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Maintaining Quality of Fresh Strawberries Through Various Modified Atmosphere Packaging

By Cengiz Caner and Mehmet Seckin Aday*

Department of Food Engineering, Faculty of Engineering and Architecture, Çanakkale Onsekiz Mart University, Çanakkale 017020, Turkey

The influence of various modified atmosphere packaging (MAP) (21/0.05, 4/8 and 60/20% O_2/% CO_2) on fresh strawberry qualities [pH, acidity, °Brix, colour (L, a) and texture profile analyses] was investigated and compared during storage.

Among the gas combinations used, pH of fresh strawberry was 3.281 at 1 day, and increased to 3.561 for air [21/0.05% (O_2/CO_2)], 3.53 for low (4/8) and 3.538 high (60/20) at 12 days. At the end of the storage, °Brix had evolved from the initial 7.07 to 5.47, 5.65 and 5.62 for 21% O_2; 4% O_2 and 60% O_2, respectively. Storage in 60% O_2 or 4% O_2 delayed the decrease of °Brix, titratable acidity and increased pH compared with 21% O_2. At the end of the storage, the strawberry L values had slightly decreased.

Initial values of the firmness were 1067 gf and reduced to 501 gf (21% O_2); 613 gf (4% O_2) and 575 gf (60% O_2) at 12 days storage. Higher O_2 resulted in better springiness and chewiness than those treated with 4% O_2 and 21% CO_2, but did not significantly affect resilience.

These results show that the use of various MAP gas compositions, including high oxygen, could be a good alternative to maintain fresh strawberry qualities for at least 12 days. Copyright © 2008 John Wiley & Sons, Ltd.

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KEY WORDS: Strawberry; modified atmosphere; high oxygen; quality parameters; shelf life

INTRODUCTION

There has been increasing interest in the market for fresh fruit and vegetables due to increasing consumers' preference for fresh, healthy and natural products. Strawberries have short shelf life and are highly perishable, with a high rate of respiration,[1] and suffer relatively high post-harvest losses due to fungal development, mechanical injury, physiological deterioration and water loss.

Modified atmosphere packaging (MAP) and low temperature are extensively used to extend the shelf life of many fruits and vegetables products.[2–4] The MAP system is a dynamic one, where the respiration of the packaged product and gas permeation through the packaging film takes place simultaneously. The accumulation of CO_2 and the depletion of O_2 to beneficial levels by the application of MAP is known to prolong the shelf life or maintain product value.[2]

In distribution and retail outlets, strawberries are generally stored in closed, perforated-top containers. Within these containers, the fruits continue to respire the 'trapped air' until the CO_2 concentra-

*Correspondence to: C. Caner, Department of Food Engineering, Faculty of Engineering and Architecture, Çanakkale Onsekiz Mart University, Çanakkale 017020, Turkey.
E-mail: ccaner@comu.edu.tr

tion rapidly approaches the critical 10–15% CO_2 level necessary. Strawberries have previously been the subject of MAP studies largely relying on the use of elevated CO_2 and reduced O_2 levels.[2] However, excessively high levels of CO_2 and/or very low levels of O_2 can induce the development of off flavours and often too close to the level of fruit tolerance.[5]

The applications of high oxygen packaging (more than 50% O_2) are a new approach for the retailing of fresh fruits and is capable of overcoming the many disadvantages of current favourable gas concentrations (standard air or low oxygen MAP) in MAP.[6,7] Using elevated O_2, rather than elevated CO_2, may be an alternative in retaining fruit quality and firmness. This system has been used with meat and, more recently, with cut vegetables.[7,8] The use of O_2 at concentrations much greater than that present in air (50% > O_2) prevent microbial spoilage by dramatically reducing the activity and proliferation of lower organisms.[9] High O_2 treatment (80% O_2) compared to 40% O_2 + 30% CO_2; 80% O_2 had a beneficial effect on table grapes' adherence strength, °Brix, Vitamin C, browning and visual appearance.[10] The application of high O_2 concentrations (60% O_2) could overcome the disadvantages of low O_2 MAP for some fruits such as strawberries.[5]

Fresh green vegetables have been experimenting with O_2 mixtures ('oxygen shock' or 'gas shock') between 60 and 100%.[7,8] The treatment has been found to be effective in inhibiting enzymatic discoloration, preventing anaerobic fermentation reactions and inhibiting aerobic and anaerobic microbial growth. High levels of O_2 can inhibit the growth of microorganisms since the optimal O_2 level for growth is surpassed.[7,8] High O_2 MAP of vegetables is not yet fully commercialized probably because of the lack of understanding of the basic biological mechanisms involved in inhibiting enzymatic browning, the effect on respiratory activity, and its unknown effect on the quality of packaged fruits and vegetables and concerns about possible safety implications during packaging.[11–13] Limited information is available in the literature on high MAP application on quality changes on strawberries,[3,6,8,11,12] especially textural changes. Further research is also needed to identify the best atmosphere conditions for MAP, which is a more convenient method for marketing. The objective of the present study was to investigate

1. The effects of various MAP gas [high (60% O_2), low (4% O_2) and air (21% O_2)] based on quality changes of strawberries [pH, °Brix, titratable acidity (TA), and colour (L^* and a^*)].
2. Textural quality evaluation by means of TPA of strawberries (TPA: firmness, cohesiveness, gumminess, chewiness, resilience, adhesiveness and springiness) during storage periods at 4°C.

MATERIALS AND METHODS

Materials

Fresh daily 'camarosa' strawberries (*Fragaria* × *ananassa* Duch.) were harvested, selecting for uniformity. The polyvinyl chloride–polyethylene trays (20 × 30 cm) were filled with 250 g strawberries, and the packages were flushed with the following gas compositions inside the containers:

- Air (21% O_2/0.03% CO_2).
- Low oxygen atmospheres (4% O_2; 8% CO_2; 88% N_2).
- High oxygen atmosphere (60% O_2; 20% CO_2; 20% N_2).

After flushing, the packages were heat-sealed with linear low density polyethylene (LLDPE) lid films by ReePack ReeTray 25TC MAP APACK (Istanbul, Turkey).

The O_2 and CO_2 transmission rate of LLDPE were 4050 and 14 000 cc/m^2/day, respectively.

The samples were stored at 4°C. At 0, 5, 10 and 12 days of storage, each gas type was evaluated: 10 strawberries were used to measure skin colour and TPA evaluation (in quadruple), and three strawberries (80 g) were pressed to obtain the juice used to measure other quality parameters (°Brix, titratable acidity and pH) at 20°C. Three replicates per measurement were used.

pH measurement

The pH values were determined for the pressed strawberries juice and measured using a PP 50 Sartorius (Sartorius PP-50, Goettingen, Germany) pH meter.

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Total soluble solids

The total soluble solid (TSS) content of the pressed strawberry juice was measured with an Atago Pal-1 pocket refractometer (Atago Co. Ltd, Tokyo, Japan) and expressed in °Brix.

TA

TA was measured on the 10 mL of pressed strawberry juice that was diluted to 250 mL with distilled water, and 50 mL of diluted juice was titrated with 0.1 N sodium hydroxide to a pH of 8.1. The results were expressed as milligrams of citric acid.

Colour

Surface colour as (CIE LAB *L*, *a*, *b* parameters) was evaluated by CR-400 portable colorimeter (Minolta CR-400 chromometer, Konica Minolta Sensing, Osaka, Japan).

Results were expressed as *L-a-b* values as *L* (lightness), *a* (green to red; higher positive *a* values indicate red colour) and *b*. These values were then used to calculate

- hue degree h0 = arctangent [b/a]; and
- Chroma C* = $[a^2 + b^2]^{1/2}$ that indicates the intensity or colour saturation.[14]

TPA

TPA were performed with a TA-XT2i texture analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) with the following parameters: pre-test speed 5.0 mm/s, test speed 1.0 mm/s and post-test speed 8.0 mm/s; penetration distance 4 mm and a rest period of 5 s between two cycles; and trigger force 1.0 N. The SMS-P/10 CYL Delrin probe always returned to the trigger point before beginning the second cycle. Values for firmness, springiness, cohesiveness, adhesiveness, gumminess, resilience and chewiness were automatically calculated by the software.

Statistical analysis

Statistical procedures on all the measured parameters among various MAP during storage time were done using least square means (LSM-PROG GLM) of the statistical analysis software program SAS. Statistical significance was defined as p values of 0.05 or less.[15]

RESULTS

Due to the permeability of LLDPE lid film and the respiration rate of the strawberry, the initially added atmospheres changed to different compositions within a few days. The CO_2 concentration increased rapidly after packaging, reaching equilibrium within the first 48 h, in which O_2 consumption was parallel to CO_2 production.

Soluble solids content

Soluble solids content (SSC) of strawberries with various gas combinations significantly decreased as expected during storage due to post-harvest metabolism (Table 1). The high oxygen and low oxygen [4/8 (O_2/CO_2)] showed higher values than air [21/0.03 (O_2/CO_2)] during storage at 4°C; however, the difference became not statistically significant from day 10 of this period. At the end of the storage period, the SSC had evolved from the initial 7.077°Brix to 5.475 (21/0.03); 5.65 (4/8) and 5.625 (60/20) (Table 1). The high oxygen concentration (60/20) showed lesser decrement after 5 days of storage. It appears that the reduction in SSC is reduced and successfully retained with various gas concentrations used in MAP.

This effect was similar by Almenar *et al.*[1,3] and Garcia *et al.*,[16] as well as by Picon *et al.*,[17] who reported that the SSC of different strawberry varieties in various packaging materials decreased during storage. Exposure to superatmospheric O_2 levels may stimulate or reduce rates of respiration, depending on the commodity, maturity stage, O_2 concentration, time and temperature of storage, and CO_2 and ethylene concentrations.[6] Wszelaki and Mitcham[18] also reported higher respiration rates and a parallel TSS decrease in berries exposed for 14 days to high O_2 (90 and 100% O_2, and 40% O_2 plus 15% CO_2).

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Table 1. Changes in TSS (°Brix), TA (mg of citric acid per 50 mL juice) and pH during 12 strawberry storage at 4°C in different atmospheres: 21/0.05, 4/8 and 60/20 (% O_2/% CO_2)

Days/MAP compositions	SSC (°Brix)	TA	pH
0	7.0775^{a}	0.591^{a}	3.281^{a}
5			
Air (21% O_2/0.05% CO_2)	6.155^{b}	0.581^{a}	3.312^{a}
Low oxygen (4% O_2/8% CO_2)	6.125^{b}	0.562^{a,c}	3.367^{a}
High oxygen (60% O_2/20% CO_2)	6.225^{b}	0.570^{a}	3.306^{a}
10			
Air	5.650^{b,c}	0.566^{a}	3.394^{a}
Low oxygen	5.775^{b,c}	0.571^{a,d}	3.370^{a}
High oxygen	5.800^{b,c}	0.562^{a,c}	3.321^{a}
12			
Air	5.475^{c}	0.510^{b,c}	3.561^{b}
Low oxygen	5.650^{b,c}	0.549^{a,b}	3.530^{b}
High oxygen	5.625^{c,b}	0.539^{b,c,d}	3.538^{b}

For each property in the same column, values with the same letter are not statistically different $p < 0.05$.

TA

The acid content (TA), mainly malic and citric acid, decreased gradually over the storage period; consequently, the quality of strawberries decreased.[19] This is due to CO_2 dissolution in water present on the fruit surface, generating carbonic acid and acidifying the fruit. The decline in acidity was dependent on storage time ($p < 0.05$). Although TA content in the 60/20 and 4/8 atmospheres was higher on day 12, no significant differences ($p < 0.05$) were found between all various gas contents of stored strawberries at the end of the experiment. On the contrary, at the beginning of storage (day 5), TA content in (21/0.03) O_2 MAP-stored strawberries was lower than others, but not significantly ($p < 0.05$). As the main substrates of respiratory metabolism, sugars and acids are depleted causing corresponding changes in SSC and TA during storage.

pH

The pH of strawberry juice increased slightly during storage, corresponding to a decrease in TA in all treatment. No statistically significant differences were found between the values obtained from the all MAP strawberries up to 12 days of storage. After 12 days of storage, pH values of strawberries were significantly higher then 5 and 10 days values and increased up to 3.561 in air (21/0.03) ($p < 0.05$) (Table 1).

The differences in pH, TA, and SSC results among different studies may be related to differing effects of elevated O_2 on the respiratory rates of the commodities.

Strawberries skin colour

Fruit colour is crucial in a purchase decision, especially if the products are packaged (cannot be touch or smelled). There was a slight decrease in brightness expressed by the *L* value (lightness), meaning that the fruit developed a darker colour over the storage period. However, no significant differences were found in skin colour parameters of strawberry fruit among all various gas combinations used during storage (Table 2). *L* values had slightly dropped right after initial days. Comparable *L* values were found in all treatments throughout the experiment in the similar range. Red skin colour, estimated by the *a* values indicating redness slightly decreased during storage, but no significant differences were observed in values at various

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Table 2. Changes in strawberry fruit colour values (*L*, *a*, Chroma and Hue) during strawberry storage at 4°C in different atmospheres: 21/0.05, 4/8 and 60/20 (% O_2/% CO_2)

Days/MAP gas compositions	*L*	*a*	Chroma	Hue
0	30.05[a]	28.53[a]	28.85[a]	15.08[a]
5				
Air (21% O_2/0.05% CO_2)	28.86[a,b]	26.26[a]	27.34[a]	14.82[a]
Low oxygen (4% O_2/8% CO_2)	28.25[a,b]	27.41[a]	27.62[a]	14.05[a]
High oxygen (60% O_2/20% CO_2)	30.28[a]	27.96[a]	28.96[a]	16.60[a]
10				
Air	28.89[a,b]	25.99[a]	27.46[a]	15.33[a]
Low oxygen	27.40[a,b]	26.92[a]	28.15[a]	15.49[a]
High oxygen	28.42[a,b]	29.23[a]	30.65[a]	17.78[a]
12				
Air	27.94[b]	26.78[a]	27.72[a]	14.23[a]
Low oxygen	28.13[b]	27.75[a]	28.67[a]	14.03[a]
High oxygen	27.73[b]	27.13[a]	27.92[a]	14.18[a]

For each column, *L*, *a*, Chroma and Hue values with the same letter are not statistically different $p < 0.05$.

gas combinations during storage. However, higher *a* values, indicating a redder colour, were detected in fruits stored at 60/20 on day 10 in comparison with the others. Chroma and hue angle were not significantly changed and comparable values were found in all treatments during the storage. However, Perez and Sanz[6] reported that lower hue values (initial values 30.93) for 80 kPa O_2 + 20 kPa CO_2-stored strawberries were found on 7 (31.36–28.98) and 9 days (34.11–30.54), respectively.

TPA parameters

Loss of texture – mainly firmness – during storage of soft fruit such as strawberries, is one of the main factors limiting fruit quality (post-harvest shelf life). This firmness change is softening, which is related to biochemical alterations at the cell wall components (mainly pectins), middle lamella and membrane levels. Thus, treatments of strawberries have proven to be effective in reducing their firmness loss.[20–22]

The TPA values as fruit firmness, cohesiveness, gumminess, chewiness and resilience decreased, whereas adhesiveness and springiness increased during most of the storage in each gas composition (Figure 1).

Strawberry firmness was significantly lower during storage ($p < 0.05$). Firmness decreased from 1067 to 846 gf in air, 830 gf in 4/8 and 900 gf in 60/20 by day 5. By day 12, the firmness of the fruit stored in air was 2.12 (501 gf), 1.74 (613 gf) and 1.85 (575 gf) times lower than 21/0.03, 4/8 and 60/20 (O_2/CO_2), respectively (Figure 1a). Compared to 21/0.03, strawberry firmness was significantly maintained in high O_2 (60/20) and 4% O_2 (4/8) treatment conditions.

Adhesiveness values increased rapidly and significant differences were observed ($p < 0.05$) throughout the storage period. However, no significant differences were observed among the adhesiveness values each storage periods (Figure 1b).

Over time, springiness values significantly increased during storage. However, there were no significant differences between 4/8 (O_2/CO_2) and 21/0.03 (O_2/CO_2) and, significantly lower values than 60/20 (O_2/CO_2) at the end of storage. Compared to 21/0.03 and 4/8 MAP, strawberry springiness improved in high O_2 treatment conditions (Figure 1c).

Cohesiveness values significantly declined after the first days of storage ($p < 0.05$); however, there were increments after 10 days of storage. Compared with the other parameters, cohesiveness

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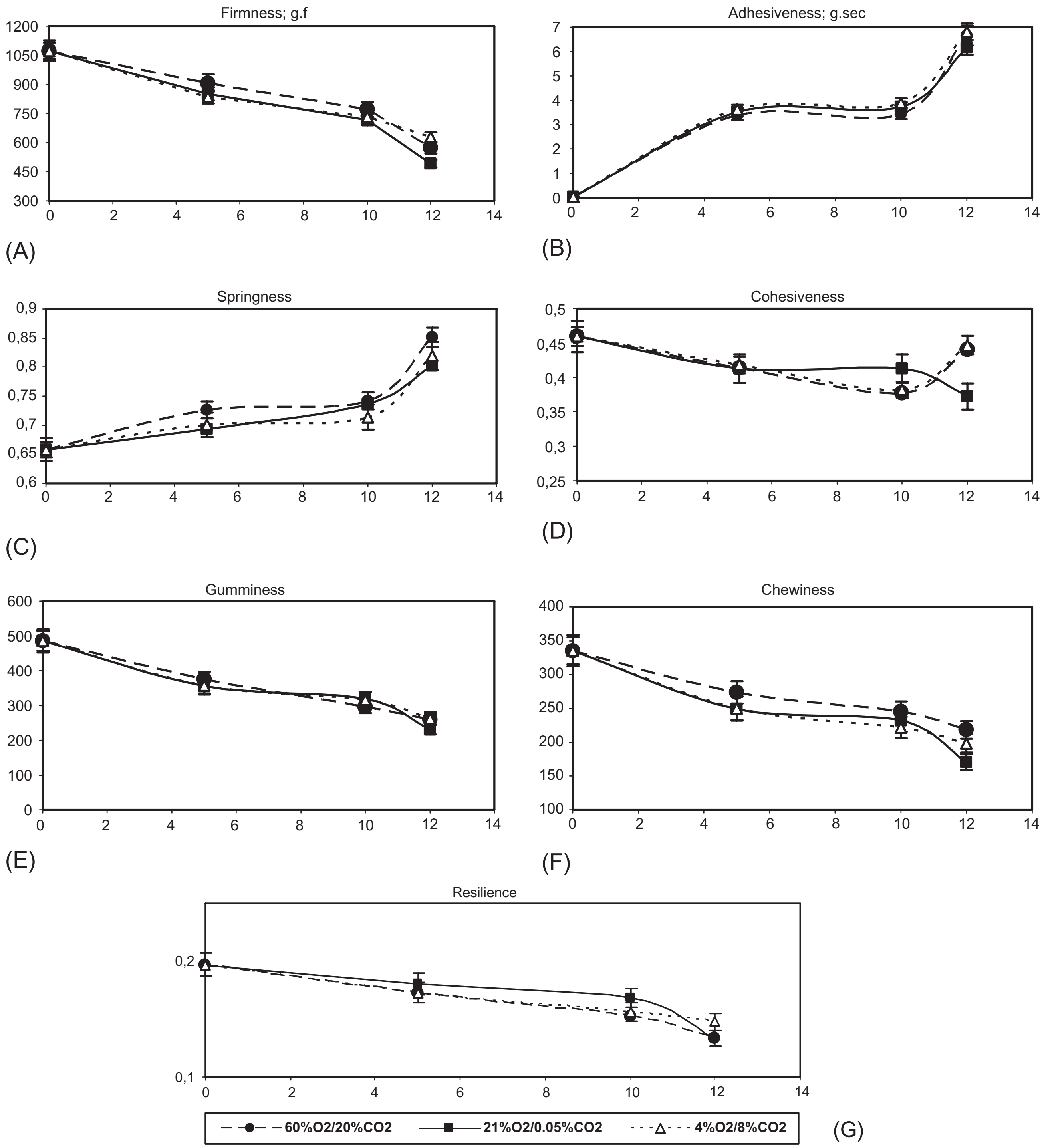

Figure 1. Effect of various MAP on (a) firmness; (b) adhesiveness; (c) springiness; (d) cohesiveness; (e) gumminess; (f) chewiness; and (g) resilience of strawberries stored at 4°C in various atmospheres and gas combinations: 21/0.05, 4/8 and 60/20 (% O_2/% CO_2). Error bars represent the standard deviation. The x-axis shows the days and the y-axis shows the TPA values.

declined at a relatively slower rate at 10 days of storage (Figure 1d).

Gumminess values of the strawberries were significantly decreased from 483 to 231 [21/0.03 (O_2/CO_2)], 259 (4/8) and 257 (60/20) at the end of the storage. However, there were no significant differences among storage times at all gas combinations used (Figure 1e).

Chewiness values decreased significantly from the initial value of 334 to 247 gf (21/0.03), 252 gf (4/8) and 273 gf (60/20) at the end of the fifth day. After 12 days, chewiness values were 172 gf (21/0.03), 216 gf (4/8) and 217 gf (60/20) with no significant differences among them. Overall, compared to 21/0.03 and 4/8 MAP, chewiness was maintained in high O_2 treatment conditions (Figure 1f).

Resilience values significantly decreased from 0.195 to 0.133 in air, 0.147 for 4/8 and 0.14 for 60/20 at the end of the storage period. However, there were no significant differences among each test days (Figure 1g).

It has been well-established that strawberry texture is closely related to cell wall structure and composition and that fruit softening is the consequence of the disassembly of the primary cell wall and the middle lamella structures.[20] Therefore, the more rapid decrease of fruit firmness, cohesiveness, springiness, resilience and chewiness, and increase of adhesiveness in strawberries could be a result of solubilization and depolymerization of cell wall constituents, including pectin.

The decrease of texture parameters such as firmness, cohesiveness, springiness, resilience and chewiness, and the increase of adhesiveness have also been reported in 'Fuji' and 'Gala' apples during storage.[21]

The decrease of firmness, cohesiveness, springiness, resilience and chewiness, or the increase of adhesiveness could be used as potential indicators of fruit quality and shelf life for fresh strawberries. Our results suggest that TPA tests could provide an objective measurement of fresh strawberries quality during storage.

CONCLUSIONS

The overall results expressed that strawberry quality can be maintained effectively for at least 12 days by exposure to proper atmosphere composition.

High oxygen concentration was also effective treatment to retain the freshness of strawberries, and had been successfully used commercially to extend the quality of highly perishable fresh fruits such as strawberries. Packaging of strawberries is a viable alternative if there is a desire to extend their shelf life.

The present study clearly demonstrated that TPA is a reliable instrumental measurement for evaluating the textural quality changes of strawberries during storage. Compared to 21/0.03 MAP, firmness, springiness, and chewiness was significantly improved in high oxygen (60/20). In addition, high O_2 treatment also controlled the decrease in TA and SSC and increase in pH. Compared to 21/0.03, 4/8 and 60/20 had a beneficial effect on strawberry TPA – especially firmness, SSC, TA and pH values – and can be used for commercial purposes. Before such a treatment can become commercially viable, safety issues surrounding the flammability of O_2 must be addressed. Packaging with optimum film permeability will need research to extend the quality of the strawberries. Packaged strawberries with various gas combinations and/or different lid films will need to be researched to maintain desirable attributes longer than 12 days, such as 20–25 days, to see more fungal development.

These results show that the use of heat treatments in combination with refrigerated storage could be a good alternative to keep strawberry fruit quality. Additional improvement can be obtained by performing the heat treatment in bags that allow the CO_2 produced as a consequence of the enhanced respiration rate during treatment to be retained.

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