged fruits were more than those of the control fruits at the same time of harvest.

Effects of bagging and harvest time on fruit spot size, spot density and spot color

The fruit spot size, pulp density spot color were influenced by bagging and time of harvest in the 2013 and 2014 seasons (Table 5). Fruit spot size increased with time and was more pronounced in un-bagged fruits than the bagged ones. The largest spot size occurred when fruits were harvested 190 DAFB in both 2013 and 2014 seasons. Fruit spot density was affected most by time of harvest. The greatest spot density in the 2013 season was found in the fruits which were harvested 190 DAFB while the least occurred in fruits harvested 175 DAFB. The greatest spot density in 2014 was in fruits harvested 190 DAFB while the least occurred in bagged fruits harvested 175 DAFB. Fruit spot color varied with bagging and time of harvest but did not differ with the growing season. Bagged fruits harvested 170 DAFB had light olive spots while the un-bagged fruits harvested at the same time had deep olive spots. At 175 DAFB, bagged fruits had olive spots while the un-bagged fruits had dark olive spots. Bagged fruits harvested 180 DAFB exhibited yellow spots while the un-bagged fruits showed grayish yellow spots. At 185 DAFB, however, the spot color of both bagged and un-bagged fruits was yellow. Bagged fruits at 190 DAFB had grayish spots while the un-bagged fruits had dark gray spots.

Table 5. Changes of spot traits of bagged and un-bagged fruits harvested at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Fruit spot size (mm)		Fruit spot density (number cm^{-2})		Fruit spot color	
		Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged
2013	170	0.87±0.01e*	0.95±0.02de	4.17±0.01def	4.31±0.12cd	Light olivine	Deep olivine
	175	0.95±0.01de	1.03±0.01cd	4.09±0.02f	4.23±0.01de	Olivine	Dark olivine
	180	1.02±0.06cd	1.09±0.01abc	4.13±0.02ef	4.27±0.01cd	Yellowish	Grayish yellow
	185	1.06±0.05bc	1.13±0.01ab	4.27±0.01cd	4.49±0.04b	Light grayish yellow	Deep grayish yellow
	190	1.09±0.03abc	1.15±0.02a	4.39±0.04bc	4.68±0.01a	Grayish	Dark gray
2014	170	0.83±0.01f	0.86±0.01ef	4.14±0.06def	4.33±0.02cd	Light olivine	Deep olivine
	175	0.89±0.02de	0.90±0.001de	4.07±0.01f	4.23±0.02de	Olivine	Dark olivine
	180	0.93±0.04cd	0.94±0.004cd	4.13±0.03ef	4.25±0.02cd	Yellowish	Grayish yellow
	185	0.98±0.02bc	1.00±0.01b	4.25±0.03cd	4.47±0.04b	Light grayish yellow	Deep grayish yellow
	190	1.07±0.02a	1.11±0.01a	4.36±0.01bc	4.64±0.01a	Grayish	Dark gray

* The different letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

Table 6. Changes of soluble solid contents in 'Red Fuji' apples harvested in 2013 and 2014 at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Soluble solid contents (°Brix)			
		Bagged	Un-bagged	Stored bagged fruits for 100 days	Stored un-bagged fruits for 100 days
2013	170	13.08±0.05f*	13.39±0.03d	13.91±0.03g	14.74±0.03de
	175	13.35±0.06e	14.29±0.03c	14.34±0.23f	15.17±0.23c
	180	13.90±0.03d	14.79±0.05b	14.62±0.07e	15.46±0.07b
	185	14.13±0.05cd	15.04±0.04ab	14.77±0.12d	15.64±0.12a
	190	14.30±0.03c	15.19±0.02a	14.66±0.08de	15.52±0.08ab
2014	170	13.08±0.02f	13.93±0.04cd	13.90±0.02g	14.68±0.02de
	175	13.23±0.25ef	14.17±0.04bc	14.38±0.21f	15.16±0.02c
	180	13.58±0.11de	14.45±0.03b	14.63±0.12e	15.46±0.03b
	185	13.85±0.03cd	14.85±0.09a	14.74±0.05d	15.69±0.05a
	190	14.17±0.06bc	15.02±0.04a	14.67±d0.06e	15.53±0.04ab

* The different lower letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

Table 7. Changes of soluble sugar contents in 'Red Fuji' apples harvested in 2013 and 2014 at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Soluble sugar contents (%)			
		Bagged	Un-bagged	Stored bagged fruits for 100 days	Stored un-bagged fruits for 100 days
2013	170	11.46±0.04h*	12.35±0.04f	12.68±0.1f	13.56±0.04cd
	175	11.83±0.01g	12.76±0.08e	12.90±0.04f	13.76±0.05cd
	180	12.43±0.03f	13.28±0.03c	13.20±0.03e	14.02±0.05c
	185	12.74±0.02e	13.65±0.01b	13.41±0.03de	14.83±0.02a
	190	12.91±0.02d	13.82±0.03a	13.56±0.03cd	14.45±0.01a
2014	170	11.45±0.18e	12.49±0.03cd	12.63±0.18f	13.53±0.07cd
	175	11.94±0.02de	12.55±0.04c	12.89±0.12f	13.78±0.05cd
	180	12.19±0.03cd	13.25±0.07b	13.22±0.03e	14.09±0.04c
	185	12.33±0.01cd	13.61±0.04ab	13.32±0.03de	14.41±0.07a
	190	12.54±0.02c	13.88±0.03a	13.51±0.06cd	14.50±0.13a

* The different lower letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

Table 8. Changes of titratable acid contents in 'Red Fuji' apples harvested in 2013 and 2014 at different times (in days after full bloom – DAFB). Data are means ± SE ($n = 3$).

Years	Harvest dates (in DAFB)	Titratable acid (%)			
		Bagged	Un-bagged	Stored bagged fruits for 100 days	Stored un-bagged fruits for 100 days
2013	170	0.38±0.01a*	0.39±0.01a	0.28±0.01d	0.31±0.00b
	175	0.35±0.00bc	0.37±0.01ab	0.26±0.01e	0.30±0.00bc
	180	0.32±0.01de	0.35±0.00bc	0.29±0.01cd	0.33±0.01a
	185	0.29±0.01ef	0.33±0.01cd	0.25±0.00e	0.30±0.01bc
	190	0.27±0.01f	0.31±0.01de	0.21±0.00f	0.28±0.00d
2014	170	0.38±0.00a	0.39±0.00a	0.29±0.00d	0.32±0.01b
	175	0.35±0.00c	0.38±0.01a	0.26±0.01e	0.30±0.01cd
	180	0.31±0.01e	0.36±0.01b	0.29±0.00cd	0.34±0.00a
	185	0.29±0.01f	0.34±0.00c	0.25±0.01e	0.30±0.00bc
	190	0.28±0.00f	0.22±0.01d	0.21±0.00f	0.28±0.00d

* The different lower letters indicate significant difference ($P < 0.05$) from all of treatments by the method of Duncan.

Table 9. Changes in vitamin C, anthocyanin and pulp density of bagged and un-bagged 'Red Fuji' apples harvested in 2013 and 2014 at different times (in days after full bloom – DAFB). Data are means ± SE (n = 3).

Years	Harvest dates (in DAFB)	Vitamin C (mg 100 g^{-1})		Anthocyanin (A530 g^{-1})		Pulp density (g cm^{-3})	
		Bagged	Un-bagged	Bagged	Un-bagged	Bagged	Un-bagged
2013	170	7.05±0.10d*	7.15±0.42d	0.21±0.06g	0.64±0.01e	0.91±0.02a	0.89±0.03a
	175	9.15±0.18ab	9.27±0.05ab	0.51±0.004f	0.71±0.004e	0.88±0.05a	0.87±0.02a
	180	9.21±0.30ab	9.87±0.51a	1.18±0.02a	0.81±0.01d	0.86±0.05a	0.85±0.07a
	185	8.96±0.03bc	9.15±0.08ab	1.22±0.004a	0.92±0.01c	0.84±0.02a	0.83±0.05a
	190	8.27±0.02c	8.71±0.07bc	1.25±0.04a	1.03±0.04b	0.83±0.05a	0.82±0.05a
2014	170	7.52±0.06c	7.13±0.19d	0.24±0.01g	0.63±0.01e	0.86±0.05a	0.88±0.06a
	175	9.54±0.33a	9.01±0.29abc	0.52±0.01f	0.70±0.02e	0.85±0.03a	0.86±0.01a
	180	9.27±0.33ab	9.85±0.18a	1.25±0.004a	0.81±0.01d	0.84±0.05a	0.85±0.02a
	185	9.08±0.04ab	9.40±0.04ab	1.23±0.01ab	1.01±0.02c	0.82±0.01a	0.83±0.04a
	190	8.83±0.04b	9.17±0.03ab	1.28±0.01a	1.15±0.01b	0.85±0.01a	0.88±0.05a

* The different lower letters indicate significant difference (P < 0.05) from all of treatments by the method of Duncan.

Effect of bagging and harvest time of on internal fruit quality

Soluble solids, soluble sugar and titratable acidity

The effect of bagging and number of days at harvest on soluble solid content of fresh and stored fruits is presented in Table 6. The treatments significantly (P<0.05) affected soluble solid content in both 2013 and 2014 seasons. In 2013, the un-bagged fruits harvested 190 DAFB had the highest soluble solid content before storage while the bagged fruits harvested 170 DAFB had the least soluble solid content. After 100 days storage, the soluble solid content of fruits was similar to those before storage. The un-bagged fruits harvested 185 DAFB had the highest soluble solid content while the bagged fruits harvested 170 DAFB had the least after 100 days storage. The influence of the treatments in 2013 season was very similar to that in 2014 season. Generally, soluble solids in the fruits increased with time and after storage and were relatively higher in un-bagged fruits than in bagged fruits. This result is in contrast with Sharma *et al.* (2013), who reported higher levels of soluble solids in bagged apple fruits. The soluble sugar content of the fruits before and after storage was affected (P<0.05) by the treatments in both 2013 and 2014 seasons (Table 7). The highest soluble sugar content in 2013 and 2014 occurred in un-bagged fruits which were harvested 190 DAFB. The least soluble sugar content for the two seasons were found in bagged fruits harvested 170 DAFB. Similarly, the highest soluble sugar content after storage was in bagged fruits which were harvested 170 DAFB for both seasons. Generally, soluble sugar content in the fruits increased with time and after storage and was relatively higher in un-bagged fruits than in bagged fruits. Titratable acidity of fruits before and after storage was significantly (P<0.05) affected by the treatments (Table 8). For the 2013 season, the highest titratable acidity was measured in un-bagged fruits harvested 170 DAFB while the least occurred in bagged fruits harvested 190 DAFB. In 2014 season, the highest titratable acidity also occurred in un-bagged fruits harvested 170 DAFB. The least titratable acidity was also in un-bagged fruits harvested 190 DAFB. After 100 days of storage, the highest titratable acidity for both 2013 and 2014 seasons was found in un-bagged fruits harvested 180 DAFB. The least titratable acidity after storage for both seasons occurred in bagged fruits harvested 190 DAFB. Titratable acidity was higher in un-bagged fruits and increased with time, especially for fresh fruits. The highest titratable acidity after storage, however, was obtained when un-bagged fruits were harvested 180 DAFB.

Vitamin C, anthocyanin concentration and pulp density

The vitamin C content, anthocyanin concentration and pulp density of the fruits as influenced by the treatments are shown in Table 9. The highest vitamin C content in 2013 was in the un-bagged fruits harvested 180 DAFB. The least vitamin C content was measured in bagged fruits which were harvested 170 DAFB. Similarly, in 2014, un-bagged fruits harvested 180 DAFB had higher vitamin C content while the least was measured in un-bagged harvested 170 DAFB. Regardless of bagging or no bagging, early harvesting (170 DAFB) was associated with less vitamin C in the fruits. Anthocyanin was generally higher in the bagged fruits than in the un-bagged fruits. The highest anthocyanin content for both 2013 and 2014 seasons occurred in bagged fruits harvested 190 DAFB. Pulp density was not affected (P>0.05) by the treatments in both seasons.

Conclusion

The appearance quality of horticultural produce including fruits is a major factor influencing consumer acceptability. We studied the interaction effect of bagging and time of harvest on the external and internal quality of 'Red Fuji' apple in a high altitude area in China. Bagging improved most of the external quality characteristics. Fruits that were bagged had increased longitudinal and vertical lengths, improved skin color, cleanness and firmness of fruits. In addition, bagging decreased spot size and spot density on the fruits. Anthocyanin concentration was the only internal quality improved by bagging. Internal qualities, including soluble solids, soluble sugar, titratable acidity and vitamin C contents were high in the un-bagged fruits. All the quality characteristics of the fruits were better when harvesting was done either 185 or 190 DAFB. Soluble solid and soluble sugar levels increased after 100 days storage while titratable acidity decreased after storage. Bagging and harvesting at 185 or 190 DAFB will contribute to improving the appearance quality of the 'Red Fuji' apples in the high altitude areas of China. Agronomic strategies such as quality varieties, optimum fertilizer use and improved irrigation systems should be developed to improve the internal quality of the bagged fruits in the area.

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