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ORIGINAL PAPER

Extending the quality of fresh strawberries by equilibrium modified atmosphere packaging

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Abstract The impact of equilibrium-modified atmosphere packaging (EMAP) technology on extension quality [pH, acidity, brix, color (*L*, *a*, Chroma, hue)] and texture profile analyses of fresh strawberries was studied and compared during storage. Cast polypropylene (CPP), linear low density polyethylene (LLDPE) and polyethylene-terephthalate (PET)/Ethylene vinyl alcohol (EVOH)/Polyetlene-low-acetyl fractions (LAF) were used as heat-sealed lid and polyvinyl chloride (PVC/PE) tray with the purpose of obtaining equilibrium atmospheres. Among the various films used, pH of fresh strawberry was 3.275 at initial days, and increased to 3.39- for LLDPE; 3.42 for CPP and 3.44 PET/EVOH-LAF at the end of 10 days' storage. Acidity values were 0.609 mg ml^{-1} and decreased to 0.56 mg ml^{-1} for LLDPE; 0.47 mg ml^{-1} for CPP and 0.49 mg ml^{-1} for PET/EVOH-LAF at end of storage. The strawberry brix had evolved from the initial 7.125 and reduced to about from 5.6 to 6.07 at the end of the storage. At the end of the storage, the strawberry *L* values had not significantly changed from the initial from 29.10 (L) to 28.9–26.46. Initial values of the firmness were 1,089 gf and reduced with ranged from 769 gf to 527 gf at end of the 10-day storage period. All the parameters in texture profile analyses showed a decline, except adhesiveness and springiness and used potential indicators of fresh strawberries. The overall results expressed that strawberry quality can be maintained effectively at least for 10 days using various polymeric lid films. PET/EVOH-LAF and CPP were much more effective then LLDPE due to barrier properties during storage periods. Quality of strawberry packaged with suitable high-barrier lid films have been prolonged significantly.

Keywords Strawberry · Equilibrium modified atmosphere · Packaging · Quality parameters

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Introduction

Strawberries have short shelf life due to highly perishabIility and are susceptible to mechanical injury, physiological deterioration, water loss, and decay. The postharvest preservation of fresh strawberries is very complex owing to a high-metabolic activity due to high rate of respiration (50–100 mL of $C0_2$ per kg per hour at 20 °C) [1]. Their short shelf-life has limited the marketability of this product, and losses can reach upto 40% during storage. Appropriate preservation methods can minimize losses and extend shelf life.

The shelf-life of minimally processed vegetables decreases greatly after a series of preparation operation including distribution handling. Modified atmosphere packaging (MAP) is extensively used to extend the shelf-life of many minimally processed fruits and vegetables products because they reduce respiration rates [2–5]. Shelf-life extension also results in the commercial benefits of less wastage in manufacturing and retail display, long distribution channels and improved product value. In retail outlets, strawberries are generally stored in perforated-top closed containers. Within these containers, the fruits continue to respire until the CO_2 concentration rapidly approaches the necessary critical level 10–15%. The approach generally involves gas mixes confined to 5–15% CO_2, 2–5% O_2, with N_2 as the remainder [2–5] or new approach (applications of novel high oxygen; more than 50% O_2 in MAP) [5, 6]. In a previous study, the quality of fresh strawberries was extended to about 12 days by storage at 4 °C in various MAP conditions; air (21%O_2/0.03%CO_2), classical gas atmospheres (4%O_2, 8%CO_2; 88%N_2), and high oxygen atmospheres (60%O_2, 20%CO_2; 20%N_2) [5].

In equilibrium-modified atmosphere packaging (EMAP), the gas atmosphere of package consists usually of a lowered level of O_2 and a heightened level of CO_2. In EMAP, atmosphere modifications relies on modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the respiration of the strawberries and the transfer of gases through the packaging, that leads to an atmosphere richer in CO_2 and lower in O_2. The equilibrium atmospheric composition within a MAP is determined by the O_2 consumption and CO_2 evolution rate of the product as well as film permeability (O_2 and CO_2) of the package. The package itself restricts the movement of gases in and out of the sealed package due to its selective permeabilities to O_2 and to CO_2. Over time, the system achieves an equilibrium-modified atmosphere composition which, if appropriate, extends the shelf life of the produce with the O_2 lower than that found in air (20.9%) and the CO_2 concentration higher than that in air (0.03%) [7]. Qualities can be improved by altering the gas atmosphere surrounding fresh strawberries depending on the various polymeric films used [1].

Current knowledge and use of EMAP are mainly empirical, but a systematic approach to designing optimal EMAP is being developed [8, 9]. The films used in MAP include various kinds of plastic polymers that provide protection, strength, sealability, clarity, and a printable surface. The atmosphere that will obtain inside a MAP is a function of the film and the product [2]. New studies are needed to determine the film for packaging high-respiration rates of fresh produce such as fresh strawberries. Among the different permeability properties that need to be studied based on the unique function is to restrict the movement of O_2 and CO_2 through the bag and allow the establishment of a modified atmosphere [10, 11]. The application of EMAP can be a new approach for the retailing of fresh strawberries and is capable of overcoming the many disadvantages of current favorable gas concentrations. The quality of fresh strawberries packaged with various films can be effectively maintained during storage.

Fruit textural quality is a very complex process that is influenced by the synthesis and action of hormones responsible for the rate of ripening, the biosynthesis of pigments and the metabolism of sugars. In addition, the modifications of the structure and composition of the cell wall are known to affect the texture of the fruit [12]. Texture profile analysis (TPA) using a universal texturometer has become a useful means to analyze a series of textural quality parameters in various fruits and vegetables [13]. However, use of TPA to evaluate the textural properties of fresh strawberries fruit has not been reported in detail. It can be used for fresh fruits such as strawberries to study the texture attributes.

Previous work on texture of strawberries showed that instrumental Texture Profile Analysis (TPA) can detect minute differences in several TPA parameters induced by differences in gas compositions used [14].

The objective of present study was to determine:

1. The most suitable modified atmosphere packaging in different lid films [CPP, LLDPE and PET/EVOH-LAF) based on quality changes of strawberries (total soluble solids (TSS), titratable acidity (TA), pH, color (*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

Material and sample preparation

Fresh daily "camarosa" strawberries were obtained from LEZZETLI GIDA Tic and San Ltd. Sti. (Istanbul, Turkey) and then selected (damaged, non-uniform, unripe or overripe discarded) for uniformity. The polyvinyl chloride-polyethylene (PVC/PE) trays (20 × 30 cm) were filled with 250 g. fresh strawberry fruits and heat-sealed with the different lid films by ReePack ReeTray 25TC MAP APACK (Istanbul, Turkey) and stored at 4 °C. Polypropylene (CPP), linear low density polyethylene films (LLDPE) and polyethylene-terephthalate (PET)/ethylene vinyl alcohol (EVOH)/polyethylene-low-acetyl fractions (LAF) were used as heat-sealed lid polymeric films and polyvinyl chloride (PVC/PE) used for tray cups supplied by APACK (Istanbul, Turkey). Table 1 presents the transmission rate of these films. The initial gas composition in the package headspace was 21% O_2/0.03% CO_2.

At 0, 5 and 10 days of storage ten strawberries were used to measure surface skin color and for TPA evaluation (in quadruple) and three strawberries were pressed to

Table 1 Transmission rate of different lids used for equilibrium-modified atmosphere packaging of fresh strawberries (at 23 °C)

Packaging materials used	O_2 transmission rate cc/(m^2 day)	CO_2 transmission rate cc/(m^2 day)
LLDPE	4,050	14,000
CPP	1,607	6,000
PET/EVOH-LAF	1.5	5.5

PE polyethylene, *CPP* cast polypropylene, *PET/EVOH-LAF* poly(ethylene terephthalate)/Ethylene vinyl alcohol

obtain juice used to measure other quality parameters (Brix, titratable acidity and pH). The analysis were carried out at 20 °C. Three replicates per measurement were used.

pH measurement

For each replicate, of three strawberries were squeezed. The pH values were determined for the squeezed strawberry juice and measured using a pH meter (Sartorius PP-50, Goettingen, Germany).

Total soluble solids

The total soluble solid (TSS) content of the squeezed strawberry juice was measured with an Atago Pal-1 pocket refract meter (Atago Co. Ltd, Tokyo, Japan). Results were expressed in Brix.

Titratable acidity

Titratable acidity (TA) was measured on the 10 mL of pressed strawberry juice, which 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 with pH meter (Sartorius PP-50, Goettingen, Germany). The results were expressed as milligrams of citric acid in terms of fresh weight acid for strawberries.

Surface color

Ten strawberries were evaluated by colorimetric analysis. A model CR-400 portable colorimeter (Minolta CR-400 Chronometer; Konica Minolta Sensing, Osaka, Japan), color space *L*, *a*, *b* values, was used. Strawberries were taken at random locations and the CIE LAB *L*, *a*, *b* parameters were recorded.

Results were expressed as *L–a–b* values as *L* (lightness), *a* (green to red; higher positive *a* values indicate red color), and *b* (blue to yellow; higher positive b values indicate a more yellow skin color) values were recorded.

Texture profile analyses (TPA)

Texture profile analyses (TPA) were performed according to [13] with a TA-XT2i texture analyzer (Stable Micro Systems Ltd., 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; trigger force 1.0 N. The SMS-P/10 CYL. Delrin probe always returned to the trigger point before beginning the second cycle. After the second cycle, the probe returned to its initial position. To obtain a good estimation of overall strawberries TPA, measurements were made on ten strawberries per gas concentration of MAP and sampling day. Values for firmness, springiness, cohesiveness, adhesiveness, gumminess, resilience and chewiness were automatically calculated by the software.

The data obtained from the force relaxation curve were used to calculate maximum and residual force, while the data obtained from TPA curve were used for the calculation of textural parameters. Amongst the TPA parameters, firmness is expressed as maximum force for the first compression, whereas adhesiveness is expressed as negative force area for the first bite or the work necessary to pull the compressing plunger away from the sample. Springiness is a measure of how much the flesh structure is broken down by the initial penetration. Cohesiveness is a measure of the degree of difficulty in breaking down the flesh internal structure. Cohesiveness and springiness have been reported as ratios between areas under second and first compression and the height that the sample recovers during the time that elapses between the end of first bite and initiation of the second one, respectively. Gumminess and chewiness have been reported as products of firmness, cohesiveness, gumminess, and chewiness, respectively. Resilience reflects the redeformation capacity of fruit tissue after penetration [13].

Equilibrium calculation

Steady-state Eqs. 1 and 2 were used for calculation of O_2 partial pressure (atm) and CO_2 partial pressure (atm) in tray sealed with different lid films for strawberries' equilibrium conditions according to [14]:

$$RO_2.W = PO_2A\{(O_2)_{out} - (O_2)_{in}\} \quad (1)$$

$$RCO_2.W = PCO_2.A.\{(CO_2)_{in} - (CO_2)_{out}\} \quad (2)$$

In these equations; $(O_2)_{out}$ is the O_2 concentration outside packaging (Air = 20.9 /100 mL), $(O_2)_{in}$ is the O_2 concentration inside packaging, $(CO_2)_{in}$ is the CO_2 concentration inside packaging, $(CO_2)_{out}$ is the CO_2 concentration outside packaging (Air = 0.03 /100 mL), *W* is the fill weight (0.25 kg), *A* is the area of the film

(0.06 m^2), RO_2 is the respiration rate of packaged strawberries at 4 °C explained as O_2 consumption (mL/kg h), RCO_2 is the respiration rate of packaged strawberries at 4 °C explained as CO_2 production (mL/kg h), PO_2 is the permeability of film for O_2 (mL/m^2 24 h) and PCO_2 is the permeability of film for CO_2 (mL/m^2 24 h).

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

Headspace gases

In EMAP respiration and transpiration rates of package are vital factors that determine the adequate gas composition to delay the deterioration processes that shortened shelf life. Improper control of the gas compositions may lead to undesirable results such as anaerobic respiration, accelerated physiological decay, and shortened shelf life. Consequently, the atmospheric evolution was calculated based Eqs. 1 and 2 during storage and the results are presented in Fig. 1. As can be seen, CO_2 reached equilibrium concentrations within the first 48 h after packaging, except for the trays sealed with PET/EVOH, in which a CO_2 increase without O_2 consumption was verified, due to anaerobic respiration. Once CO_2 and O_2 were equilibrated, values ranged between 4 and 7% and 18% dependent on the lid film used.

Total soluble solids (TSS)

Total soluble solids of strawberries packaged with various polymeric films significantly decreased (7.125 vs. 5.60–6.07 $P < 0.05$) during storage periods as expected due to high-postharvest metabolism (Table 2) [10, 16]. The decrease in brix was significantly depending on storage time but there was no clear difference between packaging films used.

CPP and PET/EVOH-LAF showed higher Brix values than the LLDPE during storage; however, the difference was not statistically significant. At the end of the storage periods, the TSS had evolved from the initial 7.125 °Brix to 5.60 (LLPPE); 5.87 (PET/EVOH-LAF) and 6.07 (CPP). Higher level decrease of brix is related to higher strawberry

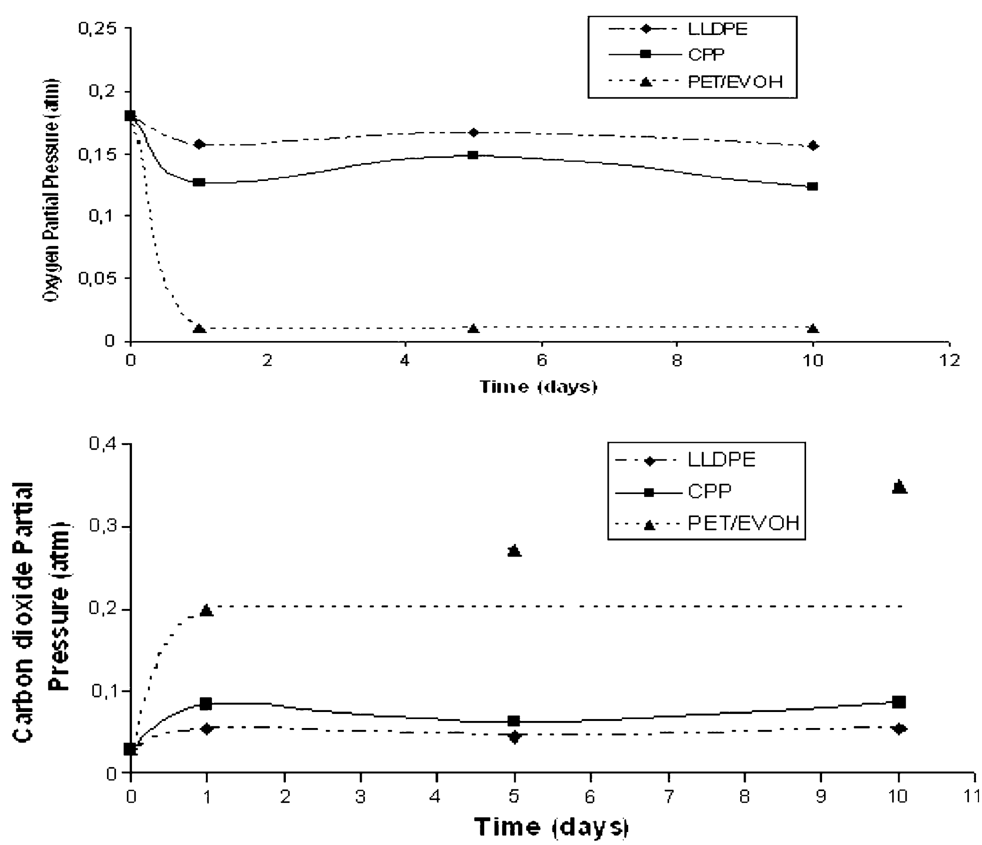

Fig 1 Calculated oxygen and carbon dioxide contents of strawberries packaged with different films

destruction. It was also possible to see effect of various polymeric lid films in delaying the decrease in TSS, even though it was not statistically significant (Table 2). LLDPE showed basically more reduction than other polymeric films due to its very high permeability properties. The high oxygen barrier PET/EVOH-LAF and CPP showed the lesser the decrease of brix values during storage. Garcia et al. [10] and P'Icon et al. [17] reported that the TSS of different strawberry varieties in various package materials dependent decreased during storage. Wszelaki and Mitcham [18] also reported higher respiration rates and a parallel TSS decrease during 14 days.

It appears that the reduction in TSS is somehow reduced and maintained with various polymeric lid film used in EMAP.

Titratable acidity

The acid content (TA) of strawberries was decreased during storage periods (Table 2); consequently the quality of strawberries decreased due to CO_2 dissolution on the fruit surface generating carbonic acid and acidifying the fruit.

The decline in acidity was dependent on storage time ($P < 0.05$). The acidity was depending on the permeability of packaging materials and the equilibrium reached in packaging. There was a corresponding decrease in TA. Although citric acid content in the CPP and PET/EVOH-LAF was higher on day 10, no significant differences ($P < 0.05$) were found between all polymeric films used (Table 2). The acidity of the strawberries packed in above films decreased slightly over time and differed significantly from that of the fruits packed in LLDPE films at the end of the storage time (Table 2). The titratable acidity of the strawberries is used as indicator of potential storage quality, and decline gradually over the storage period. The fact that acidity was maintained in the fruits packed in CPP and PET/EVOH-LAF films Indicates that the modified atmospheres slowed down the senescence process and the loss of fruit quality.

Table 2 Changes in TSS (°Brix), TA (mg of citric acid) and pH of fresh strawberry packaged with different polymeric films during 10 days of storage at 4 °C

Days/MAP films used	SSC (°Brix) (SD)	TA (SD)	pH (SD)
0	7.125^{a}	0.609^{a}	3.27^{a}
5			
LLDPE	$6.125^{b,c}$	0.580^{a}	3.31^{a}
CPP	$6.575^{a,b}$	0.596^{a}	3.30^{a}
PET/EVOH/LAF	$6.30^{b,c}$	$0.571^{a,b}$	3.33^{a}
10			
LLDPE	5.60^{d}	0.521^{c}	3.40^{b}
CPP	$6.07^{b,c,d}$	$0.534^{b,c}$	3.42^{b}
PET/EVOH/LAF	$5.87^{c,d}$	$0.542^{b,c}$	3.44^{b}

For each column, values with the same letter are not statistically different $P < 0.05$

pH

Strawberry pH significantly increased during storage from initial values 3.27–3.39–3.44 at the end of storage (Table 2). After 10 days of storage, pH values of strawberries were significantly higher than 5 and 10 days values and increased up to 3.40 in LLDPE, 3.42 CPP and 3.44 PET/EVOH-LAF as shown in Table 2 ($P < 0.05$). Flexible packaging films used in the MAP allow O_2 to move into the package from the outside air and CO_2 to be released from the inside of the package. Since carbon dioxide level increases naturally due to product, high respiration resulted in increasing the pH values. Higher barrier properties of PET/EVOH-LAF do not allow CO_2 to be released and increase in package.

These results are in agreement with those obtained by Almenar [1], who reported that increase in strawberries' pH depended on the various packaging materials used (three micro performed PET/PP films and PVC) during storage [1].

Fruit skin color

The retention of the inherent color of fresh fruits is often used as a quality indicator and has a substantial impact on consumer acceptance. The surface color of the fruit has to be analyzed during storage, measuring color at several locations of the sample. Therefore, the loss of color in strawberries is most likely related to degradation of pigments.

The trends of all samples showed slight differences each day. This indicated that there was not much difference in color stability. Over the storage period, the lightness (L) values of the strawberries tended to decrease (L 30, 87), meaning that the fruit developed darker color during storage. The chroma values were also decreased (Table 3). L values were found in all treatments throughout the experiment in the similar range.

L values had slightly dropped right after initial days (starting values); another 10 days of storage resulted in the L values significantly declining when compared initial days, but not at 5 days. Similar trends and rates of change in lightness, a, and chroma were also found for all samples. The a values of all samples decreased over time indicating a decrease in redness of the strawberries during storage, but not significant differences were observed in values (Table 3). Thus no significant differences in color-appearance changes were found amongst packaging lid

Table 3 Changes in strawberry fruit skin color of fresh strawberry packaged with different polymeric films during 10 days of storage at 4 °C

Days/MAP films used	*L*	*a*	Chroma	Hue
0	30.87[a]	29.13[a]	29.08	15.40
5				
LLDPE	28.19[a,b]	26.68[a,b]	27.95	15.10
CPP	28.90[a,b]	27.58[a,b]	27.58	14.99
PET/EVOH/LAF	27.87[a,b]	28.15[a,b]	29.07	15.32
10				
LLDPE	28.65[b]	25.62[b]	27.16	15.01
CPP	26.95[b]	27.30[b]	28.40	14.96
PET/EVOH/LAF	27.15[b]	27.26[b]	27.69	14.88

For each column, values with the same letter are not statistically different $P < 0.05$

films used. It was agreed that chroma values were decreased during storage [18, 19].

When comparing the different packaging materials, strawberries packed with high barrier (CPP and PET/EVOH-LAF and also) were slightly darker (decrease in lightness) than LLDPE.

Chroma and hue angle were not significantly changed and comparable values were found in all treatments during the storage. Alamenar et al. [1], reported that strawberries packaged with PE/PP were significantly darker than those packaged with PE/PP microperformed films and PVC. Fruit stored in low permeability materials presented higher chroma values than berries stored in high-permeability materials [20].

Texture profile analyses (TPA)

Texture profile analysis (TPA), is a very important indicator of strawberries' quality and can be used to determine the texture changes in the MAP during storage. In TPA test, the fruit sample is compressed twice, imitating the action of the jaw, and the parameters obtained from this test correlate well with sensory ratings [21].

During strawberries storage, one of the most notable changes is softening, which is related to biochemical alterations at the cell wall, middle lamella, and membrane levels. Thus, treatments of strawberries have been proven to be effective in reducing their firmness loss. [12, 13].

The TPA values of all berries parameters as firmness, cohesiveness, gumminess, chewiness and resilience decreased, whereas adhesiveness and springiness increased during storage depending on the films used (Fig. 2).

Firmness, as a measure of force necessary to attain a given deformation, gave a different response to the various types of MAP application [17, 21, 22]. Strawberry firmness was significantly, consistently declined during storage ($P < 0.05$) indicating significant softening. Firmness were decreased from initial values 1,108–830 gf in LLPDE, 889 gf CPP, and 850 gf PET/EVOH-LAF by day 5. By day 12, the firmness of the strawberries was 657 gf LLDPE, 719 gf CPP and 729 gf PET/EVOH-LAF (Fig. 2a). PET/EVOH-LAF and CPP were of significantly higher firmness than LLPDE. Thus compared to LLDPE, strawberries firmness was significantly maintained in CPP and PET/EVOH-LAF polymeric film used in EMAP during storage. Firmness is strongly related to water loss and deterioration of the strawberries. Low-gas transmission rates in probably provided the strawberries maintain its texture. However, material (LDPE) has a considerably higher O_2, resulting inside the package (faster deterioration of the strawberries). The results demonstrate the effectiveness of films used in softening. Softening of strawberry during storage is mainly due to loss of cell wall material, which is more pronounced in the cortical tissue than in the pith tissue [21, 22]. Strawberry softening is thought to be primarily due to the presence of polygalacturonase, which solubilizes and degrades the cell wall polyuronides; the soluble polyuronide level [22, 23]. Such effectiveness in maintaining firmness (reducing softening) is attributed partly to a slowing-down of physiological degradation processes by the modified atmospheres, and partly to the maintenance of high relative humidity, close to saturation, which prevents dehydration of the fruits.

The data pertaining to adhesiveness of fresh strawberries (Fig. 2b) showed a sharp and consistent increase ($P < 0.05$) throughout the storage period. Values in LLDPE were higher than others; especially at 10 days, there were no significant differences due to great variation each storage periods (Fig. 2b). The increment in adhesiveness during storage is related with softening of fruit pulp of strawberries and has the tendency to be sticky due to its mucilaginous nature (slimy or adhesive texture).

Springiness is an important TPA parameter and the data on springiness (Fig. 2c) showed it significantly increased from initial values 0,667 to 0,736 for LLPDE, 0.772 for CPP, and 0.751 for PET/EVOH-LAF at the end of storage. However, there were no significant differences between CPP and PET/EVOH-LAF, significantly higher values than LLDPE during storage. Compared to LLPDE, strawberries springiness was significantly maintained in CPP and PET/EVOH-LAF (Fig. 2c). Strawberry samples showed a steady increase in springiness at 5 days of storage and then followed by a very slow increase until end of storage period.

Cohesiveness contributes to the comprehensive understanding of viscoelastic properties including tensile strength [21, 22]. Cohesiveness values were significantly declined during storage ($P < 0.05$). However, there were no significant differences among the film used during

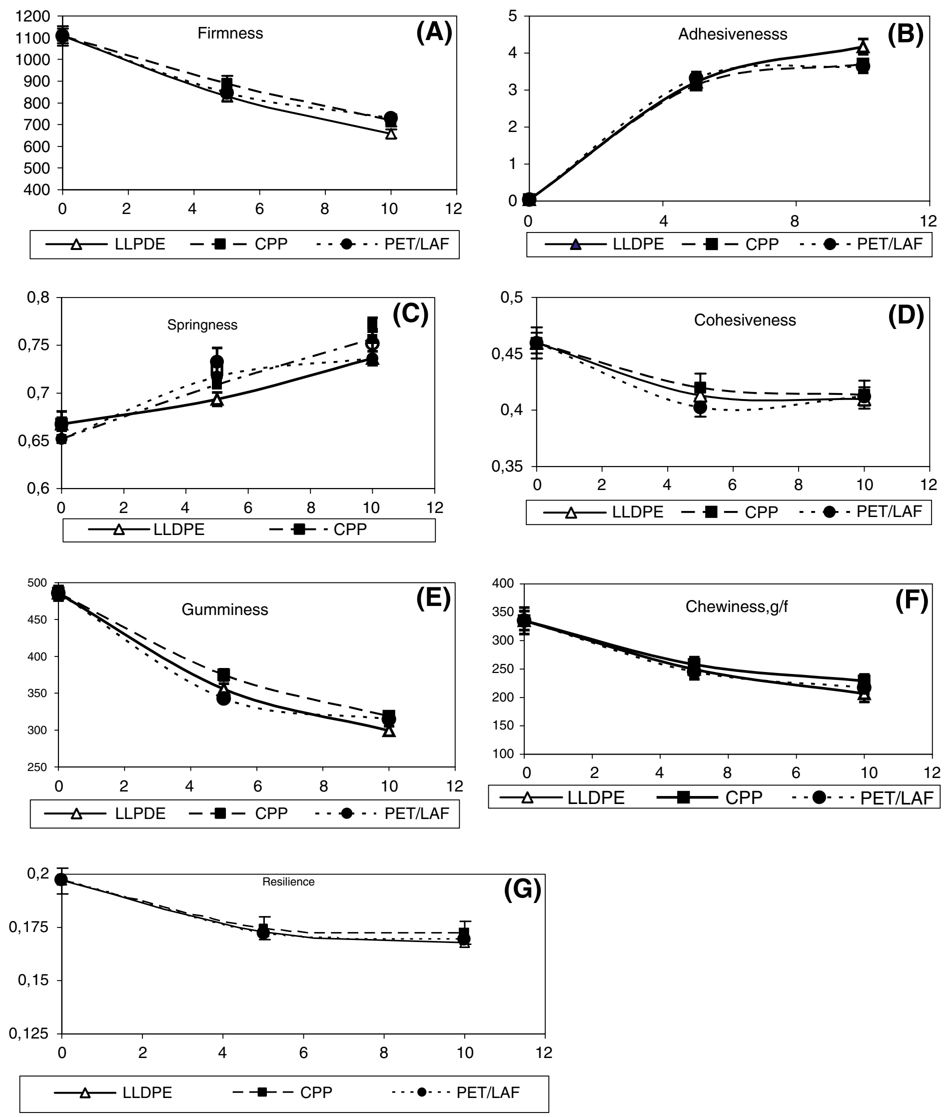

Fig 2 Effect of different polymeric films on TPA: firmness (**a**), adhesiveness (**b**), springness (**c**), cohesiveness (**d**), gumminess (**e**), chewiness (**f**) and resilience (**g**) of strawberries during storage at 4 °C in equilibrium MAP

storage (Fig. 2d). A consistent declining trend in cohesiveness was observed (Fig. 2d); however, the differences in the magnitude of cohesiveness were not found to be conspicuous as in the case of adhesiveness and springiness. Based on the declining trend, it was noticed that tissue softening resulted in loss of cohesiveness due to attributed to solubilization of pectinaceous material in the middle lamellae of adjacent cells. As far as mastication is concerned, cohesiveness plays an important role in the mouthfeel towards the end of mastication by the molar teeth.

The EMAP-stored strawberries showed gumminess pattern similar to other TPA parameters with compliance to drop in firmness (Fig. 2e). Gumminess values of the strawberries were significantly decreased from 485 to 299 (LLDPE), 318 (CPP) and 314 (PET/EVOH-LAF) at the end of the storage; however there were no significant differences among each storage times at all gas combinations used (Fig. 2e).

The persistence in gumminess during the storage of fresh strawberries can be attributed to the coalescence of cells due to greater physiological and physical stress caused by lowered O_2 as well as atmosphere conditions. EMAP maintained the strawberries' textural changes (tissue integrity) in terms of gumminess.

Chewiness is the energy required to masticate a solid food product to a state ready for swallowing [21, 22]. Therefore, it is considered as an important parameter since the final phase of mouthfeel and the ease in swallowing depends on the chewiness of the strawberry. Strawberries being a soft fruit, the mouthfeel at the time of swallowing needs to be appropriate. Chewiness values decreased significantly from initial value of 336 (gf) to 206 (gf) LLDPE, 228(gf) (CPP) and 219 gf PET/EVOH-LAF at the end of the 10th day. However, there were no significant differences among them (Fig. 2f).

Resilience values were significantly decreased from 0.196 to 0.167 for LLDPE, 0.172 for CPP, and 0.169 for PET/EVOH-LAF at the end of storage. There were no significant differences among test days (Fig. 2g).

It has been well established that fruit texture is closely related to cell wall structure and composition and that fruit softening is the consequence of disassembly of primary cell wall and middle lamella structures [21, 22]. Changes in instrumental measurement of texture parameters inclusive of firmness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness can be attributed to the structural changes in strawberries with emphasis on solubilization and depolymerization of cell wall constituents including pectin.

As such except adhesiveness and springiness, all other texture profile parameters showed a decline due to the disintegration of tissue integrity and increased solubilization. The increased springiness and adhesiveness can be due to the enhanced solubilization and it holds well in establishing the relationship between structural changes. The decrease of texture parameters such as firmness, cohesiveness, resilience and chewiness, and the increase of adhesiveness have also been reported in “Fuji” and “Gala” apples during storage [13].

The decrease of firmness, cohesiveness, gumminess, chewiness and resilience or the increase of adhesiveness could be used as potential indicators of quality criteria for fresh strawberries. The effects on TPA were most apparent for strawberries stored using the less permeable CPP and PET/EVOH-LAF films. It is possible that the gas retention abilities of these films contributed to prolonged fruit textural properties, especially firmness. Protopectin is converted to pectin by the action of pectinases during storage. When water-soluble pectin enters the cell under osmotic pressure, the pectin forms a gel, resulting in a softer and more elastic texture (especially in losing firmness). These results can be explained by the fact that the CPP and PET/EVOH-LAF films maintain, especially, firmness (indicates changes in the cell wall structure).

There was a strong correlation between results of texture profile analysis and the changes in Brix, TA and pH. Our results suggest that TPA tests could provide an objective measurement of fresh strawberries’ fruit texture especially firmness.

Conclusions

The quality of fresh strawberries was dependent on the characteristics of the packaging material and the choice of appropriate quality parameter.

EMAP using various lid films was shown to maintain the initial quality of fresh strawberries at least for 10 days storage. Compared with the LLDPE, CPP and PET/EVOH-LAF were much more successfully maintained initial strawberries quality during storage. Reduction in packaging film permeability was accompanied by retention in the quality of strawberries.

As conclusion, the present study demonstrated that the response of strawberries toward EMAP application during storage was varied and changes were conspicuous in a number of TPA parameters. TPA is a reliable instrumental measurement for evaluating the textural quality changes of strawberries during storage. Compared to LLDPE, strawberries’ firmness, springiness and gumminess were significantly maintained in high CPP and PET/EVOH-LAF. In general, a reduction in packaging films permeability was accompanied by an increase in the initial quality of the strawberries.

Packaging of strawberries might be viable alternative for producers that for some reason are in need of a few more days prolonged storage, for example to facilitate longer transportation distribution in order to expand the market.

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