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Effect of modified atmosphere packaging on quality and shelf life of baby leaf lettuce

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RESEARCH ARTICLE

Abstract

Freshly harvested baby leaf lettuce (*Lactuca sativa* L. cv. Red Romaine) leaves were packaged with 1,300, 20,000, 40,000, or 100,000 cm^3/m^2/day/atm oxygen transmission rate (OTR) packaging films as modified atmosphere packaging (MAP), as well as perforated film, then stored at 8 °C with 90% relative humidity in order to determine the most suitable OTR film. The results indicated that the 20,000 cm^3 OTR film modified the atmosphere created in the package so that it consisted of 19.25-19.95% oxygen, 1.55-4.90% carbon dioxide and 5.10-8.06 μl/l ethylene. Changes in quality of the lettuce, including weight loss, visual quality, chlorophyll concentration, colour (L*, a*, b*, chroma and hue angle) and off-odour were lowest under the 20,000 cm^3 OTR film. Leaves under the 20,000 cm^3 OTR film also exhibited the highest shelf life at 30 days. The anthocyanin concentration was highest and the peroxidase activity, which results in browning, was lowest under the 20,000 cm^3 OTR film, compared with the other treatments. In the baby leaf lettuce, the antioxidant capacity was tested and measured as flavonoid, phenolic, 1,1-diphenyl-2-picrylhydrazyl and total vitamin C concentrations, all of which showed the highest concentrations under the 20,000 cm^3 OTR film. Therefore, the 20,000 cm^3 OTR film, as a MAP, could be useful for the cold chain distribution of baby leaf lettuce for maintaining quality and thus exporting lettuce for consumer satisfaction.

Keywords: anthocyanin, chlorophyll, DPPH, flavonoid, red romaine

1. Introduction

Baby leaf lettuce is a perishable product, and quality loss starts soon after harvesting. The loss of quality mainly depends on gaseous, physicochemical and microbial activity (Islam *et al.*, 2018a,b). In 2013, the total loss of vegetables and other food items in the Republic of Korea was 1,272.90 thousand tonnes (calculated) (FAOSTAT, 2013).

Modified atmosphere packaging (MAP) provides the appropriate atmosphere from shortly after harvesting to immediately prior to consumption (Kader *et al.*, 1989). MAP, combined with a low storage temperature, may reduce post-harvest losses in leafy vegetables because MAP maintains a suitable atmosphere in the package by preserving the quality and reducing spoilage (Islam *et al.*, 2018a,b). However, the inappropriate use of MAP may increase carbon dioxide and ethylene concentrations, thus leading to increased losses (Islam *et al.*, 2014). This may further minimise the benefits of MAP storage for fresh produce. In contrast, successful MAP will maintain near-optimum oxygen and carbon dioxide levels in order to achieve benefits, which can minimise the detrimental effects (Kader *et al.*, 1989). The optimal conditions for different crops may vary according to cultivar, maturity and storage temperature (Islam *et al.*, 2014; Mele *et al.*, 2017).

MAP has been shown to reduce chlorophyll degradation and enzymatic browning of harvested fruits and vegetables (Selman, 1993). Because MAP is effective only when appropriately used (Islam *et al.*, 2014), appropriate conditions should be selected for baby leaf red romaine lettuce. Prior to the research carried out in the present study, no study had been conducted on the use of oxygen transmission rate (OTR) films to provide the appropriate atmosphere for maintaining desirable quality and shelf life in baby leaf lettuce. Therefore, this research was conducted to identify the most appropriate OTR film for MAP with the purpose of maintaining the quality and shelf life of baby leaf romaine lettuce.

2. Materials and methods

Lettuce and treatments

Lettuce (*Lactuca sativa* L. cv. Red Romaine) was cultivated in a greenhouse at Gangwon-do, Korea. The greenhouse was maintained at 20/10 °C (day/night), with ambient light supplemented with quantum dot light-emitting diodes to maintain a light intensity (photosynthetic photon flux density) of 200 $\mu mol/m^2/s$. The baby lettuce leaf was harvested when it reached a length of 10 cm. Each 60 g sample of plant leaves was stored in a 12.5×8.2×3.5 cm sized box. The box was sealed with 1,300, 20,000, 40,000 and 100,000 cm^3/m^2/day/atm OTR MAP film and with a perforated film (100,000 cm^3/m^2/day/atm OTR film) to which four 0.6-cm diameter holes were punched, prior to being stored at 8 °C with 90% relative humidity for 30 days. The film thickness was 50 μm and it was prepared from polypropylene (Dae Ryung Precision Packaging Industry Co., Ltd, Kyeonggi-do, Korea), which regulated OTR, maintained moisture content, and balanced oxygen and carbon dioxide concentration conditions.

Lettuce quality parameters

The baby leaf lettuce fresh weight loss was measured by subtracting the sample weight at specific time intervals during storage from the initial harvest weights, and the weight loss was presented as a percentage (Mele *et al.,* 2017). The visible quality observed range was from 1 to 5 (1 = very bad, 2 = bad, 3 = good, marketable, 4 = very good and 5 = excellent) for the assessment of the visual quality of the cut lettuce (Islam *et al.,* 2016). Shelf life was measured according to visual quality (≥3; good, marketable) and determinants such as decay, homogeneity, mould growth, shrivelling, smoothness and shininess.

Gaseous parameters

The gaseous parameters (oxygen and carbon dioxide concentrations) were measured using a PBI Dansensor Checkmate 9900 (Mocon, Inc., Brooklyn Park, MN, USA). The ethylene concentration was measured with a gas chromatograph fitted with a GC 2010 Shimadzu wax column (30 m × 0.25 mm × 0.25 μm; SGE Analytical Science, Ringwood, Australia), flame ionisation detector (at 127 °C) and injector (50 °C) at a 0.67 ml/s N_2 gas run rate (Islam *et al.,* 2016).

Colour values and chlorophyll concentration

The baby leaf lettuce colour values (L*, a*, b*, chroma and hue angle) were determined using a CR 400 Chroma Meter (Konica Minolta Sensing, Inc., Osaka, Japan) (Mele *et al.,* 2017). A SPAD-502-plus chlorophyll meter (Konica Minolta Sensing, Inc.) was used to measure the SPAD value (reflecting total chlorophyll concentration). The chlorophyll from a sample of fresh baby leaf lettuce (100 mg) was extracted in 5 ml N, N-dimethylformamide overnight. The absorbance of the supernatant was measured by a UV-1601 spectrophotometer (Shimadzu, Kyoto, Japan) at 647 nm and 664 nm. The Chl a and Chl b concentrations were determined using the equations presented by Moran (1982).

Anthocyanin concentration

The total anthocyanin concentration was measured according to the technique described by Park *et al.* (2012). Each 2 g fresh leaf sample weight was extracted for 24 h of 4 °C in 10 ml of 1.5 N HCl-95% ethanol (85:15, v:v), the sample was centrifuged, filtered and the anthocyanin concentration determined by measuring absorbance at 530 nm using a spectrophotometer (Shimadzu). The anthocyanin concentration was calculated according to the following equation:

$$\text{anthocyanin (mg/100 g fresh wt.)} = \frac{[\text{absorbance at 530 nm} \times \text{volume of extraction solution}] \times 100}{\text{wt. of sample (g)} \times 98.2}$$

where 98.2 was the molecular extract co-efficient.

Peroxidase activity

An aliquot (50 μl) of leaf extract, 800 μl of phosphate-citric acid buffer (90 mM Na_2HPO_4 and 55 mM citric acid), pH 4.5 and 100 μl of 35 mM H_2O_2 were thoroughly mixed and incubated at 25 °C for 5 min. The mixture was filtered through 0.20 μl regenerated cellulose membrane filters. The absorbance of the filtrate was measured using a spectrophotometer at 654 nm (Degl'Innocenti *et al.,* 2005).

Total flavonoid concentration

The total flavonoid concentration was measured according to Chong and Lim (2012) with a slight modification. Briefly, an aliquot 0.5 ml of leaf extract, 0.1 ml of 10% aluminium nitrate, 1.5 ml of ethanol, 0.1 ml of potassium acetate (1 M) and 2.8 ml of distilled water were added into a test tube, mixed and incubated. After 30 min, the filter (filtered through 0.20 μl regenerated cellulose membrane filters) was used to measure the total flavonoid content of the spectrophotometer at 450 nm. For the blank, 0.1 ml of aluminium nitrate was replaced by 0.1 ml of distilled water.

Phenolic concentration

An aliquot (0.2 ml) of leaf extract, 0.4 ml of Folin-Denis reagent and 0.8 ml of distilled water were added to a test tube. After incubation of 5 min, 2 ml of sodium carbonate (7%) was added and the mixture was incubated at room temperature (20 °C) for 1 h before measuring the absorbance. The reaction mixture was filtered through 0.20 µl regenerated cellulose membrane filters and the filtrate used to measure the concentration of total phenolics using a spectrophotometer at 734 nm.

DPPH radical scavenging activity

An aliquot (0.5 ml) of the methanol extract was mixed with 0.25 ml of an ethanolic 0.5 mM 1,1-diphenyl-2-picrylhydrazyl (DPPH) solution and 0.5 ml of 100 mM acetate buffer (pH 5.5) was incubated at 20 °C for 30 min. The reaction mixture was then filtered through 0.20 µl regenerated cellulose membrane filters and DPPH activity was measured using a spectrophotometer with absorbance at 517 nm (Kang and Saltveit, 2002).

Total vitamin C concentration

An aliquot (0.5 ml) of leaf extract was mixed with 5 ml of 5% (w/v) metaphosphoric acid to measure the vitamin C concentration according to Islam *et al.* (2016). The absorbance of the filtered reaction mixture (filtered through 0.20 µl regenerated cellulose membrane filters) was measured at 525 nm.

Off-odour

Off-odour was rated from 1 to 5 (1 = excellent, 2 = good, 3 = moderate, marketable, 4 = bad and 5 = worst) (Mele *et al.*, 2017).

Statistical analysis

Data were analysed by one-way ANOVA, followed by *post-hoc* Duncan's multiple range pairwise comparison tests in SPSS v.16 (IBM, Armonk, NY, USA). Pearson correlation analysis was used to confirm the correlation between treatment and measured parameters.

3. Results and discussion

Lettuce quality parameters

The lowest percentage of fresh weight loss rate was shown by leaves under the 20,000 cm^3 film treatment, wherein the baby leaf lettuce remained freshest and maintained its high visible quality score for the longest period (Figure 1). The baby leaf lettuce fresh weight loss with the 20,000 cm^3 film was very low (<1%) and happened due to expansion of the headspace by generation of vapour. The moisture kept the baby leaf lettuce fresh for the consumer. A similar result has been reported in tomatoes (Islam *et al.*, 2014) and in leafy vegetables (Mele *et al.*, 2017) in which moisture loss (by transpiration) was suppressed by reducing evaporation through the OTR film. However, the perforated film showed 8.80% fresh weight loss because of its pores, and, thus, the water in the baby leaf lettuce evaporated, the leaf quality deteriorated and it lost market value. A weight loss of more than 5% can markedly reduce the retail prices of fruits and vegetables (Ohta *et al.*, 2002).

The highest visible quality score was observed in the 20,000 cm^3 film, which maintained the fresh visual quality of the leaves by reducing moisture loss. The shelf lives (≥3) of the perforated film, and the 1,300, 20,000, 40,000 and 100,000 cm^3 films were 8, 15, 30, 25 and 20 days, respectively. The OTR film retained the visual quality and improved the shelf life by reducing the physiological metabolic activity such as respiration and ethylene production. Consumer choice is largely determined by visible quality, with the produce with the highest visible quality receiving the highest market

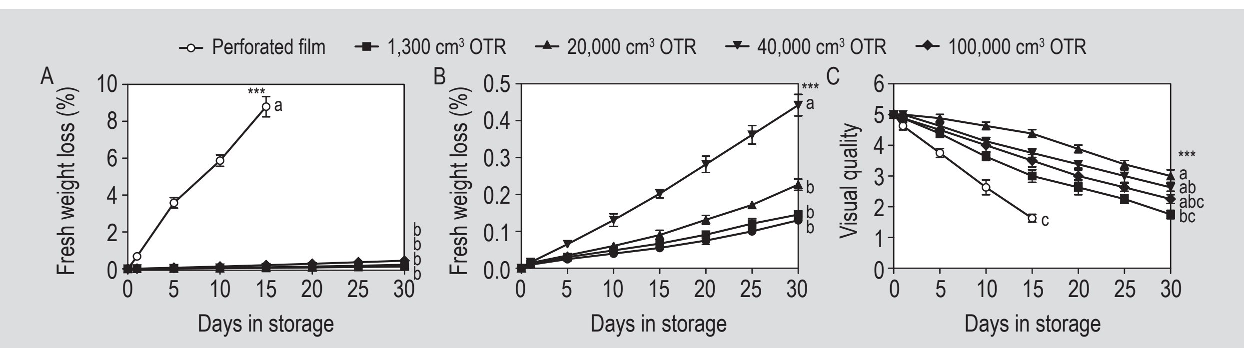

Figure 1. Changes of fresh weight loss (A,B) and visual quality (C) of red romaine leaf lettuce at 8 °C. Vertical bars represent ± SE of means (n=5). As oxygen transmission rate (OTR) films graphs line are not clearly visible with combined perforated film (A) so (B) produce separately only for OTR films. * = significant at *P*≤0.001 of Duncan's multiple range tests.**

value. Thus, MAP storage increases market value (Islam *et al.,* 2018a,b; Mele *et al.,* 2017). The treated baby leaf lettuce stored under perforated film showed the lowest visual quality due to high water evaporation and browning. This finding was similar to that of Islam *et al.* (2014) wherein the visual quality and the shelf life of the perforated film were lower than those of the MAP with altered OTR values because of the high moisture loss.

Gaseous parameters

After harvesting, vegetable quality begins to deteriorate, and optimum gaseous conditions can help to improve the shelf life (Mele *et al.,* 2017). Leaves stored under the 20,000 cm^3 film showed the highest visual quality as well as the highest shelf life in addition to maintaining atmospheric gaseous concentrations of around 19.25-19.95% oxygen and 1.55-4.90% carbon dioxide. In all the treatments, oxygen concentration decreased and carbon dioxide concentration increased under the OTR films (Figure 2). Baby leaf lettuce can tolerate a minimum of 2% oxygen and a maximum of 2% carbon dioxide concentrations (Kader *et al.,* 1989). The recommended controlled atmosphere or modified atmosphere conditions for lettuce have been reported to be 1-3% oxygen and 0% carbon dioxide concentrations at 0-5 °C temperatures (Saltveit, 2003). Higher oxygen and lower carbon dioxide concentrations were observed in the boxes under on the MAP film compared with the perforated film. Thus, baby leaf lettuce exhibits a prolonged shelf life in MAP storage because it can maintain optimum conditions. Carbon dioxide was shown to be at its highest concentration in 1,300 cm^3 film, which may lead to physiological disorders in the baby leaf lettuce.

Leaves stored under the 20,000 cm^3 film exhibited prolonged shelf life of the baby lettuce leaves and maintained 5.10-8.06 µl/l ethylene concentration. The ethylene concentration in stored baby leaf lettuce decreased from the beginning of the storage period. Ethylene is a naturally produced plant hormone which affects the plant growth and development by regulating the juvenile/adult transition and senescence, as well shortening the shelf life of many vegetables, fruits and ornamental crops, with the action of ethylene involving complicated metabolic processes in plants (Buchanan-Wollaston, 1997). Moreover, ethylene is involved in the browning of lettuce leaves (Saltveit, 1999, 2003).

Colour value and chlorophyll concentration

The colour of baby leaf lettuce is an important determinant of its market value. The colour value of leaves under 20,000 cm^3 film was the highest with respect to a* and the lowest in terms of b*, chroma and the hue angle among the MAP and/or all treatments (with the exception of L*). Compared with the initial value, the L*, b*, chroma and the hue angle value increased, and the a* value decreased (Table 1). During storage, L* and b* increased in bok choy (Pan and Sasanatayart, 2016). The a*/b* value, which reflects the redness, was highest in leaves stored under the 20,000 cm^3 film treatment. Chlorophyll degradation has been shown to be associated with leaf yellowing in harvested leafy vegetables (Buchanan-Wollaston, 1997; Mele *et al.,* 2017). All chlorophyll parameters of storage value were decreased compared with the initial value, and this may have happened due to the change from chlorophyll concentration to anthocyanin concentration. The findings from this study were consistent with those of Mattos *et al.* (2013), which suggest that chlorophyll concentration decreased during storage, although the role of ethylene in this is unclear.

Anthocyanin concentration

Leaves stored under the 20,000 cm^3 film treatment had a longer shelf life and maintained their anthocyanin concentration (5.81 mg/100 g FW) better than those under other treatments (Table 2). A large positive correlation (r=0.873, $P \leq 0.01$) was observed between 20,000 cm^3 film treatment and anthocyanin concentration. By the final

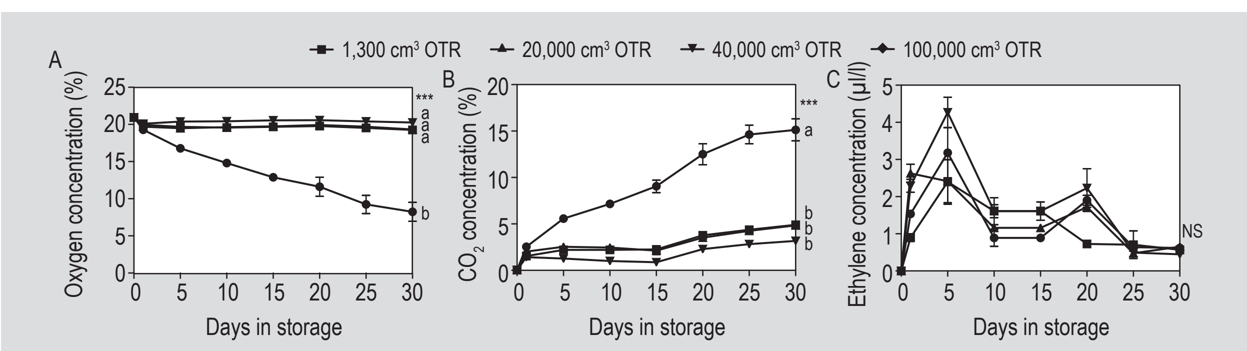

Figure 2. Changes of oxygen concentration (A), carbon dioxide concentration (B), and ethylene concentration (C) of red romaine leaf lettuce at 8 °C. Vertical bars represent ± SE of means (n=5). Mean separation within columns by Duncan's multiple range. OTR = oxygen transmission rate; NS = not significant; * = significant at $P \leq 0.001$.**

Table 1. Colour value (L*, a*, b*, a*/ b*, chroma, and hue angle) during oxygen transmission rate (OTR) film storage as a modified atmosphere packaging of red romaine leaf lettuce at 8 °C.[1]

Treatment	L*	a*	b*	a*/ b*	chroma	hue angle
Initial	37.67±0.54	1.32±0.35	3.35±0.63	0.37±0.03	3.66±0.75	106.11±1.85
Perforated film	36.86b	4.13b	8.96bc	0.43b	11.15bc	127.49a
13,00 cm^3 OTR	40.85a	7.51a	11.97ab	0.61ab	14.33ab	119.84a
20,000 cm^3 OTR	38.28ab	6.39ab	7.90c	0.82a	9.38c	88.13b
40,000 cm^3 OTR	39.40ab	7.84a	13.58a	0.57ab	15.87a	114.23ab
100,000 cm^3 OTR	41.05a	6.82ab	13.06a	0.52b	14.93ab	111.45ab
P-value	**	**	***	***	***	***
P-value of OTR	NS	NS	***	***	***	***

[1] Mean separation within columns by Duncan's multiple range tests (n=5). NS, **, ***: not significant, and significant at $P \leq 0.01$ and 0.001, respectively. Initial value indicated mean ± standard error. Note: perforated film storage day 15 and OTR film storage day 30.

Table 2. Chlorophyll a, chlorophyll b, total chlorophyll, SPAD and anthocyanin content of oxygen transmission rate (OTR) film storage as a modified atmosphere packaging of red romaine leaf lettuce at 8 °C.[1]

Treatment	Chlorophyll a µg/ml	Chlorophyll b µg/ml	Total chlorophyll µg/ml	Leaf chlorophyll content SPAD	Anthocyanin mg/100 g FW
Initial	13.11±0.39	7.84±0.78	20.94±1.17	25.85±0.73	2.76±0.99
Perforated film	6.13ab	1.21b	7.34b	16.68	2.83b
13,00 cm^3 OTR	7.55ab	2.05ab	9.60ab	17.36	5.43ab
20,000 cm^3 OTR	6.65ab	1.26b	7.92ab	18.17	5.81a
40,000 cm^3 OTR	8.66a	2.08a	10.75a	17.35	5.42ab
100,000 cm^3 OTR	5.92b	1.34b	7.26b	16.83	4.35ab
P-value	**	*	*	NS	***
P-value of OTR	*	*	*	NS	*

[1] Mean separation within columns by Duncan's multiple range tests (n=5). NS, *, **, ***: not significant, and significant at $P \leq 0.05$, 0.01 and 0.001, respectively. Initial value indicated mean ± standard error. Note: perforated film storage day 15 and OTR film storage day 30.

storage day (day 30), the anthocyanin concentration in leaves stored under 20,000 cm^3 film had increased from the initial value and the visual quality was enhanced. The anthocyanin concentration increased because of the increase in carbon dioxide concentration in the atmosphere around the lettuce (Park *et al.* 2012) and a decrease in chlorophyll concentration (Mele *et al.,* 2018). Compared with the perforated film storage, the MAP storage of baby leaf lettuce resulted in higher anthocyanin concentration, and this was possibly due to the increased carbon dioxide retained by in the film. MAP storage helps to increase the anthocyanin concentration in strawberries and carrots in response to altered carbon dioxide or oxygen content (Alasalvar *et al.,* 2005; Holcroft and Kader, 1999).

Peroxidase activity

During storage under normal atmosphere, browning of the baby leaf lettuce increased along with the peroxidase (POD) activity (Table 3). POD is involved in oxidative reactions (Mattos *et al.,* 2013) and ethylene biosynthesis (Siegel, 1993). Increased POD and the consequent browning may reduce the colour, aroma, visual quality and nutritional value of the leaves. Of the treatments in the present study, leaves under the 20,000 cm^3 film showed the lowest browning as well as the lowest POD activity, traits which are desirable for extending the shelf life of the stored baby leaf lettuce. Shengmin (2007) reported that browning could possibly be reduced by MAP conditions or by storing at a low temperature.

Table 3. Peroxidase, flavonoid, phenol, DPPH, and vitamin C of oxygen transmission rate (OTR) film storage as a modified atmosphere packaging of red romaine leaf lettuce at 8 °C.[1]

Treatment	Peroxidase U/ ml	Flavonoid µg/ml	Phenolic content µg/ml	DPPH µmole TE/ml	Vitamin C mg/100 ml	Off-odor
Initial	0.34±0.05	71.53±6.32	220.79±9.76	182.86±5.86	13.94±0.47	0.00±0.00
Perforated film	0.79b	35.87a	199.13ab	132.57c	8.73b	1.35c
13,00 cm^3 OTR	1.06a	4.03c	171.66b	123.32d	5.94d	2.80a
20,000 cm^3 OTR	0.64b	36.72a	207.52a	165.45a	9.37a	1.65c
40,000 cm^3 OTR	0.95a	11.46b	197.11ab	147.00b	6.88c	2.25b
100,000 cm^3 OTR	0.94a	2.12c	192.06ab	94.82e	5.54d	2.60ab
P-value	***	***	**	***	***	***
P-value of OTR	***	***	**	***	***	***

[1] Mean separation within columns by Duncan's multiple range tests (n=5). **, ***: significant at $P \leq 0.01$ and 0.001, respectively. Initial value indicated mean ± standard error. The off-odor was rated on the basis of 1 to 5 ranked (1 = excellent, 2 = good, 3 = moderate, marketable, 4 = bad, and 5 = worst). Note: perforated film storage day 15 and OTR film storage day 30.

Total flavonoid concentration

The flavonoid concentration was highest in leaves stored under the 20,000 cm^3 film (Table 3), and this effect would increase the acceptability of the leaves to consumers. The flavonoid concentration was retained in leaves under the 20,000 cm^3 film during the final storage by maintaining the optimum atmosphere in the package. The initial flavonoid concentration in the leaves was high at harvest, but it decreased during storage. During storage, the flavonoid content has been shown to decrease in lettuce leaves (Ferreres *et al.,* 1997; Romani *et al.,* 2002), which may be due to increased enzymatic activity, including that of peroxidase.

Phenolic content concentration

Compared with that on the day of leaf harvest, the total phenolic concentration decreased during storage (Table 3), which may have been due to peroxidase activity. However, the leaves stored under the 20,000 cm^3 film maintained the initial total phenolic content. Phenolic compounds are a cause of post-harvest quality loss. They are the result of enzymatic browning caused by the breakdown of cellular compartmentalisation, separating phenolics from the oxidative enzymes, with phenolics being oxidised by polyphenol oxidase and peroxidase enzymes to generate brown tannins (Kays, 1991). Phenolic concentration has been shown to decrease during storage of romaine lettuce and the green parts of stored 'Lollo Rosso' lettuce leaves (Ferreres *et al.,* 1997).

DPPH radical scavenging activity

Antioxidants quench active metabolic products, such as oxygen free radicals, which can damage the cell (Ercisli *et al.,* 2012). Leafy vegetables showed strong antioxidant activities because of their high levels of vitamins and phenolic compounds (Choi *et al.,* 2007). In this experiment, the DPPH radical scavenging activity decreased with storage (Table 3), possibly because of increased peroxidase activity. At the end of the storage period, the DPPH radical scavenging activity (antioxidant activity) was higher in 20,000 cm^3 film than other treatments. We found that there is a positive correlation (r=0.742, $P \leq 0.05$) between 20,000 cm^3 film treatment and DPPH radical scavenging activity. Of the treatments investigated in the present study, leaves stored under the 20,000 cm^3 film treatment showed the highest DPPH radical scavenging activity, which may have been due to high vitamin C and phenolic (principally, flavonoid and anthocyanin) concentrations.

Total vitamin C concentration

The highest vitamin C concentration was reported by leaves stored under 20,000 cm^3 film of all of the treatments on the final storage day (day 30) (Table 3). In the absence of MAP, vitamin C concentration has been shown to decrease during storage compared with that at harvest time. The decreased vitamin C concentration may have been showed due to the increased peroxidase activity in the lettuce leaf. It has been reported that during storage, the vitamin C concentration decreased in both the 'Lollo Rosso' lettuce (Selma *et al.,* 2012) and in the 'Parris Island' leaf lettuce (Konstantopoulou *et al.,* 2010).

Off-odour

The off-odour is another determinant for the selection of baby leaf lettuce by the consumer. Of the OTR film treatments, leaves stored under the 20,000 cm^3 film showed the least off-odour (Table 3), which may have been due to the lower carbon dioxide and higher oxygen concentrations in the atmosphere in the package than those present in the other treatments. The 1,300 cm^3 film showed the greatest off-odour because of the low oxygen and high carbon dioxide concentrations. Off-odour mainly increases due to increased microbial metabolism and chemical reactions (Kays, 1991). The low carbon dioxide concentration possibly reduces the off-odour in baby leaf lettuce. High carbon dioxide and low oxygen concentrations favoured the growth of lactic acid bacteria which accumulated into lactic acid, acetic acid and ethanol, due to lactic hetero-fermentative metabolism of lactic acid bacteria because of which the off-odour developed (Nguyen-the and Carlin, 1994). In this experiment, the baby leaf lettuce under the perforated film showed the least off-odour because it could not retain the gases due to its pores.

4. Conclusions

The optimum MAP storage conditions for baby leaf red romaine lettuce were found to be packaging under the 20,000 cm^3 OTR packaging film and storage at 8 °C. This was deduced because the leaves showed the longest shelf life, the highest antioxidant activities, the lowest off-odour and the lowest fresh weight loss under these packaging conditions. This film allows for adequate gas exchange for baby leaf lettuce. Moreover, this film can provide a safer and fresher baby leaf lettuce to growers and/or exporters in order to fulfil consumer demand.

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References

Alasalvar, C., Al-Farsi, M., Quantick, P.C., Shahidi, F. and Wiktorowitz, R., 2005. Effect of chill storage and modified atmosphere packaging (MAP) on antioxidant activity, anthocyanins, carotenoids, phenolics and sensory quality of ready-to-eat shredded orange and purple carrots. Food Chemistry 89: 69-76. https://doi.org/10.1016/j.foodchem.2004.02.013

Buchanan-Wollaston, V., 1997. The molecular biology of leaf senescence. Journal of Experimental Botany 48: 181-199.

Choi, E.M., Ding, Y., Nguyen, H.T., Park, S.H. and Kim, Y.H., 2007. Antioxidant activity of Gomchi (*Ligularia fischeri*) leaves. Food Science and Biotechnology 16: 710-714.

Chong, K.L. and Lim, Y.Y., 2012. Effects of drying on the antioxidant properties of herbal tea from selected vitex species. Journal of Food Quality 35: 51-59. https://doi.org/10.1111/j.1745-4557.2011.00422.x

Degl'Innocenti, E., Guidi, L., Pardossi, A. and Tognoni, F., 2005. Biochemical study of leaf browning in minimally processed leaves of lettuce (*Lactuca sativa* L. var. acephala). Journal of Agricultural and Food Chemistry 53: 9980-9984. https://doi.org/10.1021/jf050927o

Ercisli, S., Tosun, M., Karlidag, H., Dzubur, A., Hadziabulic, S. and Aliman, Y., 2012. Color and antioxidant characteristics of some fresh fig (*Ficus carica* L.) genotypes from northeastern Turkey. Plant Foods for Human Nutrition 67: 271-276. https://doi.org/10.1007/s11130-012-0292-2

FAOSTAT, 2013. Food and Agriculture Organization (FAO) of the United Nations. http://faostat.fao.org

Ferreres, F., Gil, M.I., Castaner, M. and Tomas-Barberan, F.A., 1997. Phenolic metabolites in red pigmented lettuce (*Lactuca sativa*). Changes with minimal processing and cold storage. Journal of Agricultural and Food Chemistry 45: 4249-4254. https://doi.org/10.1021/jf970399j

Holcroft, D.M. and Kader, A.A., 1999. Carbon dioxide-induced changes in colour and anthocyanin synthesis of stored strawberry fruit. HortScience 34: 1244-1248.

Islam, M.Z., Mele, M.A., Lee, H.J., Lee, K.S., Hong, S.M., Jeong, M.J., Kim, I.-S., Hong, S.-K., Choi, I.-L., Ho-Min, J.P. and Kang, H.M., 2014. Selection of non-perforated breathable film to enhance storability of cherry tomato for modified atmosphere storage at different temperatures. Protected Horticulture and Plant Factory 23: 116-122. https://doi.org/10.12791/KSBEC.2014.23.2.116

Islam, M.Z., Mele, M.A., Baek, J.P. and Kang, H.M., 2016. Cherry tomato qualities affected by foliar spraying with boron and calcium. Horticulture, Environment and Biotechnology 57: 46-52. https://doi.org/10.1007/s13580-016-0097-6

Islam, M.Z., Mele, M.A. and Kang, H.M., 2018a. Gaseous, physicochemical and microbial performances of silicon foliar spraying techniques on cherry tomatoes. AGRIVITA – Journal of Agricultural Science 40: 185-192. https://doi.org/10.17503/agrivita.v40i2.1792

Islam, M.Z., Lee, Y.T., Mele, M.A. and Kang, H.M., 2018b. Effect of preharvest potassium foliar spray and postharvest storage methods on quality and shelf life of cherry tomatoes. Research Journal of Biotechnology 13: 49-54.

Kader, A.A., Zagory, D. and Kerbel, E.L., 1989. Modified atmosphere packaging of fruits and vegetables. Critical Reviews in Food Science and Nutrition 28: 1-30. https://doi.org/10.1080/10408398909527506

Kang, H.M. and Saltveit, M.E., 2002. Antioxidant capacity of lettuce leaf tissue increases after wounding. Journal of Agricultural and Food Chemistry 50: 7536-7541. https://doi.org/10.1021/jf020721c

Kays S.J., 1991. Postharvest physiology of perishable plant products. Van Nostrand-Reinhold, New York, NY, USA.

Konstantopoulou, E., Kapotis, G., Salachas, G., Petropoulos, S.A., Karapanos, I.C. and Passam, H.C., 2010. Nutritional quality of greenhouse lettuce at harvest and after storage in relation to N application and cultivation season. Scientia Horticulturae 125: e1-93. https://doi.org/10.1016/j.scienta.2010.03.003

Mattos, L.M., Moretti, C.L. and Silva, E.Y.Y., 2013. Effects of modified atmosphere packaging on quality attributes and physiological responses of fresh-cut crisphead lettuce. CyTA-Journal of Food 11: 392-397. https://doi.org/10.1080/19476337.2013.777124

Mele, M.A., Islam, M.Z., Baek, J.P. and Kang, H.M., 2017. Quality, storability, and essential oil content of *Ligularia fischeri* during modified atmosphere packaging storage. Journal of Food Science and Technology 54(3): 743-750. https://doi.org/10.1007/s13197-017-2514-y

Mele, M.A., Islam, M.Z., Kang, H.M. and Giuffrè, A.M., 2018. Pre- and post-harvest factors and their impact on oil composition and quality of olive fruit. Emirates Journal of Food and Agriculture 30: 592-603. https://doi.org/10.9755/ejfa.2018.v30.i7.1742

Moran, R., 1982. Formulate for determination of chlorophyllous pigments extracted with N, N dimethylformamide. Plant Physiology 69: 1376-1381.

Nguyen-the, C. and Carlin, F., 1994. The microbiology of minimally processed fresh fruits and vegetables. Critical Reviews in Food Science and Nutrition 34: 371-401. https://doi.org/10.1080/10408399409527668

Ohta, H., Shiina, T. and Sasaki, K., 2002. Dictionary of freshness and shelf life of food. Science Forum Co. Ltd., Tokyo, Japan.

Pan, X.C. and Sasanatayart, R., 2016. Effect of plastic films with different oxygen transmission rate on shelf-life of fresh-cut bok choy (*Brassica rapa* var. chinensis). International Food Research Journal 23: 1865-1871.

Park, Y.G., Park, J.E., Hwang, S.J. and Jeong, B.R., 2012. Light source and CO_2 concentration affect growth and anthocyanin content of lettuce under controlled environment. Horticulture, Environment and Biotechnology 53: 460-466. https://doi.org/10.1007/s13580-012-0821-9

Romani, A., Pinelli, P., Galardi, C., Sani, G., Cimato, A. and Heimler, D., 2002. Polyphenols in greenhouse and open-air-grown lettuce. Food Chemistry 79: 337-342. https://doi.org/10.1016/S0308-8146(02)00170-X

Saltveit, M.E., 1999. Effect of ethylene on quality of fresh fruits and vegetables. Postharvest Biology and Technology 15: 279-292. https://doi.org/10.1016/S0925-5214(98)00091-X

Saltveit, M.E., 2003. Is it possible to find an optimal controlled atmosphere. Postharvest Biology and Technology 27: 3-13. https://doi.org/10.1016/S0925-5214(02)00184-9

Selma, M.V., Luna, M.C., Martínez-Sánchez, A., Tudela, J.A., Beltrán, D., Baixauli, C. and Gil, M.I., 2012. Sensory quality, bioactive constituents and microbiological quality of green and red fresh-cut lettuces (*Lactuca sativa L.*) are influenced by soil and soilless agricultural production systems. Postharvest Biology and Technology 63: 16-24. https://doi.org/10.1016/j.postharvbio.2011.08.002

Selman, J.D., 1993. Practical experiences of sensory investigations into the packaging of vegetables. Packaging Technology and Science 6: 183-193. https://doi.org/10.1002/pts.2770060403

Shengmin, L., 2007. Effect of packaging on shelf-life of minimally processed Bok Choy (*Brassica chinensis* L.). LWT – Food Science and Technology 40: 460-464. https://doi.org/10.1016/j.lwt.2005.12.004

Siegel, B.Z., 1993. Plant peroxidase-An organismic perspective. Plant Growth Regulation 12: 303-312.