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Effect of Mineral Packing Films on Preservation of Fresh Fruits

신선과일의 품질에 영향을 미치는 광물질 필름의 개발 및 효과

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석사학위논문

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지도교수 최영진

이 논문을 석사학위 논문으로 제출함

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나 현 진

나현진의 석사 학위논문을 인준함

2014년 2월

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Abstract

The necessity of a functional packing material to prevent fresh fruits from decaying has been increased. The polyethylene (PE) film is one of the most common packing materials. It has a number of advantages such as low cost, ease to manufacture with many different forms, transparency and light weight. However, it is hard to preserve the fresh food in a PE film for a long time because the PE film is a poor barrier to oxygen and water vapor transmission compared to glass or metal. The functional packing materials including mineral powder (loess, barley stone, jade, zeolite, charcoal, kaolin, feldspar, biotite and selenium) were manufactured to overcome the problems of PE film. Pulverization of mineral powder was important to form the mineral film. Thus, self-grinding method was used for pulverization of mineral powder in this study. The optimum feeding conditions for grinding of mineral powder were found 0.45 kg/h and 0.91 kg/h inputs of mineral material. Also, due to the beige color of the mineral powder, the mineral film leads to reduce transparency. The opacity of the packing film could be a

limitation for a consumer use. Hydroxyl apatite was used to improve the opacity. The hydroxyl apatite 0.5 wt% and mineral powder 2.5 wt% (HAP-3) was effective for improvement of opacity of the film. The transmission rates of relative humidity and oxygen of the mineral packing film were 5.4 g/(m^2·24 h) and 2100 cm^3/(m^2·24 h·atm), respectively. They were decreased by 26.0% and 41.7% compared with PE packing film. The tensile strength of the mineral packing film was 1.25 fold higher than that of PE packing film. To determine the effect of the mineral film on storability of fresh fruits, persimmon, tomato and banana were selected as samples. Compared to PE packing film, the mineral packing film should better behaviors on color index, firmness retention and total soluble solids of persimmon and tomato. Consequently, mineral-packing material was able to maintain the sensory and physicochemical qualities of fruits at a higher level compared with PE packing film. It could be explained as its lower relative humidity transmission rate. As the result of a lower relative humidity transmission rate, the mineral film offered a larger resistance to water vapor and gas transmission during the entire storage time. However, peel spotting and pulp to peel ratio of banana showed very little difference between mineral film and PE film. There was a difference of the effect on maintaining quality of fruits among the climacteric fruits. According to related researches, banana has higher respiration rate and ethylene production than other fruits. The manufactured mineral film had a negative impact on the quality of banana. As the results, the fruit with high respiration rate and ethylene production such as banana had a bad effect on the quality of fruits. Therefore the mineral film may appropriate to the fruits with normal respiration rate and ethylene production such as persimmon and tomato. More research will be needed to investigate the certain mechanism that mineral film functions during storage to facilitate the application of packaging technology in a broader range in the future.

Keywords: Mineral, Packing material, Mineral film, PE film, Persimmon, Banana, Tomato, Preservation quality

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1. INTRODUCTION

The ripening of fresh fruits corresponds to a series of biochemical, physiological and structural changes that make the fruits attractive to the consumer. Although these processes vary from one type of fruit to the next, fruits can be divided into two broad groups, known as climacteric and non-climacteric [1]. Categorization into one group or the other depends on whether or not a fruit exhibits a peak in respiration and ethylene production during ripening. The sharp increase in climacteric ethylene production at the onset of ripening is considered as controlling the initiation of changes in color, aromas, texture, flavor, and other biochemical and physiological attributes. In contrast, the ripening of non-climacteric fruits is generally considered to be an ethylene-independent process and little is known of the regulatory mechanisms underlying the biochemical changes [2].

Generally, persimmon is classified as a climacteric fruit. Climacteric fruits could be ripen after harvest even if harvesting fruits at early maturity stage and unripe [3]. Persimmon, unlike other climacteric fruits, is not edible at the early maturity stage and has very firm texture with a low sugar and water content. These characteristics give the opportunity to store fruits for lengthy periods with minimum loss, whereas ripe persimmons are very soft, mushy and high in sugar and water, and can be easily bruised [4]. The peel can be easily damaged or ruptured by rough handling. The reduced sugar content increases steadily during fruit development, reaching a maximum as the fruit became ripe [5]. The soluble tannin content at the early stage of maturity of persimmon fruits is very high, which contributes to its remarkable astringency, and then begins to fall during maturation and ripening [3].

Tomato fruit quality for fresh consumption is determined by a set of attributes that describe external (size, color, firmness) and internal (flavor, aroma, texture) properties [6]. Sensory analysis is an efficient way of describing these properties and has to be compared to consumer preference.

Relationships between tomato taste and fruit characteristics have been widely studied. For the most part, flavor comes from the ratio of reducing sugars to organic acids and volatile aromas. More than 400 volatiles have been identified, some of them contributing to the particular aroma of tomato fruit. Sweetness and acidity are related to sugar and acid content [7,8]. Depending on the studies, acidity is more related to the fruit pH or to the titratable acidity. Both sugars and acids contribute to sweetness and to overall aroma intensity. Texture traits are more difficult to relate to physical measure, although firmness of a tomato in mouth is partly related to instrumental measure of fruit firmness, and mealiness was found to be related to the texture parameters of the pericarp [6]. Several studies have set out to identify the most important characteristics for consumer preferences. Acceptable fruit must be high in tomato-like aroma intensity and in sweetness, but intermediate in acidity [9].

Banana is a climacteric fruit, and as such shows marked physiological changes during ripening. Banana [10], like other fruits, undergo significant textural and color transformations during the ripening process. The short shelf life of banana is due to a rapid senescence that causes the visual appearance of the fruits peel to degrade from greenish-yellow to the dark spotting on a yellow background, resulting in a brown color [11]. Bananas are usually harvested at the matured green stage and they remain firm and green without significant change in the peel color, texture, or composition (depending on temperature, humidity, and age of bananas at harvest) before ripening starts [12]. Once the ripening process is initiated, it is irreversible and involves numerous chemical changes, alterations in the fruit texture, and the synthesis of volatile components. Moreover, ripening results in non-homogeneous peel color changes and the brown spotting over the yellow background [13].

Much attention had been paid to the storage techniques of fruit, including heat treatments, edible coatings and modified atmosphere packing. However, most of these strategies are expensive and time-consuming. Thus, there is an urgent need to have alternative technologies to inhibit undesirable physicochemical and physiological changes during storage. So far, the application of biodegradable films for food packaging has been seriously limited because of their poor barrier and weak mechanical properties. For these reasons, the commonly used food packing materials are still natural polymers, which are frequently blended with other synthetic polymers or, less frequently, chemically modified with the aim of extending their applications in special or severe circumstances [14].

Hydrophilic films provide under certain conditions of relative humidity and temperature a good barrier to oxygen and carbon dioxide transmission but a poor barrier to water vapor [15]. These characteristics are favorable to quality preservation of fruits and vegetables, because they lead to a reduction in respiration rate by limiting exposure to ambient oxygen and increasing internal carbon dioxide, thus retarding ripening. The poor water vapor barrier allows movement of water across the film, thus preventing water condensation that can be a potential source of microbial spoilage in soft vegetables [5].

Natural minerals including loess, barley stone, zeolite, charcoal and feldspar could give antibacterial performance, porosity and elasticity to maintain such as commercial packing films [16]. Mineral film could be promising in the postharvest conservation of fruits and vegetables [17].

The objectives of this study were to prepare a novel packing film using natural minerals and investigate its effect on preservation of climacteric fruits during storage.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Preparation of mineral film

The mineral film manufacture was as follows : (1) Mineral powder (loess 8~14%, barley stone 5~9%, jade 5~9%, zeolite 20~24%, charcoal 1~5%, kaolin 14~18%, feldspar 2~5%, biotite 12~16% and selenium 3~10%) were pulverized about 100~150 mesh size and the grinded powder was made pellet. (2) Pellet was pulverized about 1,000~1,500 mesh size using jet-mill (4” micronizer, Sturtevant, USA) (3) Mineral powder (2%), polyethylene (98%) were blended to uniformity and the mixture was gelatinized for 15 min using a high-speed mixer (130 rpm) (4) Gelatinized suspensions were poured on the first vacuum forming equipment and were solidified it. (5) Second vacuum forming equipment to spray paraffin solution put paraffin into it. Finally, the film was made into bags.

2.1.2. Preparation of mineral film for improvement of transparency

An increase in quantity of mineral materials for manufacturing film leads to reduce transparency since the mineral materials have beige color. To solve this problem, hydroxyl apatite added to the film. Hydroxyl apatite ($Ca_{10}(PO_4)_6(OH)_2$) can be found in teeth and bones within the human body and be harmless to humans. Also it was used as a filter for absorption of harmful material. It was selected to add for improvement of transparency. Films were manufactured as Table 1 and called them HAP-1, HAP-2 and HAP-3. HAP meant ‘hydroxyl apatite was added to packing film’.

Table 1. Composition of the mineral films

Sample	PE (wt%)	HAP (wt%)	Mineral powder (wt%)
HAP-1	97.5	1.25	1.25
HAP-2	97.5	2.5	-
HAP-3	97	0.5	2.5

2.1.3. Plant materials

Persimmon, banana and tomato were selected for storage test. Fruits at the commercially ripe stage were purchased from a local market and sorted according to apparent/visual uniformity. Only fruits free from injuries were selected and, before testing, fruits were randomized to avoid bias.

2.1.3.1. Assessment of decay rate for improvement of opacity of mineral film

Ten selected mandarins were put in HAP-1, HAP-2 and HAP-3 film respectively, which were sealed and then stored at room temperature for 7 days. The decay rate was as follows :

$$\text{Decay rate} = \text{Number of decayed fruits} \,/\, \text{Number of total fruits in each treatment}$$

2.1.3.2. Verification of effectiveness for mineral film

Five selected persimmons and tomatoes were randomly packed with mineral film (18 bags) and normal polyethylene film (18 bags), which were then sealed. The persimmons and tomatoes were submitted to three treatments : (1) control samples (unpackaged persimmons), (2) samples packaged with PE (polyethylene) film, (3) samples packaged with mineral film. All the samples were stored at 26 ± 2 ℃. Persimmon quality was assessed after 2, 4, 6, 7, 14 and 21 days of storage. Also, tomato quality was assessed after 7, 10, 14, 17 and 21 days of storage. Three selected bananas were packed with mineral film (9 bags) and normal PE film (9 bags), which were then sealed. The bananas had same treatments such as persimmon and tomato. Banana quality was assessed after 3, 5 and 7 days of storage.

2.2. Method

2.2.1. Grinding method and particle-size distribution of mineral powder

Grinding process of pellet is needed to produce a mineral film Dispersion of pellet depends on particle size of mineral powder. A self-grinding method was used for preparation of the powder. An input of mineral powder varied from 0.23 kg/h to 2.70 kg/h and found out optimization of condition for grinding of pellet. Particle-size distribution of mineral powder was analyzed with particle size analyzer (Mastersizer 2000, Malve, UK).

2.2.2. Physical property analysis and microstructure observation

The physical properties of mineral packing and normal packing films, including relative humidity transmission rate, oxygen transmission rate and tensile strength were measured using gas transmission rate analyzer (BT-3, TOYOSEIK, Tokyo, JAPAN), water permeability tester (W 3/61MA, Mocon, USA) and universal testing machine (WL2100, WITHLAB, Anyang, KOREA), respectively. The microstructure of materials was observed using a scanning electron microscope (JEOL JSPM 100 electron microscope, Kanagawa, JAPAN).

2.2.3. Color index

Skin color was evaluated on samples of 10 fruits per treatment with a chroma meter (CR-400 series, KONICA MINOLTA SENSING. Inc., Osaka, JAPAN) and average readings at four points on the circumference of persimmons and tomatoes were recorded. L, a, b Hunter parameters were measured and the results were expressed as a skin color index as described by Jimenez-Cuesta et al. (1981).

$$\text{Color index} = 1000a/(L \cdot b)$$

2.2.3. Firmness

Firmness was determined with a texture analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, UK) using an 8 mm diameter disk. Fruit firmness values were the average of 6 fruits per treatment. The firmness of pericarp tissue was evaluated by measuring the maximum penetration force. Firmness was measured at the junction of the outer pericarp at the middle of inverted fruits. The results were expressed as load (kg/cm^2) to break the flesh in each fruit on opposite sides.

2.2.4. Total soluble solids (TSS)

Tissues from 6 fruits were homogenized using a blender (Super Mill HM-180, HIBELL, Hwasung, KOREA) for the determination of total soluble solids. The mixture was collected to measure total soluble solids using a refractometer (PR-100a, ATAGO, Tokyo, JAPAN), and the results were expressed as Brix°

2.2.5. Assessment of banana quality

Assessment of peel spotting A digital camera was used to capture the image of banana skin. Total surface area and area of spotted peel were calculated using Image J program (National health institute, Maryland, USA). The peel spotting (%) was calculated as follow:

$$\text{Peel spotting}(\%) = \text{area of spotted peel} \,/\, \text{area of total surface} \times 100$$

Figure 1 was showed process to calculate the area of peel spot.

Pulp to peel ratio Pulp and peel were separated and weighed individually.

And the pulp to peel ratio was expressed:

$$\text{Pulp/peel ratio} = \text{Pulp weight} / \text{Peel weight}$$

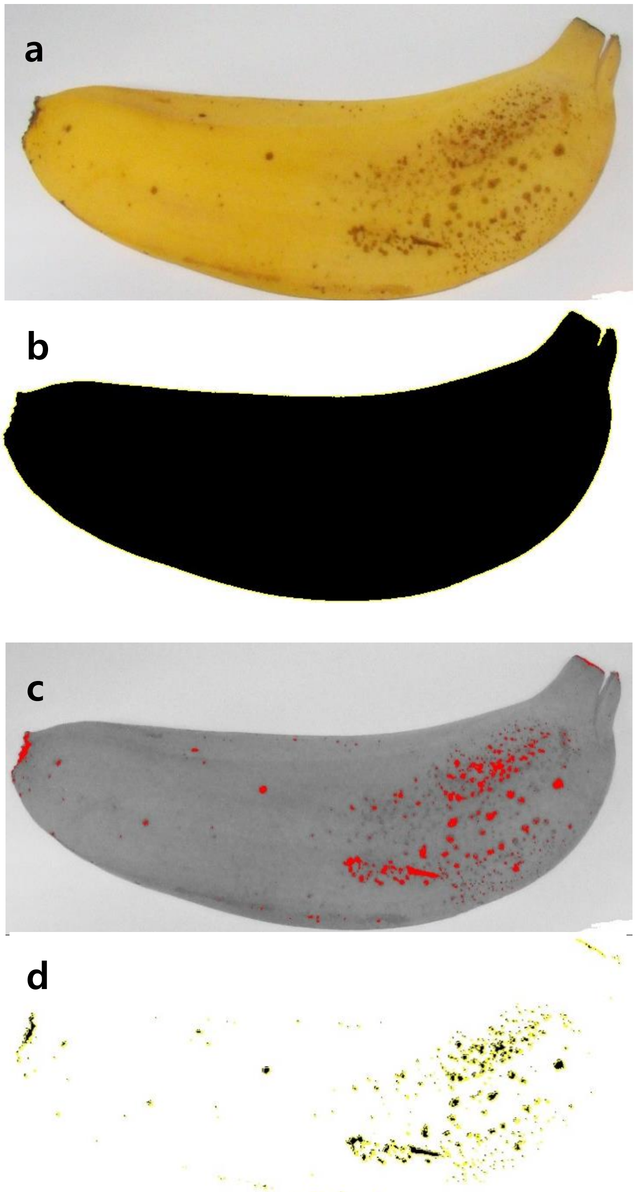

Figure 1. Process to calculate the area of peel spot. (a) Total surface area of peel (b) Calculated total surface area (c) Selected area of spotted peel (d) Calculated area of spotted peel

3. RESULTS AND DISCUSSION

3.1. Determination of conditions for grinding of pellet

Particle-size distribution of pellet before grinding was showed as Figure 2 (D_{50} = 12.5 μm, D_{max} = 631.0 μm). Table 2 and Figure 3 showed the particle-size distribution according to the pellet input rate. While the input of pellet increased, efficiency of grinding was decreased and particle size was gradually increased. The optimal particle size for making as commercial packing film was about 3 μm. 0.45-0.91 kg of the input of D_{50} value was respectively 3.23 μm, 3.40 μm. Therefore 0.45 kg and 0.90 kg inputs of pellet seem to be appropriate for grinding condition. Figure 4 was showed the microstructure of mineral powder by scanning electron micrographs (SEM). The particle size was too big to manufacture plastic film above 0.90

kg of inputs, and was too little to make the film below 0.45 kg of inputs. Accordingly in case of 0.45 kg and 0.90 kg of inputs, the appropriateness of the particle size was verified visually.

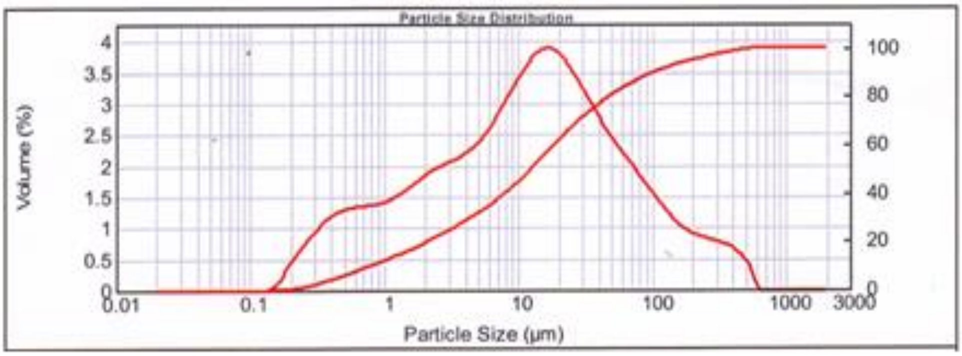

Figure 2. Particle-size distribution of mineral pellet

Table 2. Particle-size distribution of the mineral powders prepared with various inputs.

Pellet input rate (kg/hr)	Particle Size(㎛)		
	D_{50}	D_{90}	D_{max}
0.23	2.87	6.98	45.71
0.45	3.23	7.71	45.71
0.90	3.40	8.50	26.30
1.80	4.01	10.19	30.20
2.70	4.60	12.40	69.18

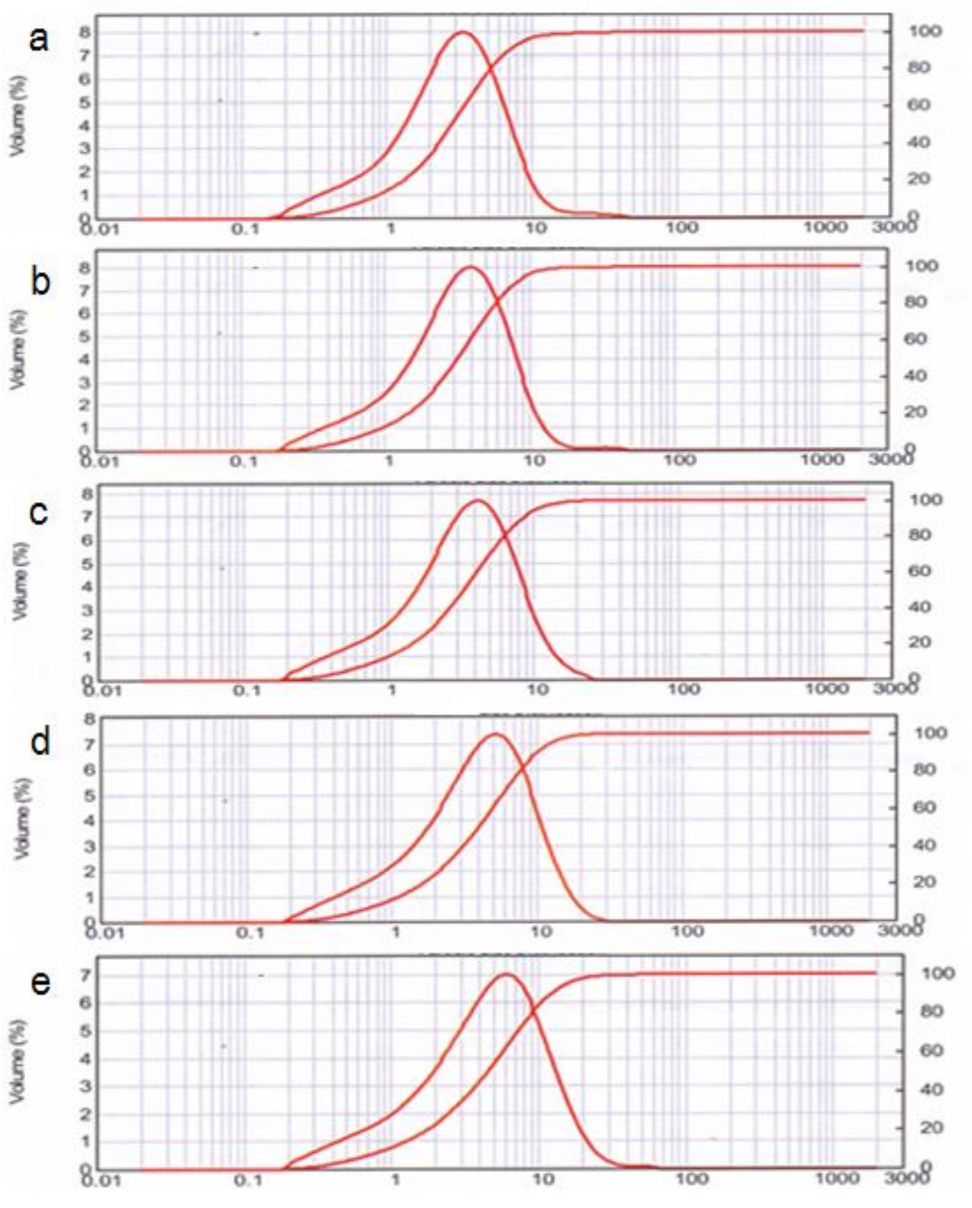

Figure 3. Particle-size distributions of mono-dispersed composite pellet in inputs per hours. (a) 0.23 kg, (b) 0.45 kg, (c) 0.90 kg, (d) 1.80 kg and (e) 2.70 kg

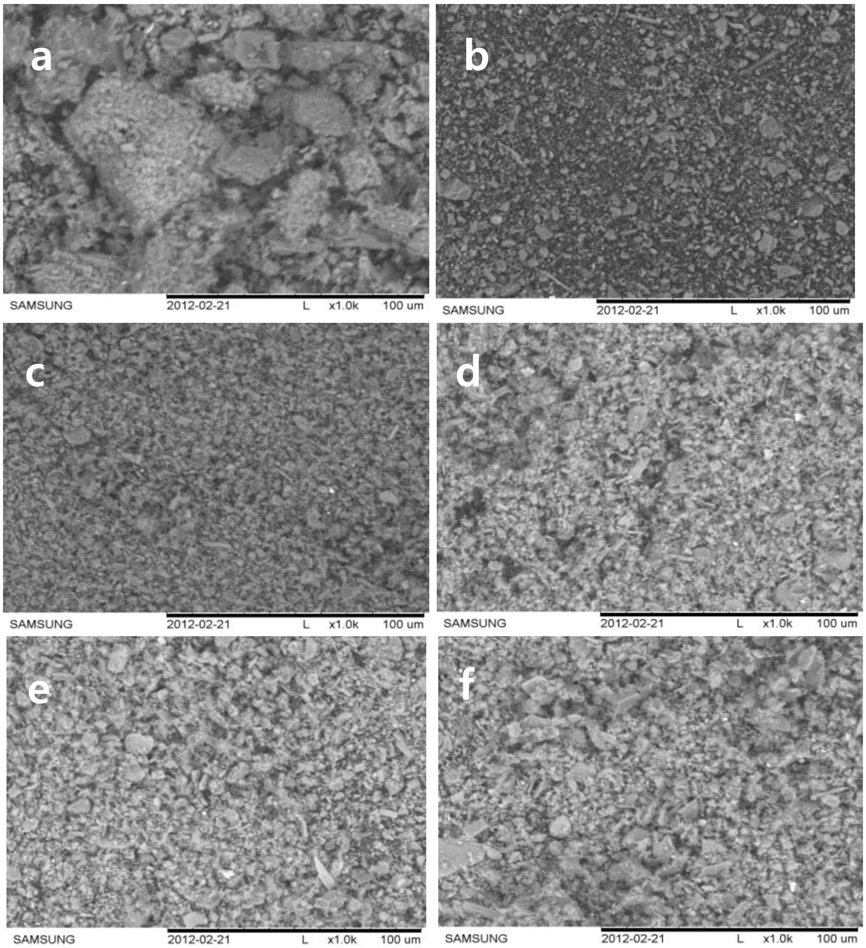

Figure 4. SEM micrographs of the mineral powder. (a) raw material, (b) 0.23 kg, (c) 0.45 kg, (d) 0.90 kg, (e) 1.80 kg, (f) 2.70 kg.

3.2. Improvement of opacity of mineral film

HAP-2 was almost as transparent as normal plastic films on the market. HAP-3 added 0.5 wt% of hydroxyl apatite was improved about 25% as compared with control (control was added 3.0 wt% of mineral powder and wasn't added hydroxyl apatite) and HAP-1 added 1.25 wt% of hydroxyl apatite was improved about 50% as compared with control (Figure 5). Table 4 showed effect of packaging on decay rate of mandarins packed with control (without packaging), HAP-1, HAP-2 and HAP-3. As the results, fruits with HAP-3 manufactured with 97.0 wt% polypropylene, 0.5 wt% HAP and 2.5 wt% mineral powder were significantly lower than decay rate of other samples. The result verified that HAP-3 film was effective for improvement of transparency and preventing of decay. Figure 6 showed distribution of mineral powder on surface of HAP-3 and the mineral powder in HAP-3 film was dispersed uniformly without lump.

Table 3. Effect of packaging on decay rate of mandarin fruits packed with control (without packaging), HAP-1, HAP-2 and HAP-3 for 7 days

Sample	Decay rate(%)
HAP-1	10
HAP-2	85
HAP-3	0
Control	90

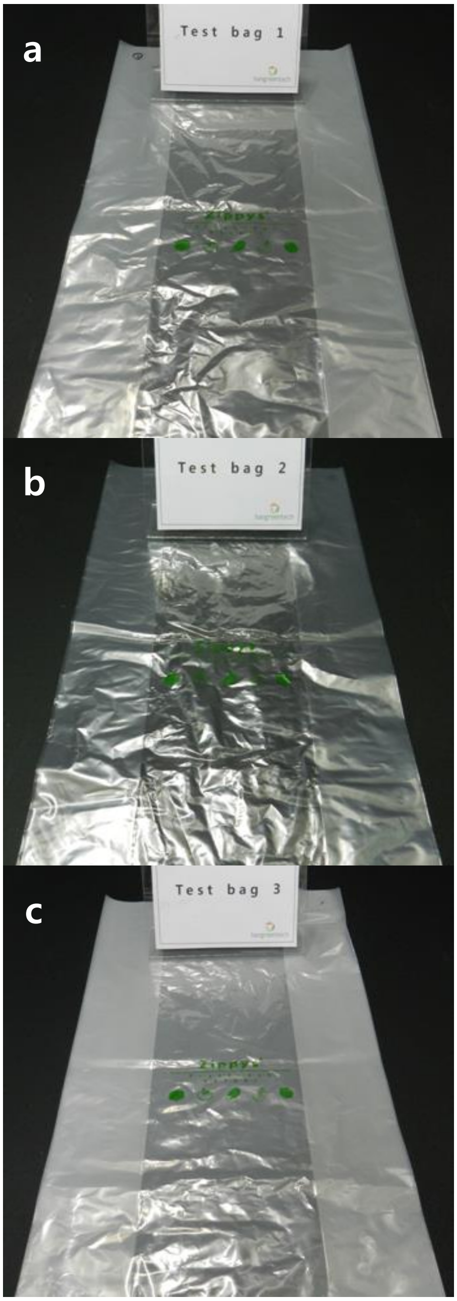

Figure 5. Pictures of (a) HAP-1, (b) HAP-2 and (c) HAP-3

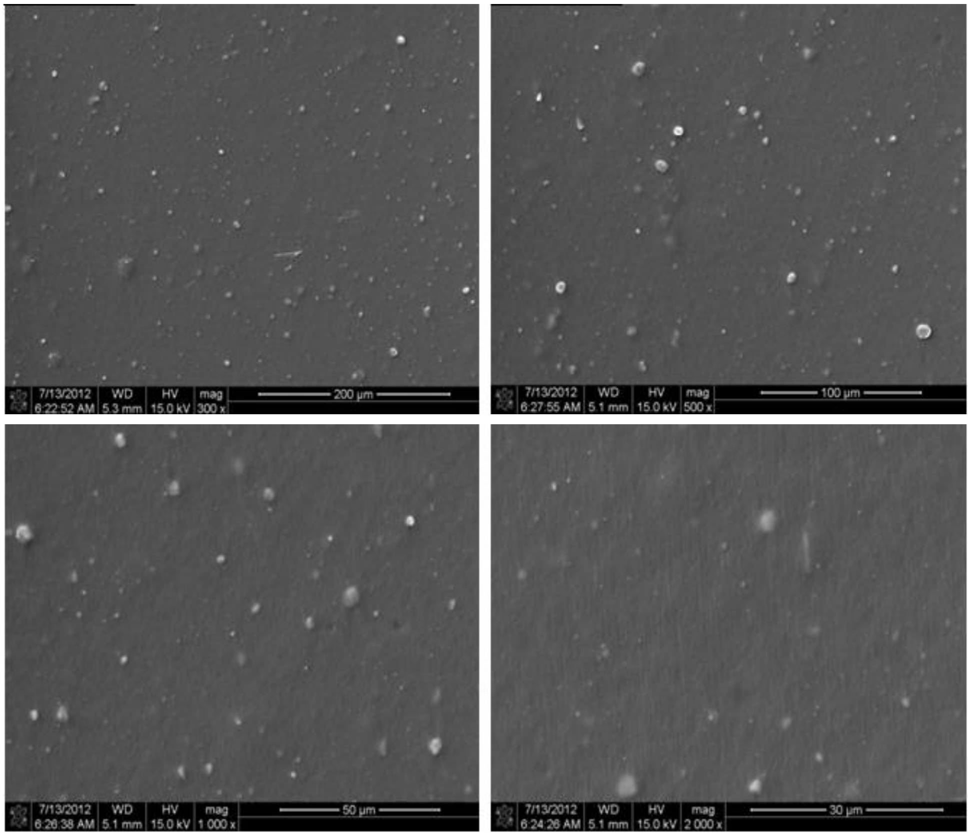

Figure 6. SEM micrographs of HAP-3 film formulated as 2.0 wt% of mineral powder

3.3. Physical properties

The physical properties of mineral and normal materials are shown in Table 4. The transmission rates of water vapor and oxygen of mineral packing film were 5.4 g/(m^2·24 h) and 2100 cm^3/(m^2·24 h·atm), respectively, which were decreased by 26.0% and 41.7% compared with those of PE film. The tensile strength of mineral packing material was 1.25 fold higher than that of PE packing material. These results indicated that the mineral film possessed better barrier and mechanical properties.

Table 4. Physical properties of PE film and mineral film.

	Relative humidity transmission rate (g/m^2 24h)	O_2 Transmission rate (cm^3/m^2 24h atm)	Tensile strength (N/cm^2)
PE packing	7.3	3600	1737
Mineral packing	5.4	2100	2170

3.4. Fruit quality assessment

3.4.1. Persimmon

3.4.1.1. Color

After storage, the color index increased with respect to the color at harvest. The results showed that color index was affected by packing films (Figure 7). Fruits without packaging showed the largest increase as compared with color index value of packaging fruits during 1 week, and then maintained same color since 1 week. Fruits packed with normal packing films for 3 weeks exhibited slightly an increase in color index as compared to freshly-harvested fruit, whereas fruits packed with mineral packing film maintained its initial color for longer time. Figure 8 showed persimmons after storage time. The control (without packaging) developed more dark orange color than other samples and was starting to go rotten. Although the fruits packaged with PE film showed a little dark orange color, they didn’t decay at all. The fruits in mineral film had the lightest orange color and kept good condition. The results show that mineral packing film provided a beneficial effect on the color index of persimmon.

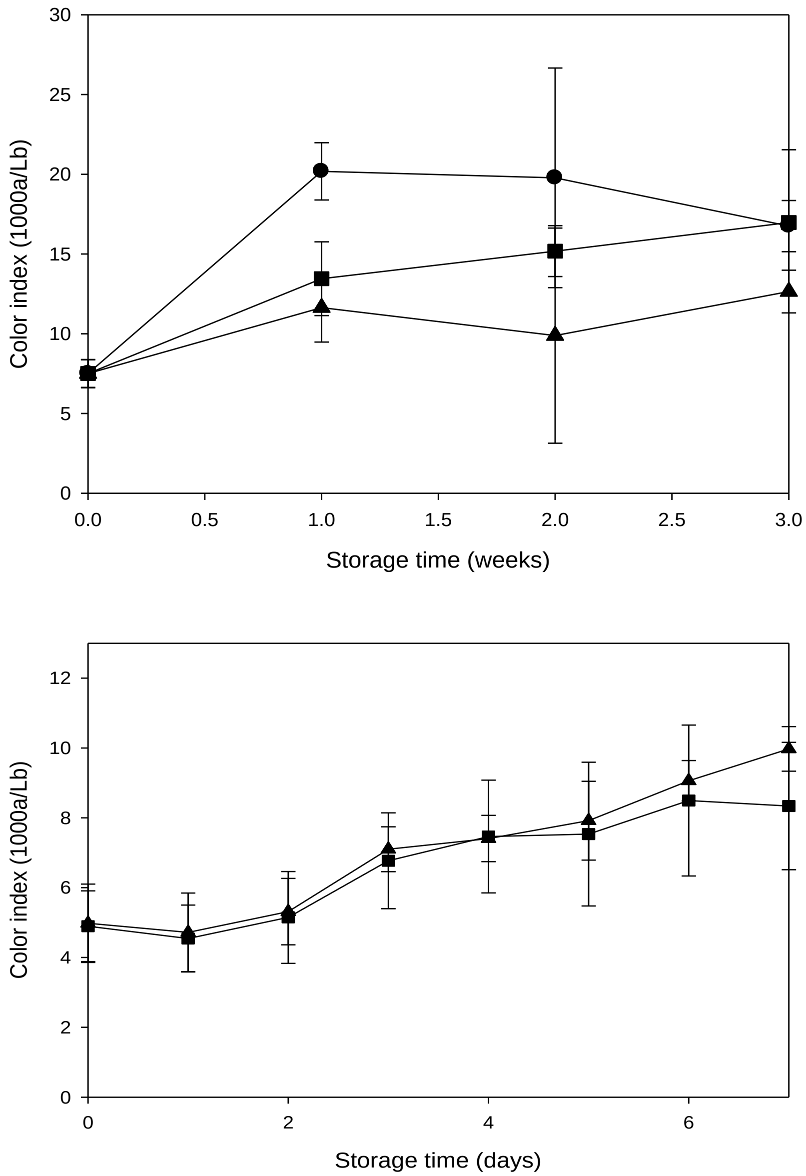

Figure 7. Effect of packaging on skin color index of persimmon stored at 25℃ and packed with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

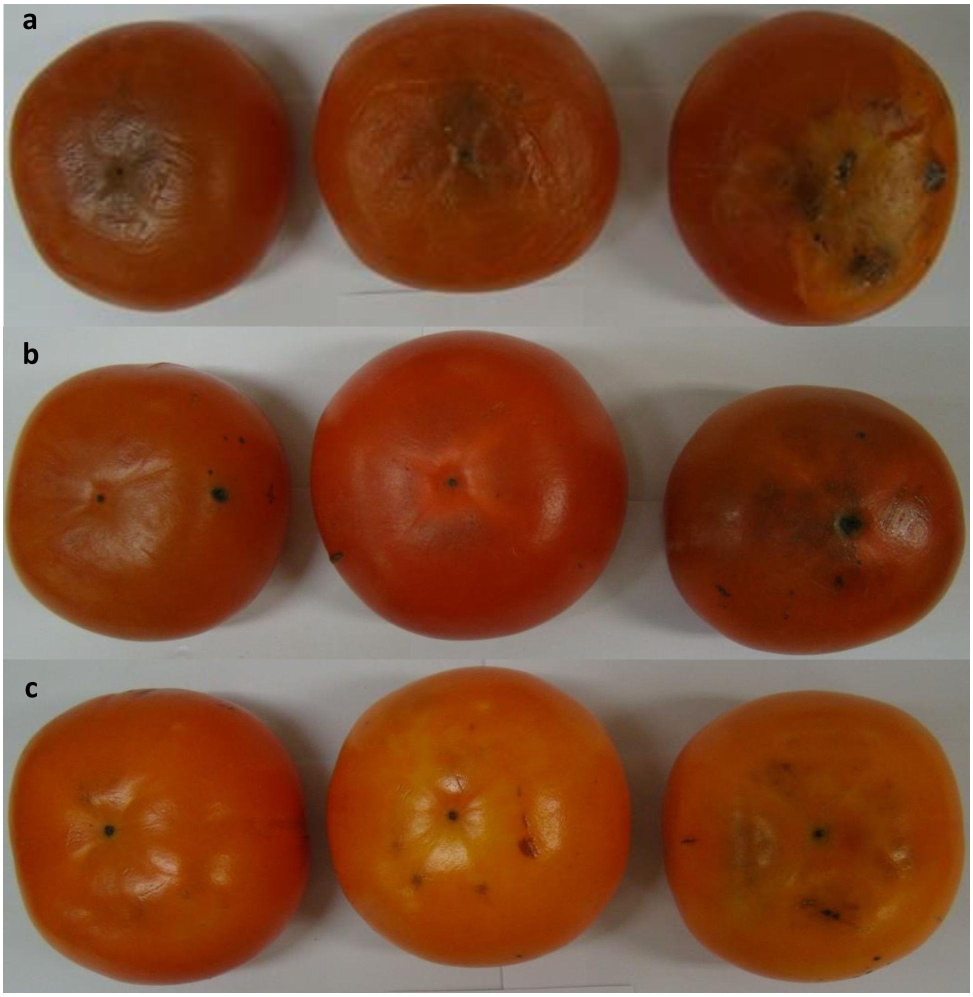

Figure 8. Pictures of persimmon packaged with (a) control (without packaging), (b) PE film, (c) mineral film after 3 weeks.

3.4.1.2. Firmness

The most perceptible changes occurring in fruits during prolonged storage are texture loss and changes in appearance, and these changes are related to metabolic changes and water content. The rate and extension of firmness loss during ripening of soft fruits, such as persimmon, is one of the main factors that determine fruit quality and postharvest shelf life [18]. Fruit softening is attributed to the degradation of cell wall components, mainly pectins, due to the action to specific enzyme activity such as polygalacturonase [19]. As shown in Figure 9, firmness of all persimmons, with different packing, continuously decreased within 3 weeks of storage at room temperature, during which the PE film group decreased more rapidly and reached a value of 3 weeks. Meanwhile, firmness of the mineral film group exhibited the value of 80.13 g_f. This showed that mineral packing delayed the decline of firmness and had a beneficial effect on firmness retention.

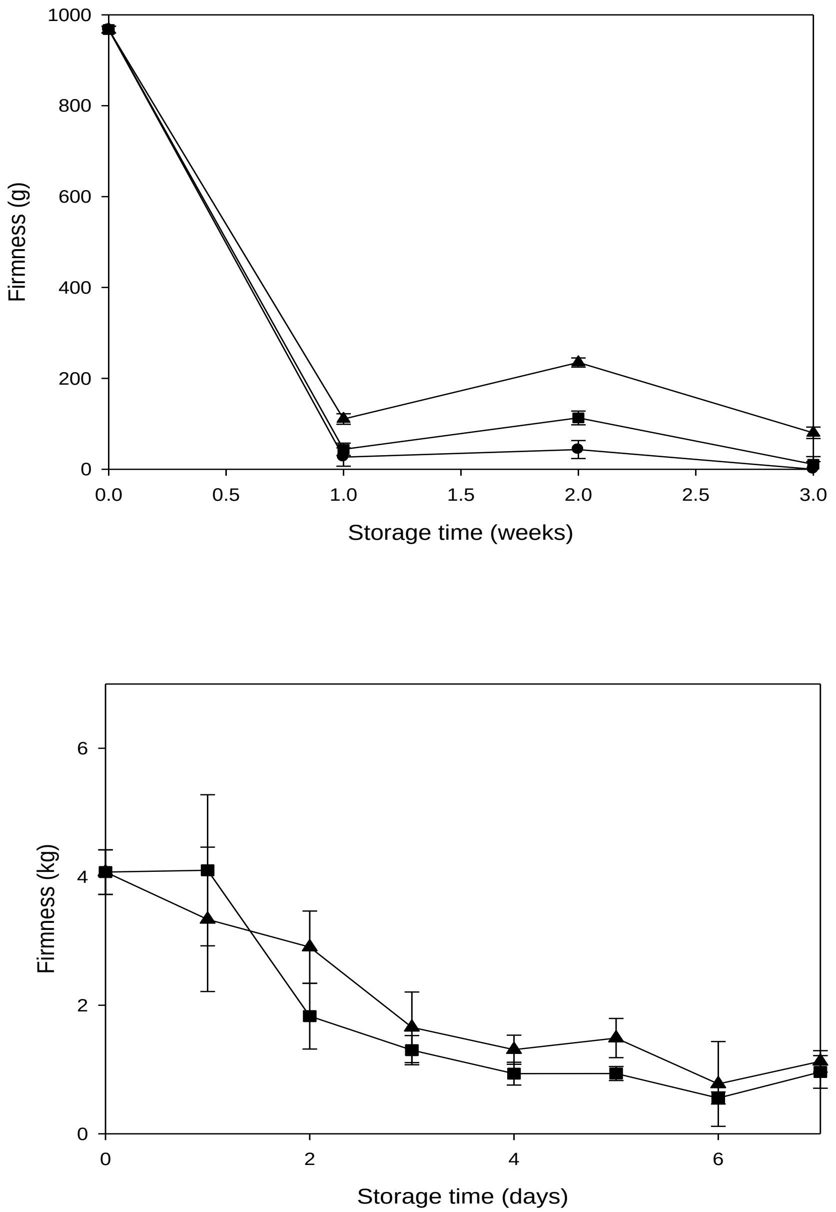

Figure 9. Effect of packaging on firmness of persimmon stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

3.2.1.3. Total soluble solid (TSS)

The total soluble solid changes in fruits are related to the metabolic changes (respiration process) that increase the reducing sugar content and the fruit sweetness during storage [20].

Total soluble solid of persimmons rapidly increased until 7 days of storage time, but was remained steady through the rest of storage time (Figure 10). Control fruits presented the greater increase in total soluble solids until 7 days, while fruits packaged with PE and mineral film showed rapidly rise during 7 days. Different behavior was observed between fruits packaged with PE and mineral films, since TSS value of fruits packaged with mineral film increased through storage time.

The results showed that control fruits presented a maturation development more pronounced that packaged fruits, and this occurred because these fruits were stored without any protection against the external atmosphere [20]. Compared to control fruits, PE and mineral films were effective in retardation of the metabolic process, and the better behavior of mineral film probably because mineral film acts as a better barrier against oxygen permeation than PE film.

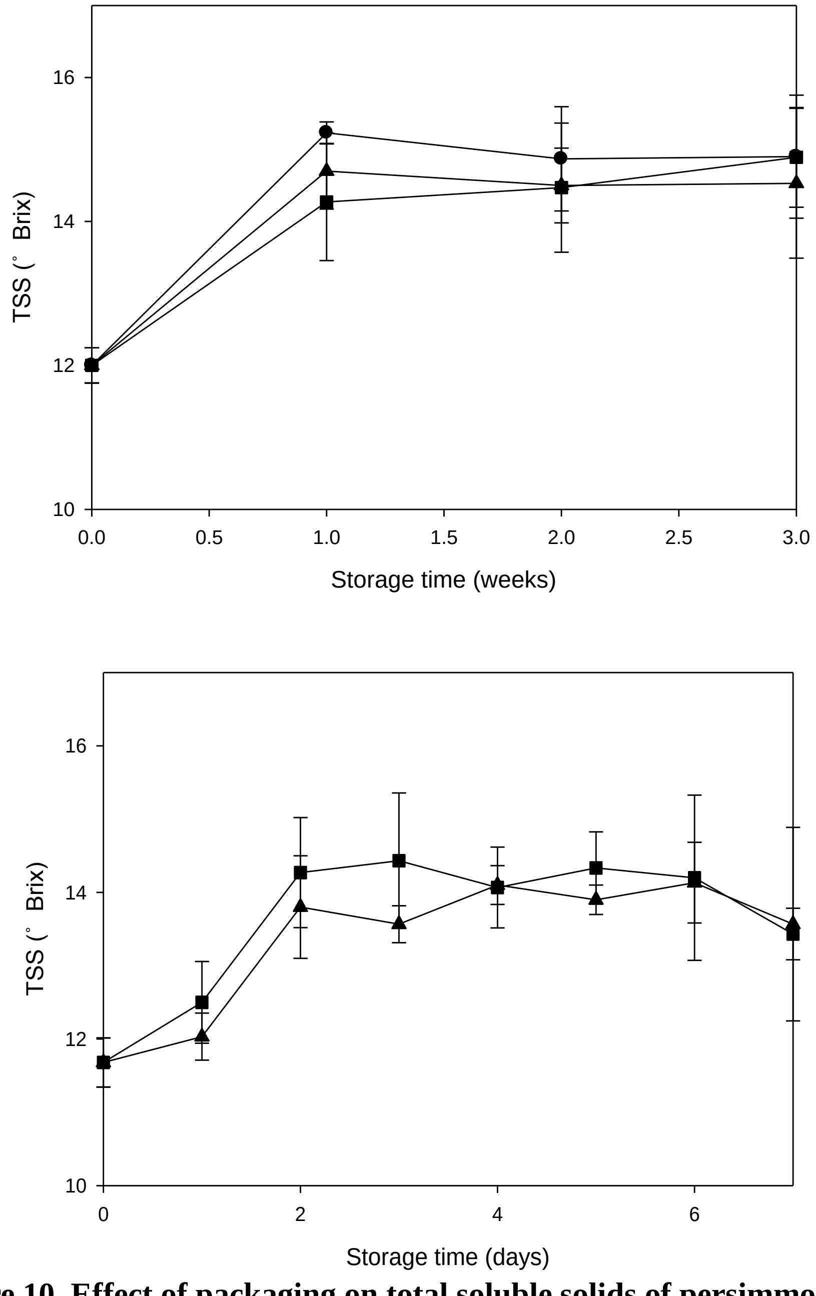

Figure 10. Effect of packaging on total soluble solids of persimmon stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

3.4.2. Tomato

3.4.2.1. Color

The color index increased with storage time (Figure 11). Unwrapped tomatoes changed color rapidly over the first week of storage and then at a slower rate over the next 2 weeks and remained the same color after that. Tomatoes stored in packing films changed rapidly during 7 days and changed color more slowly especially in mineral film as compared with the tomatoes packaged with PE film after 7 days. Figure 12 was pictures of tomatoes packaged control (without packaging), PE film and mineral film after 3 weeks. Tomatoes without packaging and packaged PE film showed many rotted spots on the fruit surface, in contrast, tomatoes in mineral film hadn’t decayed spot. The results showed that mineral film provided a beneficial effect on the color index of tomato.

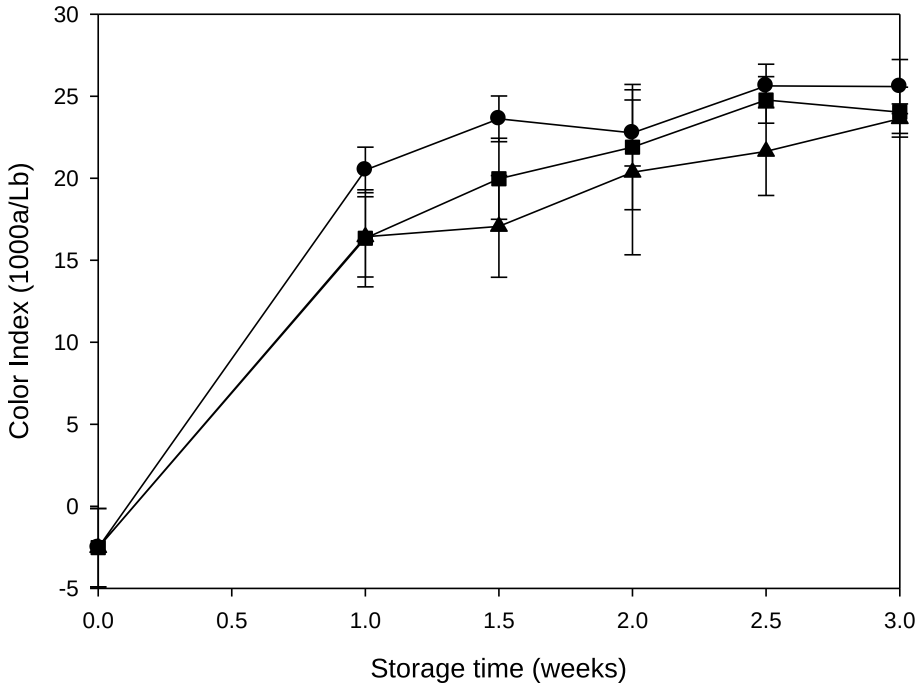

Figure 11. Effect of packaging on color index of tomato stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

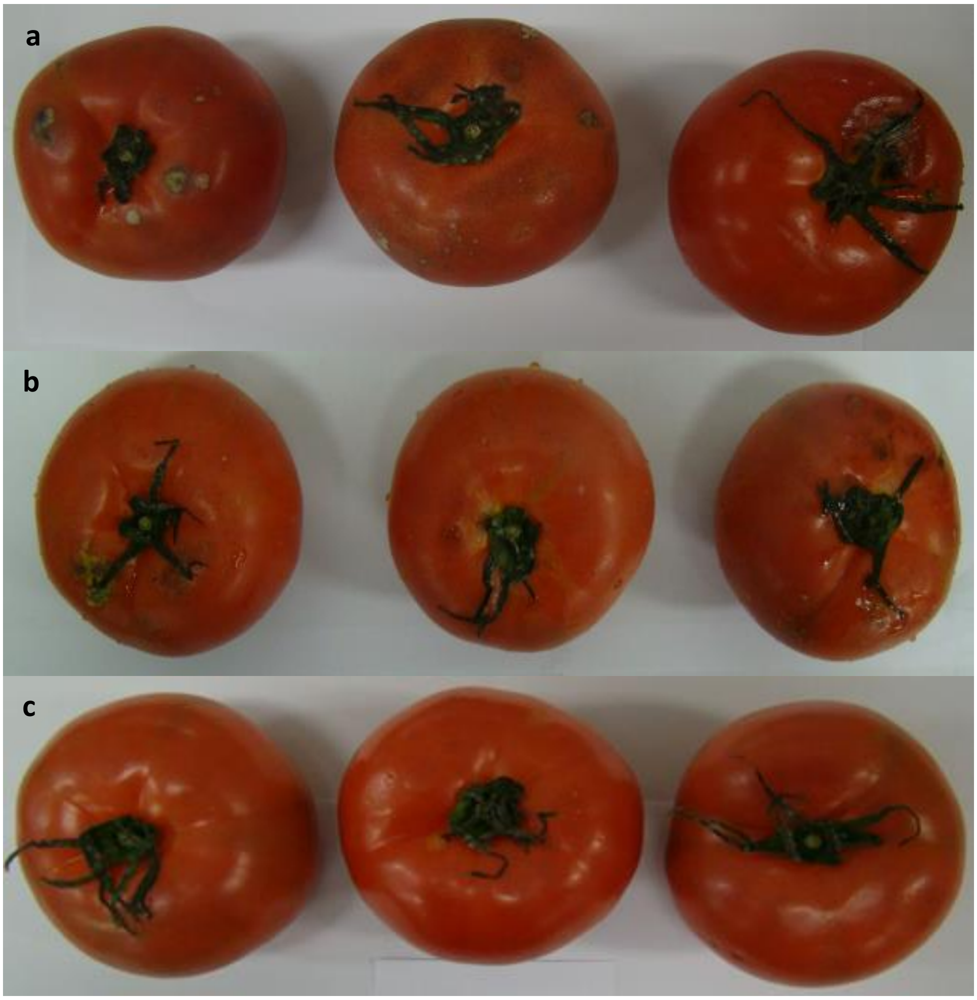

Figure 12. Pictures of tomato packaged with (a) control (without packaging), (b) PE film, (c) mineral film after 3 weeks.

3.4.2.2. Firmness

Tomatoes softened progressively during storage, but those sealed in film softened significantly more slowly than those stored unwrapped during 1.5 weeks (Figure 13). However after 1.5 weeks all tomatoes reached their minimum firmness. Although the film wrapped fruits tended to be softer than the unwrapped fruits, there was no significant difference. As the results, mineral film delayed the decay of firmness and had a beneficial effect on firmness retention.

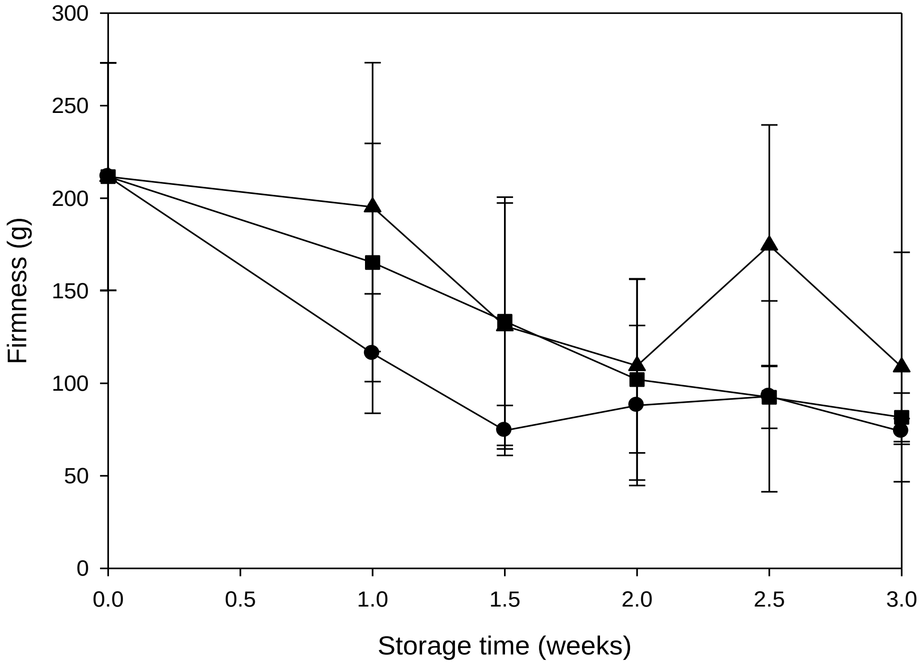

Figure 13. Effect of packaging on firmness of tomato stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations

3.4.2.3. Total soluble solid (TSS)

The results showed no significant changes in the amount of TSS both packaging group and control group (Figure 14). The range of TSS for all groups was 3.5~4.0%. There were no significant differences between the three groups. The same trend of no significant changes has been reported for 2 weeks [21] and 10 days [22]. The result showed that PE film and mineral film hadn't that much effect on retention of TSS.

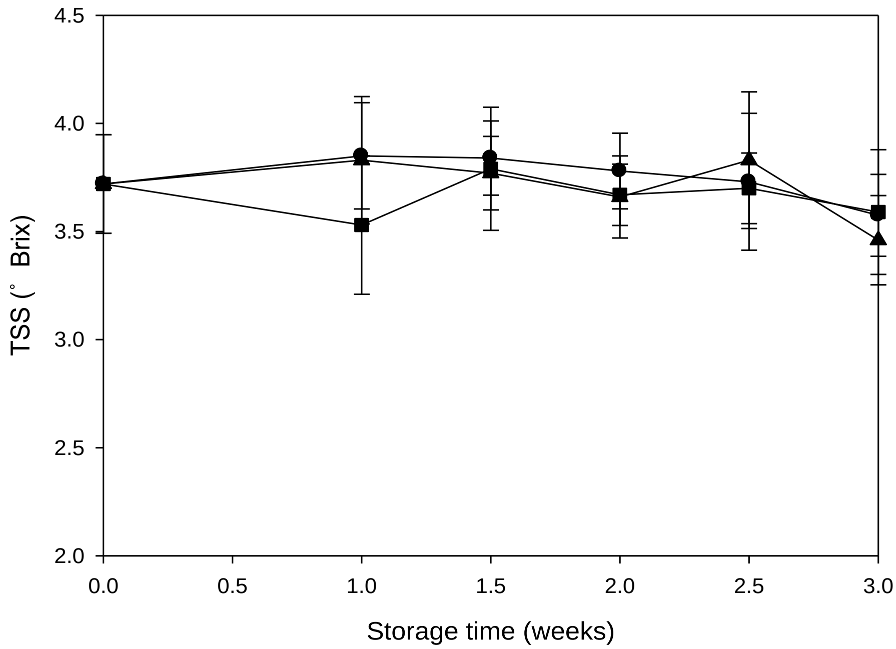

Figure 14. Effect of packaging on total soluble solids of tomato stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

3.4.3. Banana

3.4.3.1. Development of peel spotting

The results obtained for the peel spotting are shown in Figure 15. At the start of the experiment, the banana peel did not show any spotting. During ripening there was a gradual change in peel spotting. In control group, peel spotting rapidly increased from 0 to 5 days. But there was no change in packaging groups for same period. Compared to the control bananas, PE and mineral films were effective in retardation of the metabolic process. However there were no significant differences between PE film and mineral film in inhibiting of spotting development. Although the mineral film had not better effect than the PE film, both mineral film and PE film had a beneficial effect on prevention of peel spotting. Figure 16 was pictures of peel spotting before calculating area of spotting.

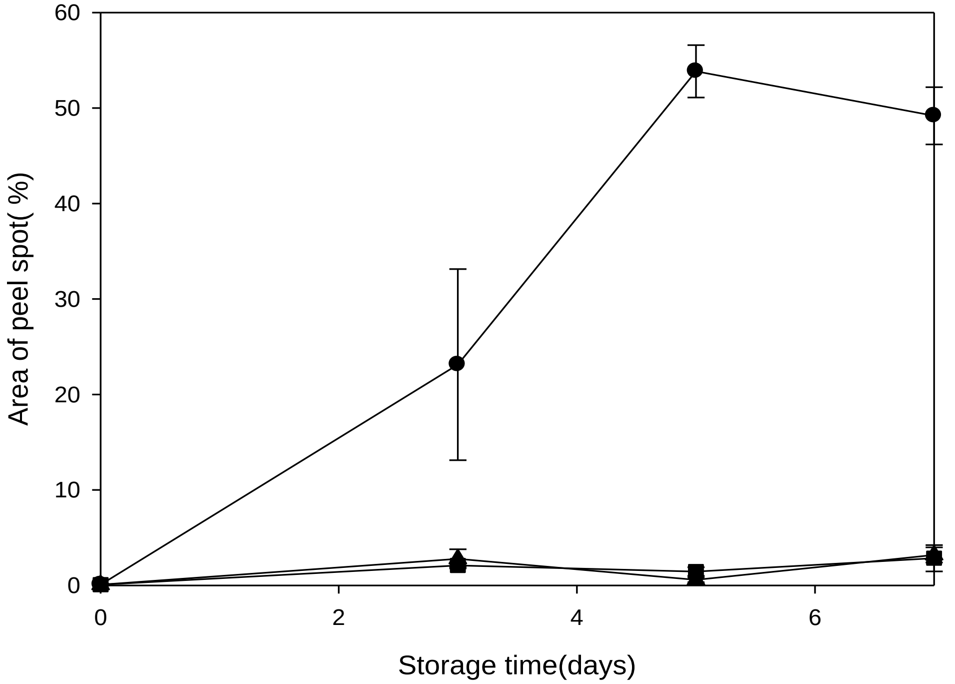

Figure 15. Effect of packaging on area of peel spot of banana stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

Figure 16. Pictures of banana packaged with (a) control (without packaging), (b) PE film, (c) mineral film after 7 days.

3.4.3.2. Pulp to peel ratio

Pulp to peel ratio was significantly increased throughout the ripening period (Figure 17). Significant difference was observed on the pulp to peel ratio of banana fruits between control and packaging groups. Bananas packaged with films were maintained lower value of the pulp to peel ratio than control. Control showed significantly higher pulp to peel ratio throughout the 7 days of storage than the pulp to peel ratio of bananas packaged with PE and mineral film. PE groups showed a little higher pulp to peel ratio throughout the 5 days of storage than the pulp to peel ratio of bananas packaged with mineral film. The result showed that mineral film provided a beneficial effect on the retention of pulp to peel ratio.

Pulp to peel ratio of bananas could be due to the loss of water from the peel to the atmosphere and to the pulp. The ratio of pulp to skin is largely governed by water relations of the fruit. The ratio is about 1.2-1.6 in green fruit and it may rise to 2.2-2.6 at advanced ripeness 3 and above in rotting fruit after prolonged storage [13]. The rise in pulp to peel ratio is related to changes in sugar concentrations in the two tissues. Sugar increased more rapidly in the pulp than in the skin and this difference is reflected in a differential change in the osmotic pressure. The consequence is that water is withdrawn from the skin by pulp and the pulp to peel weight ratio changes accordingly [23]. The same finding was reported by Simmonds (1959) [23], M. Hailu (2012) [12]. In the present study, the mineral film could be verified that it maintained loss of water from peel to atmosphere and inhibited changes in sugar concentrations in pulp and peel.

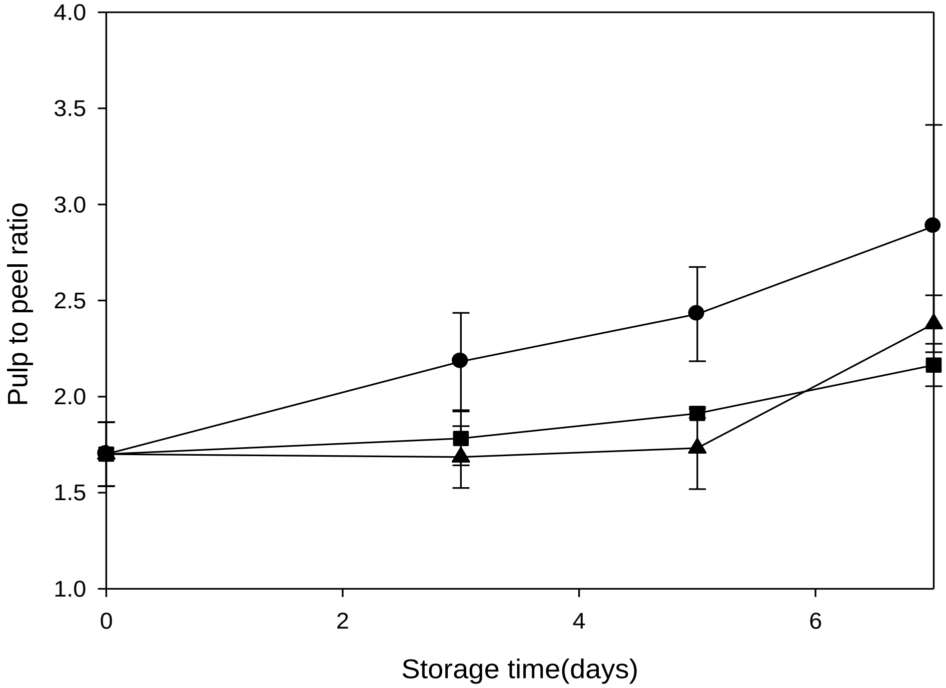

Figure 17. Effect of packaging on pulp to peel ratio of banana stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

3.4.3.3. Firmness

The changes in fruit firmness of banana were illustrated in Figure 18. It is certain that the bananas packaged with the mineral film decreased firmness towards the end of storage period compared to the bananas packaged with PE films. However, untreated fruits (without packaging) maintained higher firmness than the fruits packaged with films. The result showed that the films had a negative impact on fruit quality of banana. Because the film was inhibited water vapor transmission and oxygen transmission, water vapor from the banana was condensed into water on the film. The water could decrease firmness of banana. Therefore the fruits of high respiration rate and ethylene emission were improper to packaging with the films. To improve water vapor transmission of the film may resolve this problem.

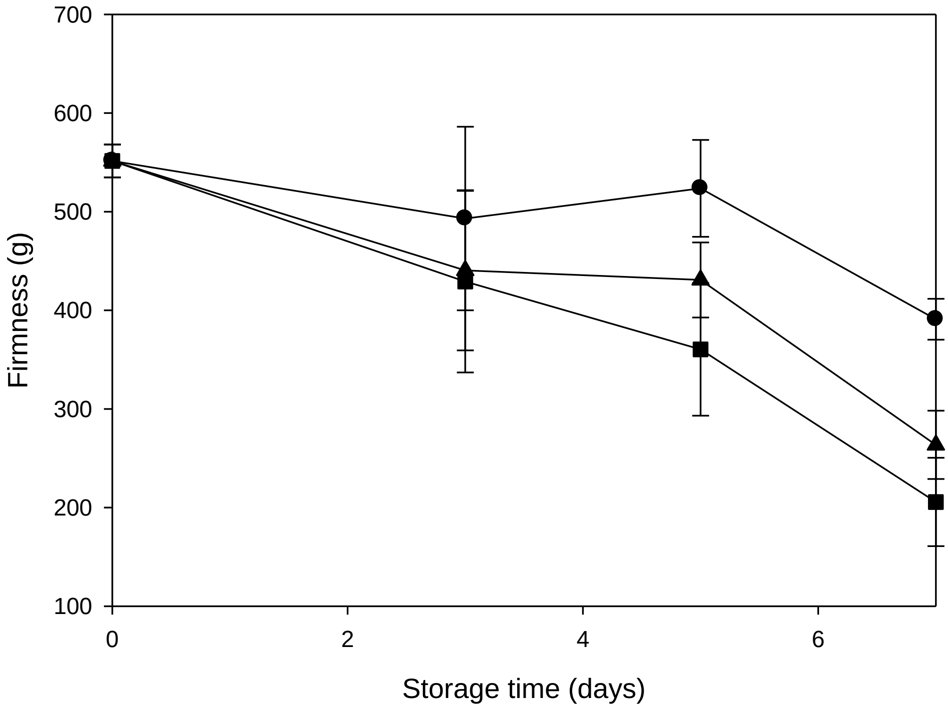

Figure 18. Effect of packaging on firmness of banana stored at 25℃ and packaged with (●) control (without packaging), (■) PE film and (▲) mineral film. Error bars indicate standard deviations.

Conclusion

A mineral film with higher barriers of water vapor and gas transmission, and mechanical properties was successfully synthesized and then were applied to the preservation of persimmon, tomato and banana during storage. The results showed that the persimmon and tomato with mineral film inhibited increasing of color index and total soluble solid, and maintained the firmness. But the banana fruits with mineral film didn’t inhibit increasing of peel spotting and pulp to peel ratio. The mineral film was inappropriate to the fruits with high respiration rate and ethylene production such a banana because of its high resistance of the transmission of vapor and gas. Although the mineral film had not beneficial effects on bananas, for the others it was highly effective compared to PE film. Also, the mineral films have the advantages of simple processing and feasibility to be industrialized in contrast with other storage methods, some of which are time-consuming and high-cost. Therefore, the mineral films may provide an attractive alternative to keep the quality of climacteric fruits during extended storage. Nevertheless, it should be noted that this research was exploratory in nature. More research will be needed to elucidate the definite mechanism that mineral film functions during storage to facilitate the application of packaging technology in a broader range in the future.

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국문 초록

신선 과일의 부패를 예방하기 위한 기능성 포장재의 필요성이 증가되고 있다. 폴리에틸렌 필름은 가장 흔하게 사용되는 포장재로 저렴한 가격과 다양한 형태로 변형이 용이하며 투명성과 가벼운 장점으로 많은 이점을 가지고 있다. 그러나 폴리에틸렌 필름은 유리나 금속 포장재와 비교하여 산소와 수분 투과율이 높아 신선 식품을 장기간 보관하기 어려운 단점을 가지고 있다. 따라서 미네랄 파우더를 첨가한 새로운 기능성 포장재는 이러한 폴리에틸렌 필름의 문제점을 극복하고자 제안되었다. 미네랄 파우더의 분쇄는 미네랄 필름의 성형에 가장 중요하다. 그래서 본 연구에서는 미네랄 파우더의 분쇄를 위해 자가분쇄방법이 사용되었다. 미네랄 파우더의 분쇄를 위한 최적화된 투입량은 0.45 kg/h 와 0.91 kg/h 였

다. 또한 미네랄 파우더가 유색을 띄어 미네랄 필름의 투명성이 감소하는 문제점을 가지고 있었다. 이러한 포장 필름의 불투명성은 소비자의 사용에 불편함을 주게 될 수 있어 불투명성을 개선시키고자 수산화아파이트를 사용하였다. 수산화아파이트 0.5 wt%와 미네랄 파우더 2.5 wt%를 첨가한 HAP-3은 불투명성 개선에 가장 효과적이었다. 이렇게 제작된 미네랄 필름의 상대습도와 산소 투과도는 각각 5.4 g/(m^2·24 h), 2100 cm^3/(m^2·24 h·atm)였으며 이 수치는 폴리에틸렌 필름과 비교하여 각각 26.0%, 41.7% 감소한 값이었다. 그리고 미네랄 필름의 경도는 폴리에틸렌 필름보다 약 1.25 배 높았다. 신선 과일의 저장에 있어 미네랄 필름의 효과를 확인하기 위해 감과 토마토, 바나나를 시료로 선택하였다. 결과도적으로 감과 토마토의 색도, 단단함과 총용해성고형물질의 보존 정도는 폴리에틸렌 필름보다 나은 양상을 보였다. 결과적으로 미네랄 포장재는 폴리에틸렌 필름보다 과일의 감각적, 생화학적 품질을 유지하는

데 효과가 있었다. 이 결과는 비교적 낮은 수분 투과도로 설명될 수 있다. 낮은 수분 투과가 저장 기간 동안 미네랄 필름이 수분과 가스 투과를 방해하기 때문이다. 그러나 바나나의 껍질의 반점과 과육과 껍질의 비율의 결과를 보면 폴리에틸렌 필름과 큰 차이를 보이지 않는다. 관련 연구들에 따르면, 바나나는 후숙 과일 중에서도 보다 높은 호흡률을 가지며 많은 에틸렌 가스를 발생해 만들어진 미네랄 필름과 같이 가스 차단성을 높인 포장재는 부정적인 영향을 미치게 된다. 추후에는 저장 기간 동안의 미네랄 포장재의 기능에 대한 확실한 매커니즘에 대한 깊은 연구를 통해 보다 넓은 범위의 포장 기술의 적용이 요구된다.

주요어: 광물질, 포장재, 광물질 필름, PE 필름 감, 토마토, 바나나, 품질변화