Journal of Applied Horticulture, 12(2): 135-139, July-December, 2010

Quality and physiological responses of Fuji apple to modified atmosphere packaging during cold storage

Xiao-Long Li[1,2], Jian-Wen Tian[3], Mark A. Ritenour[4], Jia-Zheng Li[5], Shu-Ya Song[1], Hui-Ling Ma[1]*

*[1] College of Life Science, Northwestern A & F University, Yangling, 712100, Shaanxi, China. [2]Germplasm resources institute of Ningxia Agricultural Sciences Academy, Yinchuan, 750021, Ningxia Autonomous region, China. [3]Ningxia Science and Technology Agency, Yinchuan, 750021, Ningxia Autonomous region, China. [4]Indian River Research and Education Center, University of Florida, 2199 S. Rock Road, Fort Pierce, FL 34945-3138, USA. [5]National Engineering Technology Research centre for Preservation of Agricultural Products, 300384, Tianjin, China. *E-mail: ma_huiling65@hotmail.com*

Abstract

Modified atmosphere packaging (MAP) with polyolefin bags made of modified polyvinyl chloride (mPVC), micro-perforated polyethylene (mpPE), modified polyethylene (mPE), plastic film mulch (control-1), and polyvinyl chloride with holes (control-2) were evaluated for their ability to preserve quality of Fuji apple during storage at 0 to 1^{o}C. The results showed that atmosphere in mPVC bag was adjusted to 2.73%~2.38% CO_2 and 15.70%~18.13% O_2 while in mpPE, mPE and control-1 bag CO_2 levels were elevated and O_2 level declined to 0.10~0.72%，20.53~20.9%, respectively. In mPE bag, fruits recorded significantly less weight loss than other packagings throughout the storage, while fruit in mPVC, fresh weight loss was same as in control-1. The overall fruit quality of flesh firmness (FFF), soluble solid content (SSC) and ascorbic acid remained at almost the same level in each packaging during the first 40 days of storage, and changed thereafter. Control-1 resulted in significantly lower FFF than other packagings till day 220 and SSC showed the same trend as in control-2. Respiration rate of fruit in mPVC, control-1 and control-2 peaked on day 220 and those in mpPE and mPE peaked on day 240. Ethylene production of fruit in each packaging increased since day 40 and peaked on day 80 for mPE and control-1, day 100 for mpPE and control-2, on day 120 for mPVC. A second peak for mPE appeared on day 120. Each packaging resulted a dramatic increase and drop of SOD activity in fruit in the first 40 days. After about 220 days of storage, superficial scald and core browning occurred on fruit in mpPE, mPE, control-1, control-2 by 2.4~6.0% and 1.2~1.6%, 6.3~7.9% and 15.8~17.3%, 0~1.6% and 4.4~4.6%, 15.4~16.1% and 3.2~4.5%, respectively while no such incidence was observed in mPVC. Decay and disorder developed faster when storage duration increased.

Key words: Polyolefin film, scald, core browning, respiration rate, ethylene production, modified atmosphere packaging.

Introduction

Fuji is the most important, late-maturing apple cultivar in China. Covering fruit with paper bags during fruit development (“bagging”) is now a common practice in response to market demands for reducing pesticide use. However, bagging may result in Fuji apples with thinner skin, less wax, and wax platelets that are arranged looser than in fruit not bagged (Li *et al.*, 2008; Liang and Huang, 2009). This results in poor quality retention and storage life of the fruit after harvest.

The use of modified atmosphere packaging (MAP) made with polyolefin films and holding at low temperature has been used successfully as a lower-cost alternative to controlled atmosphere (CA) storage for reducing decay and extending storage life of many fruits. However, greater caution is required when using MAP on Fuji apples because they are susceptible to CO_2 injury (Tian *et al.*, 2008). Previous research established that atmospheres containing 1.8-5.0% CO_2 and 12-19% O_2 at 0±0.5 ^{o}C are generally optimum for long term storage of Fuji apples (Guan *et al.*, 2004; Yang *et al.*, 2004). Xu *et al.* (2006) reported that ultra low-oxygen (1.6% ± 0.1% O_2) and 0.2% CO_2 reduced the incidence of superficial scald while maintaining acceptable quality after 100-day storage at 0℃. However，few studies have evaluated different polyolefin bags used to package apple fruit on their ability to maintain apple quality during storage, causing confusion in the market about which bag works best for Fuji apples. New types of breathable polyolefin bags made of modified polyvinyl chloride (PVC) or polyethylene (PE) were evaluated and compared with polyolefin bags currently used commercially for long-term storage of Fuji apples.

Materials and methods

Fruit and their handling: Uniform Fuji apple fruit of Chang-Fu No.2 variety with diameter of about 75 mm were harvested from 15-year old, healthy trees on 18 October, 2007 and 14 October, 2008 at the Baishui base of Apple Research Centre, Shaanxi, China. The trees were grown using normal commercial cultural practices. Developing fruit were covered with two-layer-paper KOBAYASHI bags [KOBAYASHI (Qingdao) CO., LTD, China] in mid-June in both years and bags were removed 6 days before harvest. Harvested fruit were wrapped with a PVC foam net (Jingfeng foam net factory, Xianyang, China), loaded in Waleng Paper Boxes (480×320×320mm, Xi’an shengda packing CO., LTD, China) and transported about 150 km by truck to the laboratory and immediately pre-cooled for 24 h using room-cooling at 0 ^{o}C.

Packagings and storage: After pre-cooling, the net wraps were removed and fruit of uniform size, colour and free of visible defect or disease were selected for further treatments. About 5 kg of fruit (23-25 apples) were packed into a 65×65 cm bag made with one of the following five different polyolefin films: 1) modified polyvinyl chloride (mPVC), 2) micro-perforated polyethylene (mpPE), 3) modified polyethylene (mPE), 4) linear low density polyethylene plastic film mulch (PFM, commercial MA control, named control-1), or 5) polyvinyl chloride with eight, 10 mm diameter holes per bag (PVC; commercial non-MA control, named control-2). Each packaging was tied with plastic bandage to make the mouth of each bag air tight, leaving almost no void space between the top and the fruit. The permeable properties for each non-holed polyolefin bag are shown in Table 1.

Table 1. Parameters of polyolefin films used in the current study**

Type of bag*	mPVC	mpPE	mPE	Control-1
Thickness (mm)	0.035	0.020	0.010	0.006
O_2 transmission rate (mL/m^2 d·atm)	6.80×10^3	2.57×10^5	1.50×10^4	1.54×10^4
CO_2 transmission rate (mL/m^2 d·atm)	4.32×10^3	2.48×10^5	7.30×10^4	6.53×10^4
Transmission ratio of CO_2/O_2	6.350	0.967	4.9	4.23
water vapour transmission rate (g/m^2 d)	25	13.4	4.48	22.8

*mPVC: modified polychloride film; mpPE: micro-perforated polyethylene film; mPE: modified polyethylene (mPE); Control-1: plastic film mulch.

**Data were provided by National Engineering Technology Research centre for Preservation of Agricultural Products, China. All parameters were measured under RH=50%, 20℃.

During the 2007-2008 seasons, each treatment consisted of 10 bags and weight loss and decay were investigated at the beginning and end of storage. In 2008-2009, each treatment consisted of 19 bags; thirteen for evaluations every 20-day, six for the investigation of weight loss and decay. All packaged fruit were held in ventilated plastic boxes (60×40×40cm, 2 bags per box) and stored at 0 to 1^{o}C.

Measurements of FFF, SSC, TA and ascorbic acid: At each sampling time in 2008-2009, 10 fruit were removed randomly from 3 polyolefin bag per treatment to measure fruit flesh firmness (FFF), soluble solids content (SSC), titratable acidity (TA) and reduced ascorbic acid (AA). For FFF, about a 15 mm diameter area of peel was removed from three equidistant locations around the equator of each fruit and the maximum penetration force was measured in Newtons (N) using a firmness tester (GY-3, Zhejiang, China) with an 11 mm cylindrical probe moving 5 mm s^{-1} and penetrating 10 mm into the flesh. A longitudinal slice of flesh was then removed from each peeled spot and squeezed to produce juice that was measured for SSC using a fruit sugar tester (WY032T, Sichuan, China). The three FFF and SSC measurements were each averaged per fruit and recorded as the value of one fruit. Longitudinal apple slices of more than 30 g fresh weight that excluded both core and peel were cut from the remaining areas of each fruit, combined with slices from the 10 fruit for each treatment, separated into three replicates of 30 g each for TA analysis and 50 g each for AA analysis, and then froze immediately with liquid nitrogen. Remaining apple flesh of the three replicate were also frozen and held at −80 ^{o}C until later analysis of SOD and MDA.

TA was determined using the method described by Akbudak and Eris (2004) with some modification as: a total 100 mL suspending sample solution was heated to 80℃ in a water bath for 30 min, centrifuged at 1500 ×g for 15 min, and then filtered through Whatman 541 filter paper from which 20 mL of the supernatant was titrated with 0.1M NaOH to an endpoint of pH 8.2 (pH-meter PHS-3c, Mettler Toledo, Germany). Results were expressed as g of malic acid per 100 mL. In the same way, additional supernatant was prepared from 50 g of fresh material to measure AA content according to the official titrimetric method (AOAC, 1990).

Respiration rate and ethylene measurement: At each sampling time in 2008−2009, an additional three replicates of 3 fruit each per treatment were randomly selected from the same 3 bags as previously chosen. The fruit were weighed; each replicate placed into its own 2.5 L jar, and respiration and ethylene production measurements were taken at 0 to 1^{o}C. Respiration rate (RR) was determined using a flow-through system with a fruit-vegetable respiration analyzer (GXH-3051H, Jun-Fang Hi-tech, China) equipped with an Infra-red CO_2 detector.

Immediately after RR determination, replicates of fruit were then sealed in 2.5 L jars for 1 hour, and headspace was evaluated for ethylene accumulation using a gas chromatograph (GC-14A, Shimadzu Corporation, Japan) equipped with a flame ionization detector (FID) and 90 ^{o}C oven temperature, 130 ^{o}C injector temperature, and 250 ^{o}C detector temperature. An empty container was used as a blank. After each measurement the volume of the three fruit was determined using water displacement.

Measurement of SOD activity and MDA content: About 1g of frozen sample was used to determine superoxide dismutase (SOD) activity and 5 g for malondialdehyde (MDA) content, both following the method of Wang *et al.* (2005)

Measurement of O_2 and CO_2 concentration in bags: Headspace of polyolefin bags made of the different treatment materials and filled with fruit was evaluated for O_2 and CO_2 concentration using an O_2 and CO_2 analyzer (accuracy: 0.01%, Checkmate 9900, PBI Denmark) on day 20 and day 220 of storage. Sample gas was taken by a syringe through a pre-pasted rubber pad.

Fruit weight loss rate and decay measurements: Weight loss was evaluated by comparing fruit weight at each sampling date to their initial weight before storage. Fruit decay and physiological disorders were evaluated after 220 days of storage during the 2007−2008 season, and after 220 and 270 days of storage during the 2008−2009 season. Results were expressed on a percentage basis.

Statistical analysis: All statistical analyses were performed with SPSS 17.0. ANOVA was used to compare difference between treatments (including control), and Duncan's test was applied to compare differences between means when ANOVA showed significant differences. Differences at $P < 0.05$ were considered to be significant.

Results

Effect of polyolefin bags on internal O_2 and CO_2 concentration: O_2 and CO_2 levels within the two control bags were similar to atmospheric conditions and did not change between 20 and 220 days of storage at 0 to 1 ^{o}C (Table 2). In contrast, three of the sealed polyolefin packagings developed significantly increased internal CO_2 levels and occasionally significantly decreased O_2 levels. In particular, mPVC bags resulted in a more extensive

Table 2. Internal O_2 and CO_2 concentrations during storage within polyolefin film bags containing approximately 5 kg of Fuji apples

	Day	Type of bag *				
		mPVC	mpPE	mPE	Control-1	Control-2
CO_2(%)	20d	2.73±0.015 a	0.17±0.06c	0.40±0.06b	0.10±0c	0.03±0c
	270d	2.38±0.016 a	0.31±0b	0.72±0.058b	0.10±0c	0.02±0c
O_2(%)	20d	15.70±0.7 a	20.70±0.05b	20.53±0.35b	20.57±0.37b	20.93±0b
	270d	18.13±0.67 a	20.90±0.05b	20.32±0.4b	20.80±0.53b	20.93±0b

*mPVC: modified polychloride film; mpPE: micro-perforated polyethylene film; mPE: modified polyethylene; Control-1: plastic film mulch; Control-2: polyvinyl chloride with eight 10 mm diameter holes per bag.
**Different small letters followed each value represent significant difference between treatments according to the LSD multiple range test ($p < 0.05$).

Table 3. Weight loss (%) of Fuji apples in polyolefin film bags after different storage durations

Type of bag *	Storage duration (days)								
	0	20	40	60	80	100	160	200	220
mPE	0	0.39a**	0.03a	0.04a	0.08a	1.5a	2.05a	3.79a	5.08a
mpPE	0	0.32a	0.59a	0.83ab	1.22ab	4.4b	5.4b	7.58b	7.82b
Control-1	0	1.15a	1.64a	2.01b	2.53b	4.6b	6.09b	7.59b	8.05bc
mPVC	0	2.38b	3.49b	3.97c	4.23c	5.4b	6.54b	7.83b	8.25bc
Control-2	0	0.29a	3.91b	4.96c	4.61c	5.54b	6.47b	7.17b	9.62c

*mPVC: modified polychloride film; mpPE: micro-perforated polyethylene film; mPE: modified polyethylene; Control-1: plastic film mulch; control-2: polyvinyl chloride with eight 10 mm diameter holes per bag.
**Different small letters followed each value represent significant difference between treatments according to the LSD multiple range test ($p < 0.05$).

modified atmospheres (MA) compared to other MAPs after both 20 and 220 days. Between day 20 and day 220, O_2 increased 2.43% and CO_2 decreased by 0.35% in mPVC bags. This agrees with Guan *et al.* (2004) who reported O_2 increased 2.0% and CO_2 decreased slightly in mPVC packagings between 10 to 100 days at 0 °C. Use of mPE resulted in CO_2 levels doubling and O_2 levels decreasing by 0.17 to 0.58% compared to mpPE. However, both mPE and mpPE have greater gas permeability (Table 1) and, thus, less of a MA developed inside the bags than when mPVC was used. The gas permeability of control-1 was the greatest of the bags tested and resulted in no significant difference in CO_2 or O_2 compared to control-2. To extent, no real MA-effect was developed by control-1(PFM bag).

Fruit quality responses of Fuji apple stored in the different polyolefin bags: Table 3 shows that apples in mPE bags lost significantly less fresh weight than those in other packagings after 100-day storage. This trend remained same until day 220 when weight loss from control-2 became significantly more than other packagings including control-1. Each sealed packaging retained > 92.8% of the original apple fresh weight after 220 days of storage, which was 1.4 % higher than the hole-opened control-2. No visible shrinkage was noticeable on apples from any of the sealed treatments.

Fruit flesh firmness (FFF) within all packagings declined gradually with storage duration and there were few significant differences between treatments at each sampling period (Table 4). Only on day 220, mpPE and control-2 were significantly firmer than mPVC, mPE and control-1.

In the first 180 days of storage, all SSC values declined slowly, then it began to decline more quickly. There were no significant differences in fruit SSC among the different treatments at each sampling period until the last evaluation on day 220 when mpPE had the highest SSC, and control-2 had the lowest (Table 4).

Titratable acidity (TA) levels steadily declined during storage from an initial value of 0.37 to 0.09 g $100g^{-1}$ after 220 days (data not shown), but there were no significant differences among treatments. Overall, there were few differences in apple ascorbic acid (Vc) content within each packaging. Only after 100-day storage Vc content of apples in mPE, control-1 and control-2 decreased faster than the other treatments, but after 140 days these differences disappeared.

Postharvest physiological responses of Fuji apple stored in the different polyolefin bags: Apple respiration rate (RR) was variable until 200-day storage when climacteric peaks began to appear (Fig.1). Fruit within control-1, mPVC and control-2 bags peaked on about day 220, whereas those in mPE and mpPE appeared to peak on day 240.

Peak ethylene production in apples held in control-1 and mPE bags occurred earliest after 80-day storage, followed by apples in mpPE, mPVC and control-2 bags after 100 days (Fig. 2), which corresponded with the accelerated loss of fresh weight and firmness. The peak in ethylene production was longest in apples held in mPE bags and lasted from 80 to 120 days during storage.

Superoxide dismutase (SOD) activity peaked dramatically from 125 to about 540 iu $g^{-1} h^{-1}$ after 20-day storage before dropping

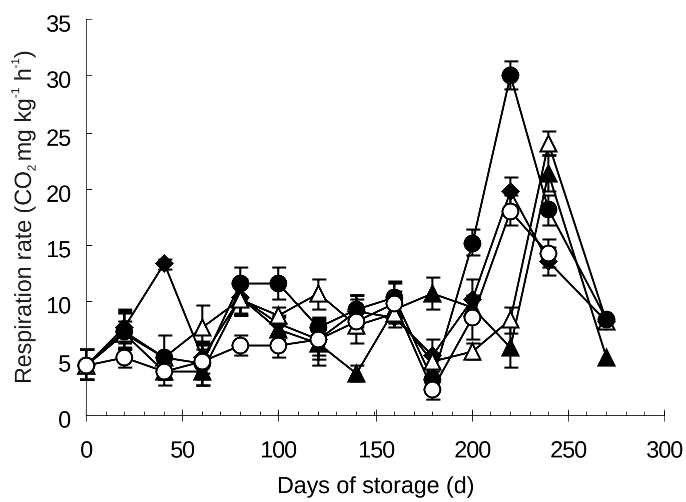

Fig. 1. Respiration rate changes of fruit from each packaging with storage time. Leagend: mPVC(♦), mpPE (▲), mPE(□), Control-1 (●) and Control-2(○)

Table 4. Changes in Fuji apple flesh firmness, soluble solids and ascorbic acid content during storage in different polyolefin bags

Storage duration (days)	Type of bag*	Firmness (N)	Soluble solid content (%)	Ascorbic acid content (mg 100g^{-1} FW)
0		78.05a**	15.49a	5.20a
40	mPVC	76.7ab	15.35ab	5.24a
	mpPE	74.7ab	15.36ab	4.95a
	mPE	70.7ab	15.52ab	5.26a
	Control-1	73.3ab	15.23ab	4.96a
	Control-2	70.4b	15.14ab	5.02a
100	mPVC	65.9bc	15.03b	4.20b
	mpPE	72.0ab	15.28ab	4.30b
	mPE	69.7b	15.18ab	2.65cd
	Control-1	68.3bc	14.64bc	3.20c
	Control-2	68.7b	14.86bc	3.30c
140	mPVC	66.0bc	15.17ab	2.90cd
	mpPE	69.7b	13.98d	3.77bc
	mPE	67.0bc	15.21ab	3.11cd
	Control-1	68.0bc	14.12cd	3.33c
	Control-2	67.0bc	14.59bc	2.90cd
180	mPVC	65.0bc	14.86bc	2.33d
	mpPE	67.3bc	14.75bc	2.93cd
	mPE	65.6bc	14.28cd	2.88cd
	Control-1	61.3cd	14.67bc	2.66cd
	Control-2	66.8bc	14.50c	2.77cd
220	mPVC	60.8cd	13.20e	2.23d
	mpPE	64.4bc	13.78d	2.54cd
	mPE	61.1cd	13.02e	2.24d
	Control-1	56.3d	13.00e	2.07d
	Control-2	62.4c	12.16f	2.16d

*mPVC: modified polychloride film; mpPE: micro-perforated polyethylene film; mPE: modified polyethylene; Control-1: plastic film mulch; control-2: polyvinyl chloride with eight 10 mm diameter holes per bag.

**Different small letters followed by each value represent significant difference between treatments according to the LSD multiple range test ($P < 0.05$).

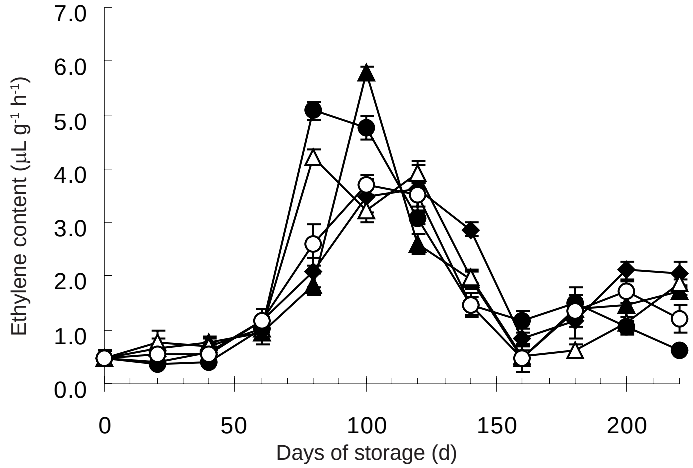

Fig. 2. Ethylene production changes of fruit from each packaging with storage time [mPVC (♦), mpPE (▲), mPE (□), Control-1 (●) and Control-2 (○)]

back to about 76 iu g^{-1} h^{-1} on day 40 (data not shown). Levels fluctuated at low levels thereafter. There were no significant differences between packagings.

Malondialdehyde (MDA) content of apples increased from 1.0 mmol g^{-1} FW^{-1} to 8.3 mmol g^{-1} FW^{-1} during the first 120 days of storage (data not shown). There were two main periods of rapid increase during this time spanning between 20−40 d and 80−120 d. After this, MDA levels decreased slightly.

Decay and disorders of Fuji apples stored in the different polyolefin bags: Over two seasons after 220 days of storage, the incidence of decay and core browning was consistently most severe on fruit held in mPE bags, whereas superficial scald developed most severely on apples held in mpPE, mPE, and control-2 bags (Table 5). As storage duration increased to 270 days during the 2008−2009 season, decay and disorders increased, but fruit in mPVC bags usually developed significantly less scald and core browning than other treatments as well as controls.

Discussion

Reports on peaches (Akbudak and Eris, 2004) and Teng-Mu No.1 apple (Liu and Ren, 2009) revealed that the maintenance of FFF within polyolefin bags is related to reduced water loss. In the current investigation, apples held in mPVC and control-1 bags lost significantly more fresh weight than other MAPs during 220

Table 5. Development of decay, scalds and core browning of Fuji apples after storage in different polyolefin film bags

Disorder	Storage duration (days)	Season	mPVC*	mpPE	mPE	Control-1	Control-2
Decay fruit rate (%)***	220	2007-2008	0.0a**	0.0a	6.3b	0.0a	0.0a
		2008-2009	0.0a	0.0a	4.2b	0.0a	0.0a
	270	2008-2009	3.2a	1.2a	23.9b	4.7a	7.5a
Scald fruit rate (%)****	220	2007-2008	0.0a	6.0b	7.9b	1.6ab	15.4c
		2008-2009	0.0a	2.4ab	6.3b	0.0a	16.1c
	270	2008-2009	30.9a	59.5b	71.2c	40.1a	50.6b
Core browning rate (%)	220	2007-2008	0.0a	1.6a	15.8b	4.6a	4.5a
		2008-2009	0.0a	1.2a	17.3b	4.4a	3.2a
	270	2008-2009	25.0a	35.9b	40.3b	39.4b	34.8b

*mPVC: modified polychloride film; mpPE: micro-perforated polyethylene film; mPE: modified polyethylene; Control-1: plastic film mulch; control-2: polyvinyl chloride with eight 10 mm ø holes per bag.

**Different small letters followed each value represent significant difference between treatments according to the LSD multiple range test ($p < 0.05$).

Fruit with visible deteriotion excluding scald defect stands for decay fruit which was counted immediately after each bag was removed from store room. * Scald fruit was counted 24 h after each bag was removed from store room.

days of storage, which was associated with the higher moisture permeability of the two bag material. However, in mPE bag, significantly less fresh weight loss was recorded than all other bags throughout the storage; it developed the same low FFF on apples as mPVC and control-1 in the end of storage; mpPE resembles mPE in gaseous permeability, but higher moisture permeability resulted significant higher apple FFF than mPE. This suggests that too much moisture in Fuji apple may obscure the MA-effect from packaging and enhance FFF drop as the same as too much water loss (control-1). Meanwhile, on day 40, FFF, SSC and AA were all at par as on 0 day for each packaging except for control-2, and then declined as storage time increased (Table 4). It revealed that Fuji apple was able to maintain a primary quality for at least 40 days with respect to physical and chemical changes under sealed packages and conditions of this work.

The initiation of the apple respiratory climacteric corresponded to a reduction in SSC in most packagings (Table 4). Apple RR peaks on day 220 coincided with significant decreases in SSC of fruit in control-1, mPVC and control-2 bags. These results support the fact that respiration consumption causes the decline of SSC in Fuji apple. Fruit in mPE bag didn't follow this rule due to the combined dilute effect from high moisture content. Sometimes SSC values decline because the fruit develops a mealy texture. Fruit with low firmness often have lower SSC because the cells aren't broken open and don't release the sugars. In this work SSC did not decrease in pace with FFF, two independent process were implied.

Within first 20 days of storage, SOD activity of apples in all packagings increased after detachment from the tree and exposure to storage conditions. The high SOD could be another reason for ascorbic acid content being maintained during the first 40-day storage (Table 4). After another 40-day storage, SOD activity fluctuated at low levels, implying its antioxidant protection became sustaintially weaker.

Sandhya (2010) reported MA containing < 8% O_2 and > 1% CO_2 retarded Fuji apple fruit ripening. This study supports Sandhya's conclusion because only mPVC bags, which elevated CO_2 to more than 2% (2.0 kPa), delayed fruit decay and disorder development through 220-day storage. Control-1 is applied popularly in storage industry as a cheap MA packaging. It actually developed no gaseous-MA condition according to the measurement in this study; however, it resembled mpPE on reducing superficial scald significantly compared to non-MA packaging (control-2), though higher scald than mPVC. Its advantage over control-2 in less fresh weight loss as well as higher SSC maintenance may work as a function of moisture-MA, enabling it control some disorder of apple. Thus, MA means proper modified CO_2, O_2 and moisture; the more conditions are satisfied, the better storage result will be achieved.

Core browning of apple fruit was found to be induced by low endogenous O_2 (<1.6%) (Yeardley *et al.*, 1997) or high CO_2 (10%) (Guan *et al.*, 2004). Wang *et al.* (2002) also found that >5% CO_2 induced core browning, however, core browning could result from fruit senescence as well. In the current study, mPVC bags resulted in the highest CO_2 and lowest O_2 concentrations among four MAPs and also the least core browning, which implies that core browning was more due to senescent processes than MA conditions.

For a 0-1 ^{o}C storage as long as about 7 months, polyolefin bags made of mPVC maintained Fuji fruit in best quality. The fruit developed no decay or disorder after 220-day storage and only had among the lowest decay, the least superficial scald and core browning after 270-day storage. The maximum storage life of Fuji apples is likely around 220 days in mPVC bags at 0-1 ^{o}C because scald and core browning accelerated thereafter. For a 0-1 ^{o}C storage shorter than 6 months, PFM (control-1) bag is suggested the preferred packaging for Fuji apple because similar results as that from mPVC bag could be obtained at a lowest cost. PFM showed no gaseous-MA effect, but proper moisture-MA function, which benefited the partly control of superficial scald of the apple. The combined effects of reduced ethylene production and respiration resulted from an effective MA delayed senescence and resulted in the overall better fruit quality after storage.

Acknowledgement

This work was funded by the project 'National Technical System for Agricultural Industry' financed by the Ministry of Agriculture of China.

References

Akbudak, B. and A. Eris, 2004. Physical and chemical changes in peaches and nectarines during the modified atmosphere storage. *Fd. Control*., 15: 307-313.

AOAC, 1990. Vitamin C (ascorbic acid), 2,6-dichloroindophenol titrimetric method[S]. In: *Official Methods of Analysis*, Helrich, K. (Ed.), 15th ed. AOAC, Arlington, VA, 1058-1059.

Guan, W.Q., L. Chen, X.H. Li and Y.F. Hu, 2004. Effect of modified atmosphere packaging on the quality of Fuji apple. *Trans. CSAE,* 20(5): 218-221. (In Chinese)

Li, M., Y.S.Liu, Z.H.Liang and G.F.Li, 2008. Effect of pericarp microstructure and storage quality on bagged fruits of Hongfushi apple types. *Gansu Agric. Sci. Technol.*, 30(4): 14-16. (In Chinese)

Liang, Z.H. and Y.L. Huang, 2009. Effect of fruit bagging and postharvest coating on fruit storage property of red Fuji apple. *Storage & Process*, 9(5): 25-28. (In Chinese)

Liu, Y.P. and X.L. Ren, 2009. Effect of MA packaging and 1-MCP Treatment on qualities of apple during storage. *Henan Agricultural Sci.*, 38(6): 116-119. (In Chinese)

Sandhya, 2010. Modified atmosphere packaging of fresh produce: Current status and future needs. *LWT – Fd. Sci. Technol.,* 43: 381-392.

Tian, Y.G. and H.D. Liu, 2008. Problems of modified-atmosphere warehouse in China. *Storage & Process.,* 8(3): 53-54. (In Chinese)

Wang C.S., J.X. Shi, M. Zhao, L.X. Zhang and L.J. Hua, 2002. Study on CA storage indices of Fuji apple. *Acta Agriculturae Boreali-Sinica.* 17(5): 100-103. (In Chinese)

Wang, Y.S., S.P. Tian and Y. Xu, 2005. Effects of high oxygen concentration on pro- and anti-oxidant enzymes in peach fruit during postharvest periods. *Fd. Chem.,* 91: 99-104.

Xu, K. and Q.G. Wang, 2006. Effects of ultra low-oxygen treatment on storage quality of Fuji apple during storage. *Fd and Ferment. Ind.,* 32(12): 167-170. (In Chinese)

Yang, Q.L., L. Li and X. Liu, 2004. Modified atmosphere storage of apple fruit. *Yantai Fruits,* 25(4): 49-50. (In Chinese)

Yearsley, C.W., N.H. Banks and S. Ganesh, 1997. Temperature effects on the internal lower oxygen limits of apple fruit. *Postharvest Bio. Technol.,* 11(2): 73-83.

Received: March, 2010; Revised: June, 2010; Accepted: July, 2010