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Effect of initial hermetic sealing on quality of 'Kyoho' grapes during storage

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ABSTRACT

Experiments of initial hermetic sealing using high barrier film were carried out on 'Kyoho' grapes (*Vitis vinifera* L. × *V. Labrusca* L. cv. Kyoho) in the 2008 and 2009 fruit seasons, to investigate their potential to enhance quality and extend storage life of the fruit. In the 2008 season, grapes were packaged in high barrier film bags for 1, 2, 3, 4 and 5 weeks, and a modified atmosphere (MA) of low oxygen and high carbon dioxide was formed after sealing. After packaging, fruit were removed from bags and stored in air for up to 90 d at 0 °C. In the 2009 season, grapes were packaged in perforated bags, or in high barrier film bags for 2 weeks and subsequently perforated bags to avoid further anoxia and excessive CO_2 accumulation. After treatment, fruit were stored for up to 90 d at 0 °C, followed by shelf-life at 20 °C for 7 d. Non-packaging air storage was used as a control in both seasons. Fruit quality attributes including soluble solids, titratable acidity, stem browning, berry drop and decay incidence were measured. The results indicated that short-term initial MAP (≤2 weeks) had potential for improving appearance of bunches and maintaining the quality of berries during long-term storage, and significantly reduced quality deterioration. Stems were greener and berry drop and decay incidence were more effectively controlled when fruit were sealed in high barrier film bags for 2 weeks and the bags were subsequently perforated.

1. Introduction

Table grapes are non-climacteric fruit with low physiological activity. Their shelf-life is limited by stem and rachis browning, loss of firmness or water, berry drop and decay caused mainly by *Botrytis cinerea* (Deng et al., 2006; Lurie et al., 2006; Wu et al., 2008). Many previous studies have shown that controlled atmospheres (CA) and modified atmosphere packaging (MAP) are useful to control berry decay, extend storage life, and maintain the quality of table grapes. For example, CA with CO_2 at 15 kPa or higher results in good control of *Botrytis* (Retamales et al., 2003), and a 3-d high CO_2 (more than 10 kPa) pretreatment reduces rachis browning (Crisosto et al., 2002; Retamales et al., 2003). Romero et al. (2006) and Sanchez-Ballesta et al. (2006) reported that pretreatment with 20 kPa CO_2 and 20 kPa O_2 for 3 d reduced fungal decay in table grapes stored at 0 °C while maintaining fruit quality. Martínez-Romero et al. (2003) reported that MAP could preserve table grape organoleptic quality, and Artés-Hernández et al. (2004) showed that MAP with 15 kPa O_2 + 10 kPa CO_2 provided the best treatment for keeping quality of 'Autumn seedless' grapes. Artés-Hernández et al. (2006) packaged 'Superior seedless' table grapes using micro-perforated polypropylene film and oriented polypropylene film and found that MAP could keep the overall quality of clusters close to that at harvest. Del Nobile et al. (2009) packaged table grapes using five different packaging films and found that the best results were obtained using high barrier films for preserving the quality of grapes.

'Kyoho' grape is a cross between *Vitis vinifera* L. and *V. Labrusca* L. grapes and an important table grape in China, that has compact medium-to-large bunches with large irregular berries and a deep black colored skin. The aims of the present work were to determine the effects of initial hermetic sealing using high barrier film bags on keeping quality of 'Kyoho' table grapes during long-term cold storage, and to develop a MAP technology which is a more convenient method for postharvest handling and marketing.

2. Material and methods

2.1. Plant material and treatments

'Kyoho' grapes were harvested at commercial maturity stage (>15% total soluble solids and approximately 0.52% tartaric acid) from a 9-year old vineyard located in Fengyang, Anhui Province, China. Fruit were transported to the laboratory and air-cooled to a berry temperature of approximately 0 °C. The clusters were selected on the basis of uniform color, size, absence of injuries, and

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healthy or greenish rachises. Experiments were conducted in the 2008 and 2009 fruit seasons to evaluate the effect of different durations of initial hermetic sealing on grape quality. In the 2008 season, grapes were packaged in high barrier film bags (60 μm thickness) made of polyamide/polyethylene (PA/PE), which had gas transmission rates of 20.5×10^{-15} for O_2 and 65×10^{-15} mol m^{-2} s^{-1} Pa^{-1} for CO_2 (data provided by the manufacturer), hermetically sealed using a heat sealer (FR-900, Shanghai Shenyue Packaging Machine Manufacturing Co., Ltd, Shanghai, China) and stored for 1, 2, 3, 4 and 5 weeks. After treatment, fruit were transferred to air and were continued to be stored for up to 90 d. In the 2009 season, grapes were packaged in perforated bags with 10 holes of 0.7 mm diameter per 100 cm^2, or in high barrier film bags for 2 weeks and then the bags were perforated as described above to avoid further anoxia and excessive CO_2 accumulation. A preliminary experiment showed that the gas in perforated bags was close to ambient atmosphere during all the experiments. Non-packaging air storage was used as a control and each cluster (220–240 g) was packed individually into a bag similar in size to cluster (approximately 20 cm × 15 cm) in both seasons. There were four replicates of 40 fruit for each treatment, and all fruit were stored at 0 °C. The gas compositions and ethanol contents were analyzed weekly during sealing. Sensory quality was regularly analyzed during the 2008 season. For example, SSC and TA contents were measured on days 0, 7, 14, 21, 28, 35, 45, 60, 75 and 90, stem browning, berry drop and decay were analyzed on days 45, 60, 75 and 90, and flavor was evaluated on days 0, 7, 14, 21, 28, 35 and 90. During the 2009 season, all sensory quality parameters were analyzed at the end of storage and shelf-life.

2.2. Headspace gas composition

O_2 and CO_2 contents of the packaged grapes were measured using an O_2 and CO_2 meter (PBI Dansensor, Checkmate 9900, Rønnedevej 18, DK-4100 Ringsted, Denmark). A silicone septum was provided on the bag surface for sampling gas inside the package. The volume taken from the package headspace using a syringe for gas analysis was about 10 mL. Three bags randomly selected from each treatment were taken every week for gas analysis. Results were mean ± SE and expressed as kilopascals (kPa). To avoid changes in the headspace gas composition due to gas sampling, each package was used only for a single determination of the headspace gas composition.

2.3. Internal ethanol concentrations

Ethanol concentrations in the juice were determined following incubation of 10 mL aliquots of juice in 50 mL Erlenmeyer flasks at 30 °C for 30 min as described by Porat et al. (2005). In parallel, 50 mL Erlenmeyer flasks containing 10 mL solutions with known concentrations of ethanol (100 μL L^{-1}) were incubated together with the juice samples and used as internal standards for quantity evaluations. After the incubation period, 2 mL gas samples were withdrawn from the headspaces into syringes, and their ethanol levels were determined with a gas chromatograph (Shimadzu GC-14, Kyoto, Japan). The results are given as mean ± SE.

2.4. Quality evaluations

Quality evaluation was performed at harvest, immediately after removal from the packaging every week during sealing, every month during cold storage or at the end of shelf-life at 20 °C. At each evaluation time, the fruit were checked for soluble solids content (SSC), titratable acidity (TA), water loss, stem browning, berry drop and flavor.

Ten berries for each bag from each replication were squeezed with a hand-press juicer. The juice was measured for SSC using a hand-held sugar refractometer (WYT-I, Chendu Optical Apparatus Co., Chendu, Sichuan Province, China). TA was determined on a composite sample of the same berries using 0.1N KOH up to a pH of 8.2 and expressed as percentage of tartaric acid.

Water loss was measured by weighing individual bunches at the beginning of the experiments and again at each evaluation.

Stem browning development was assessed using the following scale based on Crisosto et al. (2002): 1, healthy, entire rachis including the cap stems (merging point between berries and rachis), green; 2, slight, only cap stems showing browning; 3, moderate, cap stems and secondary rachis showing browning, and 4, severe, cap stems, secondary and primary rachis completely brown.

For berry drop, the abscised berries from clusters were weighed at the end of storage. The weight of berry drop was recorded using a scale with an accuracy of 0.01 g (FA2004B, Shanghai Precision and Scientific Instrument Co., Ltd., China) and expressed as % initial weight.

Flavors were scored based on a nine-point scale (1: extremely poor or soft in case of texture; 3: poor or soft; 5: moderate and limit of marketability; 7: good; 9: excellent) according to Artés-Hernández et al. (2004). Flavor was analyzed by a panel of five trained people and the data obtained were used as preliminary results for sensory evaluation.

2.5. Decay assessment

For decay analysis, the number of decayed and wilted grapes for each bunch was counted, and then percentage of the total berries was calculated for each sampling date. Ten bags from each replication were analyzed and the results are given as mean ± SE.

2.6. Statistical analysis

All data were analyzed by one-way analysis of variance (ANOVA). Mean separations were performed by Duncan's multiple range test by means of SPSS 11.0 in Windows. Differences at $P < 0.05$ were considered as significant.

3. Results

3.1. Experiments in the 2008 season

3.1.1. Headspace gas concentrations

During the 2008 season, grapes were sealed in high barrier bags for 5 weeks. Fig. 1 shows the oxygen and carbon dioxide concentrations in the package headspace during sealing. The MA was

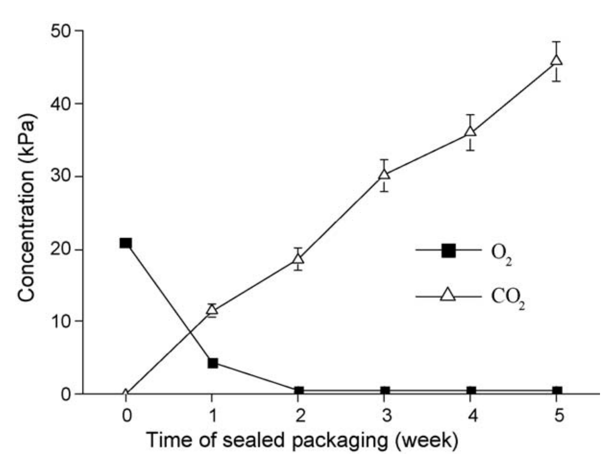

Fig. 1. Changes in gas composition within packaging during sealing of 'Kyoho' table grapes in 2008. Data are mean ± SE.

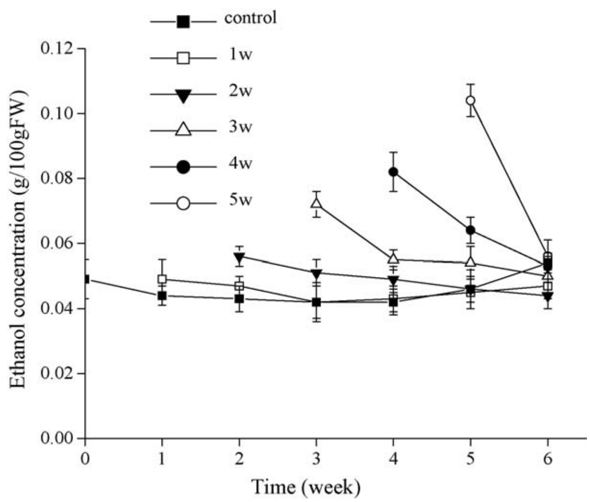

Fig. 2. Changes in ethanol contents for 'Kyoho' table grapes after sealing using high barrier film bags for 1, 2, 3, 4 and 5 weeks at 0 C. After sealing, fruit were transferred to air in 2008. Data are mean ± SE.

formed inside the packages as a result of interaction between produce respiration and barrier properties of the packaging material. As expected, a decrease in the headspace oxygen and an increase in the headspace carbon dioxide concentrations were observed. Due to the high barrier properties of the film, oxygen concentrations in packaging decreased quickly and reached about 4.5 kPa and <1.0 kPa after 1 and 2 weeks, while the CO_2 concentration increased quickly and reached 11.5, 18.6, 30.1, 36 and 45.8 kPa after 1–5 weeks of sealing, respectively, implying that anaerobic respiration was induced after 3 weeks sealing.

3.1.2. Production of ethanol

Hermetic sealing within the first 2 weeks caused only a slight increase in ethanol content in the juice, but longer periods (≥3 weeks) stimulated rapid accumulation of ethanol, showing a linear increase. The longer the treatment duration, the higher the internal ethanol concentration (Fig. 2). A reduction in ethanol was observed when fruit were removed from packaging and transferred to air, but there were no significant differences between packaging treatments and controls ($P > 0.05$).

3.1.3. Soluble solids content (SSC) and titratable acidity (TA)

SSC increased slightly in the first 35 d and then remained relatively stable in grapes packaged in sealed bags until 60 d (Fig. 3A), and the differences were not significant ($P > 0.05$). After 60 d of storage, SSC increased slightly in grapes packaged in sealed bags for longer than 4 weeks and they reached the highest values at the end of storage. The highest SSC was found in 5-week packaged grapes after 90 d of storage, followed by the control and 4-week packaged grapes. Grape packaged from 1 to 3 weeks had lower SSC contents. On the contrary, SSC decreased gradually in sealed bags for less than 3 weeks. A continuous increase in SSC was found in control grapes during the whole storage duration (Fig. 3A).

A slight decrease in TA was observed in all treatments during storage (Fig. 3B). Storage in the initial MAP and subsequently in air resulted in higher TA retention than storage in air. Packaging below 3 weeks, especially 2 weeks, retained higher TA. Packaging for more than 4 weeks led to lower TA contents at the end of storage, with similar values to that in control grapes.

3.1.4. Stem browning, berry drop and decay assessment

Stem browning was low and no significant differences were detected in all treatments for the first 2 months ($P > 0.05$),

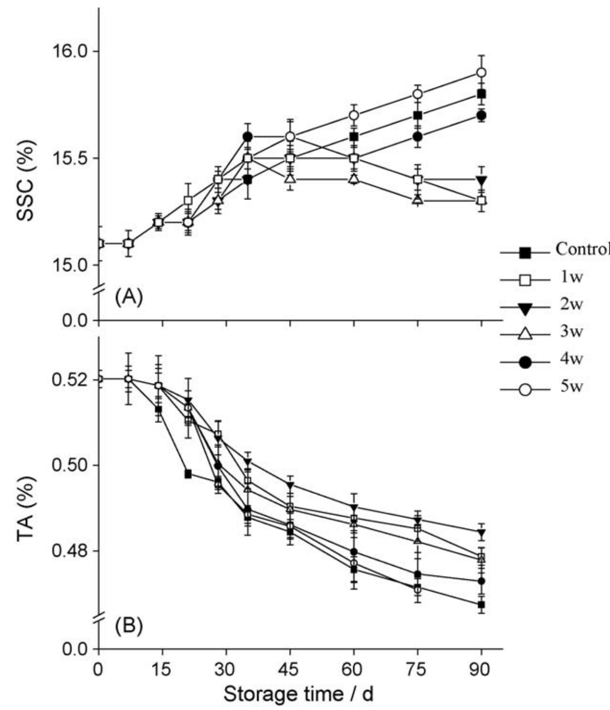

Fig. 3. SSC and TA changes in initial MAP berries during cold storage in 2008. Data are mean ± SE.

after which browning increased clearly (Fig. 4A). Stem browning increased most rapidly in control grapes and sealed grapes for ≥3 weeks. On the 90th day, extreme stem browning was observed in sealed grapes at ≥4 weeks, followed by controls and sealed grapes at 3 weeks. The treatment with initial sealed packaging for 2 weeks was the most effective in maintaining the stem green, and only a slight stem browning (<1) occurred after cold storage (Fig. 4A).

A similar trend occurred with changes in berry drop and decay incidence (Figs. 4B and C). Samples packaged for 5 weeks showed the highest berry drop followed by the samples packaged for 4 weeks and the control. The grapes packaged for 2 weeks showed the lowest incidence in berry drop (Fig. 4B). Grapes stored with ≥3 weeks of sealed packaging had higher decay incidence than grapes stored ≤2 weeks in sealed packaging (Fig. 4C). There were significant differences in decay incidence between grapes packaged for 1–2 weeks and other treatments or controls ($P < 0.05$). After 90 d of storage, some increase in decay was observed, with the highest incidence occurring in grapes with the 5-week seal treatment, followed by the control fruit.

3.1.5. Flavors

After packaging, an off-flavor was detected and increased over packaging time (Fig. 5), but disappeared after ventilation. Almost no off-flavors were detected for initial MAP for ≤2 weeks after 90 d of storage. However, severe off-flavors were detected in grapes in the initially sealed packaging for 4–5 weeks.

3.2. Experiments in the 2009 season

In the 2009 season, tests were performed based on the experiment results in 2008 to evaluate the effect of combining 2 weeks sealed packaging and subsequent perforation on quality of grapes. At harvest, values of SSC and TA were 15.5 and 0.52%, respectively (Table 1). After cold storage, the contents of SSC in grapes, both packaged with the perforated film (PF) and high barrier film initially followed by perforated film (HBF-PF) were slightly lower than those at harvest but without significant differences ($P > 0.05$), while

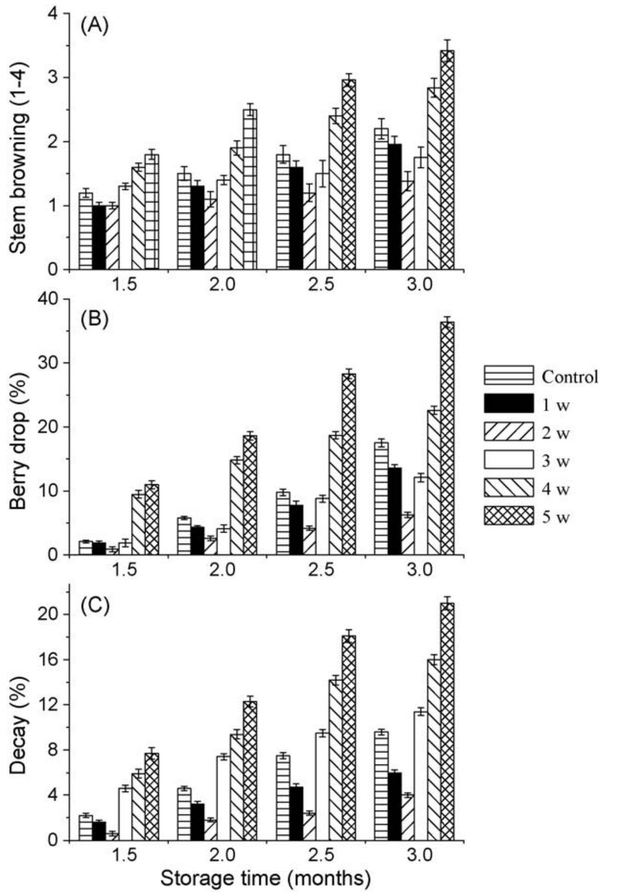

Fig. 4. Changes of stem browning, berry drop and decay for 'Kyoho' table grapes after cold storage for 90 d at 0 C with initial high barrier film packaging for 1, 2, 3, 4 and 5 weeks in 2008. Data are mean ± SE. Stem browning score: 1: healthy; 2: slight; 3: moderate; 4: severe.

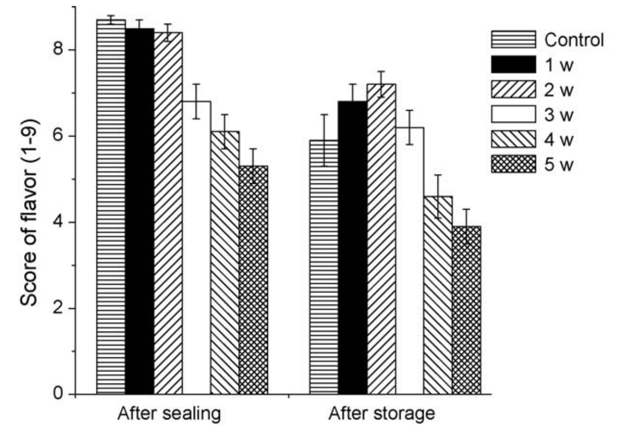

Fig. 5. Score of sensory evaluation of flavor for 'Kyoho' table grapes during sealing and after cold storage for 90 d at 0 C with initial hermetic sealing for 1, 2, 3, 4 and 5 weeks in 2008. Score of sensory evaluation of flavor: 1: extremely poor; 3: poor; 5: acceptable, limit of marketability; 7: good; 9: excellent.

the SSC of control fruit increased slightly (Table 1). After shelf-life at 20 °C for 7 d, the SSC in all grapes tended to increase compared to their values at the end of storage. The TA in all grapes decreased slightly compared to values at harvest, and no significant difference was observed among them after cold storage and shelf-life ($P > 0.05$).

Film packaging reduced weight loss significantly, and grapes treated with HBF-PF hardly suffered from weight loss (under 0.05%). The control grapes reached the highest weight losses (Table 1).

Similar trends in stem browning, berry drop and decay were found in the same sealed treatment. Grapes treated with HBF-PF had the lowest stem browning, berry drop and decay compared with PF treatment alone and the control (Table 1). These results confirmed the effect of initial MAP on maintaining quality of grapes. Stem browning, berry drop and decay incidence increased during shelf-life evaluation (7 d at 20 °C), particularly in control grapes.

Sealed packaging had a large effect on the flavor score of grapes. After cold storage, grapes packaged with HBF-PF showed a better acceptability followed by grapes packaged with PF. Severe off-flavors were detected in non-packaged grapes. After shelf-life, all grapes developed more severe off-flavors (Table 1).

4. Discussion

Film packaging can modify in-package atmospheres and an MA of low oxygen and high carbon dioxide is produced. The MA condition can reduce weight loss, and offer protection from physical, physiological, and pathological deterioration throughout marketing of products (Wang and Qi, 1997). Tolerance of fruit to low O_2 and high CO_2 is different depending on the species and variety of the fruit. For example, 'Hass' avocado fruit cannot tolerate 0.25 kPa O_2 for longer than 24 h at 20 °C (Yahia and Carrillo-Lopez, 1993). In contrast, 'Valencia' oranges and mangoes can tolerate 0.25 kPa O_2 for more than 5 d at 20 °C (Ke and Kader, 1992; Yahia and Hernandez, 1993), and 'Thompson Seedless' grapes can tolerate low oxygen (0.5 kPa) and high CO_2 (>35 kPa) for 6 d at 5 °C (Ahumada et al., 1996). El-Mir et al. (2001) concluded that hypoxic acclimation (3 kPa O_2 for 24 h) increased the tolerance of avocado fruit to subsequent 0.25 and 1 kPa O_2 atmospheres.

Table 1
Changes of quality for 'Kyoho' table grapes packaged individually in high barrier film for 2 weeks followed by perforated film for up to 90 d (HBF-PF), and packaged in perforated film for 90 d (PF) at harvest and after storage and shelf-life for 7 d at 20 °C under different treatments in 2009.

Treatments	SSC (%)	TA (%)	Water loss (%)	Stem browning (1–4)	Berry drop (%)	Decay (%)	Flavor (1–9)
At harvest	15.50 ± 0.06 cd	0.52 ± 0.02 a	–	1.00 ± 0.00 f	–	–	8.40 ± 0.08 a
After storage							
Non-packaging	15.90 ± 0.03 b	0.49 ± 0.01 a	6.84 ± 0.09 b	2.47 ± 0.06 b	7.04 ± 0.12 b	3.08 ± 0.22 b	5.00 ± 0.29 f
HBF-PF	15.30 ± 0.09 d	0.51 ± 0.02 a	0.02 ± 0.01 f	1.38 ± 0.07 e	1.25 ± 0.03 e	1.00 ± 0.04 e	7.70 ± 0.10 b
PF	15.60 ± 0.12 cd	0.50 ± 0.01 a	1.04 ± 0.01 d	1.75 ± 0.05 d	2.13 ± 0.08 d	1.38 ± 0.07 d	6.50 ± 0.12 cd
After shelf-life							
Non-packaging	16.60 ± 0.15 a	0.51 ± 0.02 a	9.31 ± 0.04 a	2.88 ± 0.07 a	9.54 ± 0.14 a	5.66 ± 0.11 a	4.70 ± 0.19 f
HBF-PF	15.50 ± 0.04 cd	0.51 ± 0.02 a	0.86 ± 0.05 e	1.69 ± 0.05 d	1.95 ± 0.05 d	1.25 ± 0.08 de	7.10 ± 0.06 bc
PF	15.80 ± 0.07 bc	0.50 ± 0.01 a	2.04 ± 0.04 c	1.97 ± 0.06 c	2.83 ± 0.09 c	2.09 ± 0.08 c	6.10 ± 0.04 e

Values within a column followed by the same letter are not significantly different ($P > 0.05$) according to Duncan's multiple range test.
Stem browning score: 1: healthy; 2: slight; 3: moderate; 4: severe.
Score of sensory evaluation of flavor: 1: extremely poor; 3: poor; 5: acceptable, limit of marketability; 7: good; 9: excellent.
PF, packaged in perforated film for 90 d; HBF-PF, packaged in high barrier film for 2 weeks followed by perforated film for up to 90 d.

Although low O_2 stress has been applied successfully to extend the postharvest life of fresh fruit (Chervin et al., 1997; Beaudry, 1999; Wang and Dilley, 2000), no research, to the best of our knowledge, has been conducted using low O_2 stress during postharvest handling of table grapes. In the present research, due to the high barrier properties of the film, the O_2 level inside the packages decreased until low O_2 stress was induced, while CO_2 increased gradually during sealing. The low O_2 concentration inside the packages, along with the high CO_2 concentration, may have induced the fruit to become partially anaerobic, resulting in the production of CO_2 and ethanol. Pesis (2005) demonstrated that short-duration low O_2 pretreatments, which induce production of acetaldehyde and ethanol, and has beneficial effects in many subtropical fruit, and treatments of longer duration can cause production of off-flavors. When anaerobic respiration was induced, the package would be perforated to alleviate the stress and to avoid injury (Burdon et al., 2008).

Many studies have shown that exogenous ethanol can be applied to improve ripening and prevent decay development of fruit (Lichter et al., 2002; Chervin et al., 2005; Lurie et al., 2006). Also, ethanol vapors might be effective in reducing polyphenol oxidase (PPO) activity that is known to be involved in browning (Pesis, 2005). Corcuff et al. (1996) reported that ethanol-enriched atmospheres improved the preservation of quality of broccoli florets by slowing down chlorophyll loss as well as weight loss. Recently, ethanol treatment was suggested as a means to prevent *Botrytis* decay during storage and to extend the shelf-life of stored table grapes (Chervin et al., 2005; Lurie et al., 2006). Chervin et al. (2003) reported that the optimal ethanol dose for effective disease control was less than 5 mL kg^{-1} of grapes, and higher ethanol doses could result in higher stem browning. Kelly and Saltveit (1988) speculated that production of endogenous ethanol due to low O_2 and high CO_2 might have similar effects as exogenous application of ethanol.

In this study, grapes packaged under short-term initial MAP conditions showed beneficial effects in terms of maintenance of the parameters related to quality as compared with those stored in air. Initial MAP could reduce stem browning of grapes, which is in agreement with the results reported by Retamales et al. (2003) who showed that the 3-d high CO_2 pretreatment reduced rachis browning of 'Redglobe' table grapes. Pesis (2005) suggested that ethanol induced by reduced O_2 has beneficial effects on the fruit in small quantities, while negative effects in large quantities. Our results showed that low ethanol levels induced by lower O_2 might reduce stem browning, berry drop and decay, and retard ripening without impairing the taste of the berries, while high ethanol levels could cause increased stem browning, decay, berry drop and off-flavors. Thus, the quality of grapes was better maintained by short-term sealed pretreatment ranging from 1 to 2 weeks due to the positive effects of MA with low O_2 and intermediate CO_2 concentrations, and residual effects of production of ethanol induced by low O_2 stress. However, high concentrations of CO_2 under long duration packaging have been shown to increase stem browning (Guevara et al., 2003). To avoid detrimental effects of long-term low O_2 and high CO_2 stress, fruit were therefore transferred to air from anaerobic conditions, and the ethanol levels were reduced (Fig. 2). A similar effect was also observed by Bonghi et al. (1999), who transferred peach fruit to air from ultra-low O_2 conditions and the concentrations of ethanol gradually decreased. Polenta et al. (2006) concluded that ethanol reduction could be probably caused by reversibility of the synthetic pathway due to pyruvate decarboxylase (PDC) and alcohol dehydrogenase (ADH) enzymes synthesis or ethanol volatilisation and/or transformation into esters.

Elevated concentrations of CO_2 in CA (15 kPa and higher) effectively controlled *Botrytis* rot infection, indicating that use of CA with higher CO_2 concentrations has the potential to replace the present technology of applying SO_2 for table grapes under prolonged storage/transport conditions (Retamales et al., 2003). Crisosto et al. (2002) showed that $CO_2 \geq 10$ kPa significantly reduced incidences of *Botrytis* while O_2 concentrations did not have an effect. The reduced decay in the present study might be attributed to high level CO_2 in package.

Initial MAP treatments had larger effects on TSS and TA contents. A slight decrease in SSC was observed in all treatments, but the differences were not significant ($P > 0.05$) during 60-d storage. After 60 d of storage, SSC continued to increase in grapes packaged in sealed bags for above 4 weeks and in the control, but decreased slightly from 1 to 3 weeks in sealed packaging (Fig. 3A). The results confirmed that short-term initial MAP induced a slower physiological maturation in table grapes (Valero et al., 2006), probably because some carbohydrates were converted into water soluble sugars due to hydrolysis and slow ripening (Artés-Hernández et al., 2004) in the first 60 d, with subsequent respiratory activity of berries using sugars as the main substrate for this physiological process (Artés-Hernández et al., 2006). On the contrary, longer duration initial MAP accelerated ripening and senescence of grapes. The increase of reactive oxygen species (ROS) has been frequently observed during senescence and fruit ripening (Vicente et al., 2006), and the accumulation of ROS could contribute to loss of membrane integrity and increased water leakage, which resulted in continuous water loss and further concentration of SSC. After the shelf-life at 20 °C for 7 d, the SSC in all grapes tended to increase compared to their values at end of storage, most likely due to the increased water loss, which concentrated the remaining solid fraction (Escalona et al., 2007).

A slight decrease in TA was observed in all treatments during storage (Fig. 3B). However, short-term initial MAP, especially 2 weeks, retained higher TA, indicating that initial MAP could effectively suppress fruit respiration.

The effect of MAP on reducing weight loss is due to the limitation of water vapor diffusion by plastic films, and in turn generating a high humidity and water vapor pressure surrounding the products (Serrano et al., 2006). This is in agreement with results from Martínez-Romero et al. (2003).

In this study, a slight off-flavor was detected after sealing but this disappeared after transferring to air, and slightly increased ethanol levels and off-flavors were detected in short-term sealed grapes after cold storage and shelf-life. This may be due to ethanol contents declining sharply to below the threshold ethanol level after fruit were removed from packaging, and may be due to the high SSC in grapes, masking the detection of the lower concentration of ethanol by taste panelists (Ke et al., 1991). Higher ethanol levels were detected in longer duration sealed grapes, and the ethanol content in fruit sealed for 5 weeks was the highest (Fig. 2), reaching 0.13%, and the alcoholic off-flavor was the most significant after cold storage (Fig. 5). These results indicated that sealing duration for more than 3 weeks was too long, leading to severe anaerobic metabolism companied by accumulation of anaerobic off-flavors related to the production of ethanol, and visible damage to grape quality.

In low O_2 and/or high CO_2 storage of fruit and vegetables, most studies showed that the desired low O_2 and high CO_2 concentrations could be achieved by purging experimental containers using a prepared required gas mixture (balance N_2). But the application of N_2 and CO_2 by release from a gas cylinder is not convenient nor often economically feasible. Low O_2 and high CO_2 concentrations were obtained due to fruit respiration by application of the initial MAP treatment, and provided an effective and convenient tool in maintaining fruit quality. In this experiment, grapes packaged in short-term initially high barrier film bags (1 and 2 weeks) followed by perforated bags preserved their quality compared with air-stored table grapes. Especially, initial hermetic sealing for 2 weeks provided the best results in terms of sensory quality close to that at harvest after 90-d cold storage. Initial hermetic sealing resulted in slight anaerobic conditions and improved grape quality. However, if sealed packaging periods were extended (≥3 weeks), they could be detrimental to fruit and lead to development of off-flavors, browning of tissues, and accumulation of ethanol and acetaldehyde, and therefore the bags must be perforated to avoid anaerobic conditions.

Application of initial low O_2 by hermetic sealing can be beneficial to many fruit for maintaining fruit firmness and color, decreasing weight loss and alleviating physiological disorders and decay. However, the efficacy of hermetic sealing may depend on cultivar, temperature of storage and treatment period. To avoid the deleterious effects of large quantities of anaerobic metabolites in fruit, it is important to optimize the durations of sealed packaging for a specific fruit crop.

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