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Research article

Effect of packaging systems on dried shrimp quality and storage stability as visualized using pattern recognition

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Abstract

Importance of the work: Dried shrimp in a conventional polypropylene bag has a short shelf life, causing food waste and retail loss. Hence, an effective packaging system is required to maintain product quality and extend the shelf life.

Objectives: To investigate the effects of different packaging systems on the quality of dried shrimp.

Materials and Methods: Dried shrimp samples were packaged in four different systems: polypropylene under atmospheric air (PP), polyamide-laminated (PA) film under vacuum (PA+V), polyamide-laminated film with an oxygen scavenger (PA+OS) and aluminum-laminated film under vacuum (AL+V). The packaged dried shrimp was monitored for changes in astaxanthin, thiobarbituric acid, water activity, color, hardness and organoleptic quality during storage for 12 wk. Linear discriminant analysis (LDA) was used for pattern recognition and data classification.

Results: The four types of packaging system produced different quality levels of the product. PA+OS was the best at preserving astaxanthin, retarding lipid oxidation, maintaining color and extending the shelf life of the dried shrimp, followed by AL+V, PA+V and PP, respectively. Oxygen scavenging was more effective at reducing the residual oxygen in the package than vacuum packaging. The LDA-based pattern recognition could visualize the effect of different packaging systems on the overall quality of the dried shrimp.

Main finding: PA+OS provided much better protection than the other types of packaging. The longer shelf life of this product should not only motivate more sales with less retail waste but also enhance product exportation.

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Introduction

Dried shrimp is widely used as an ingredient in various food products in Thailand and Asia (Hu et al., 2021). Orange-red color and a smoky flavor are desirable quality attributes of dried shrimp and have a direct effect on its price (Hosseinpour et al., 2013). Dried shrimp can be stored at room temperature for several weeks; however, dried shrimp is susceptible to color and odor deterioration and may become unacceptable to consumers following distribution and storage (Niamnuy et al., 2008; Hosseinpour et al., 2013; Castañeda-López et al., 2021). Dried shrimp products are usually packaged in transparent polypropylene (PP) bags to show their desirable appearance. However, PP has high oxygen permeability; thus, astaxanthin and some oxygen-sensitive compounds can react with oxygen leading to rapid quality changes (for example, discoloration and flavor loss); consequently, the currently available packaged dried shrimp often has a short shelf life causing substantial loss at the retail level and requiring greater waste management and disposal costs. Therefore, optimal packaging is required that can provide better protection, reduce food spoilage and extend the shelf life of the product.

Oxygen is the main factor causing changes in the color and odor of dried shrimp because shrimp contains polyunsaturated fatty acids and cholesterol that easily oxidized (Becerra et al., 2014; Gómez-Estaca et al., 2017; Dey and Neogi, 2019). Sampaio et al. (2006) found that the thiobarbituric acid-reactive substances (TBARS) values of salted-dried shrimp increased due to the oxidation of polyunsaturated fatty acids and cholesterol during distribution at the local market. Color changes in dried shrimp during storage have been reported to be due to the oxidation of astaxanthin, which is the main carotenoid pigment found in many types of seafood (Becerra et al., 2014) and has been reported to correlate with color of dried shrimp (Niamnuy et al., 2008). Packaging plays an important role in maintaining the quality and extending the shelf life of various food products. For example, the presence of oxygen in the headspace inside the package of food leads to a rapid quality degradation due to oxidation of fats or vitamins contained in food or by promoting the growth of microorganisms (Becerra et al., 2014; Castañeda-López et al., 2021). To inhibit undesirable processes in oxygen-sensitive food products, the food product should not be exposed to oxygen and any other factors that can lead to the deterioration processes (Dey and Neogi, 2019). Hence, the selection of an effective packaging system is crucial to maintaining product quality during distribution and storage. The most effective way to preserve the quality of oxygen-sensitive food products is by removing oxygen from the package headspace that can be achieved by using vacuum packaging, gas flushing, or active packaging. Vacuum packaging is a simple approach to eliminate oxygen in food packages. In an active packaging system, the product, package and its environment interact to maintain quality, improve safety and prolong shelf life more effectively than the conventional functions of passive packaging (Cichello, 2015; Devgan et al., 2019). Qiu et al. (2020) studied the effect of vacuum packaging on the astaxanthin concentration and lipid oxidation in terms of peroxide value and TBARS of semi-dried shrimp stored at refrigerated temperature and found that dried shrimp stored in vacuum packaging had a higher astaxanthin concentration and a lower lipid oxidation than that without vacuum packaging. They concluded that vacuum packaging could retard lipid oxidation and browning as a result of the astaxanthin degradation of the salted semi-dried shrimp.

Oxygen scavengers are the most used active packaging system. They are commercially available in forms of small sachets or labels to be inserted inside the package or as composite film or coating that interact with the oxygen inside the package (Devgan et al., 2019). Various oxidizable organic compounds can be used as oxygen scavengers, of which iron-based material has been the most versatile (Cichello, 2015). Oxygen scavengers can absorb oxygen trapped or dissolved in food products, oxygen in the package headspace or oxygen permeating through packaging material. As a result, they can be used to maintain the quality and extend the shelf life of oxygen-sensitive food products by preventing the food products from oxygen exposure (Cichello, 2015; Dey and Neogi, 2019).

Although vacuum packaging and oxygen scavengers have been commercially used for various packaged food products, the effects have never been reported of such packaging systems on the physical, chemical and sensory qualities of dried shrimp. Since various parameters must be considered to decide product quality, the determination of dried shrimp quality may become complicated. Therefore, pattern recognition can be used, which is a technique for extracting useful information from the complex data of multivariate analysis. With pattern recognition technique, visualization and classification of product quality based on various characteristics can be achieved. Furthermore, the pattern recognition technique can also be used to investigate how and to what extent each variable contributes to group separation.Hence, the current study investigated the effects of different packaging systems (commercially used packaging under atmospheric air, vacuum packaging, and oxygen scavenging) on the quality and storage stability of dried shrimp, with these packaging effects being visualized using pattern recognition.

Materials and Methods

Sample preparation

Dried shrimp (*Macrobrachium equidens*) was obtained from Phatthalung province, Thailand. The product contained 99% shrimp and 1% sodium chloride. Three different types of plastic bags (10 cm × 15 cm) were used, consisting of polypropylene (PP), linear low-density polyethylene (LLDPE)-laminated polyamide (PA), and LLDPE-laminated aluminum (AL). The thickness, water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) of the packaging films were tested at 25 °C and 75% relative humidity (RH) as shown in Table 1. PP is a common plastic film commercially used for packaging dried shrimp. PA was used in the current study because it has low oxygen permeability and is commonly used together with a vacuum condition or oxygen absorber for various food products. Furthermore, the transparency of PA allows consumers to see the appearance of the packaged food product. AL is opaque and has the lowest oxygen permeability.

Table 1 Thickness, water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) of polypropylene (PP), LLDPE-laminated polyamide (PA) and LLDPE-laminated aluminum (AL)

Film	Thickness (μm)	WVTR (g/m²×d)	OTR (cc/m²×d)
PP	77.40±1.50	57.25±2.63	635.52±24.41
PA	83.80±3.40	15.19±0.49	25.34±1.27
AL	92.40±3.50	~ 0	~ 0

Samples (50 g each) of dried shrimp were packaged in four different packaging systems: 1) PP under atmospheric air; 2) PA under vacuum condition; (PA+V); 3) PA with iron-based oxygen scavenger (PA+OS); and 4) AL under vacuum condition (AL+V). The oxygen scavenger (Best KEPT (S-50A); Alpine Foods Co., Ltd; Bangkok, Thailand) used in the current study was an iron-based powder packaged in a small sachet. The optimal oxygen scavenger was chosen based on the product characteristics and the oxygen level in the headspace and from permeation through packaging film during storage. The oxygen scavenger was removed from its protective package and immediately inserted into the food package. All packages were heat-sealed using a chamber machine for vacuum packaging (Multivac, Sepp Haggenmiller GmbH & Co. KG; Welfertschwenden, Germany). All packaged samples were stored at 30 °C in a chamber with controlled temperature and RH and consecutively sampled for quality measurements every 2 wk for 12 wk.

Measurement of chemical properties

The astaxanthin content in the dried shrimp was determined following the method of Biede et al. (1982) and Lamberson and Braekkan (1971), with slight modification. The absorbance of the sample was measured at wavelengths of 390 and 475 nm using an ultraviolet-vis spectrophotometer (GENESYS™ 10S; Thermo Fisher Scientific Inc.; Rochester, NY, USA). The astaxanthin content was calculated and reported as units per gram.Thiobarbituric acid (TBA) values were measured using the method of Targladis et al. (1960), with slight modification, as described by Siripatrawan and Makino (2018). The absorbance of the sample distillate was measured for optical density using the spectrophotometer. The TBA value was expressed as mg of malonaldehyde (MA) per kg of sample.

Measurement of physical properties

The water activity (a_w) was measured using a water activity analyzer (model 4 TE; AquaLab; Pullman, WA, USA). Measurement of the CIE (Commission Internationale de l'éclairage) color system was made on the surface of shrimp using a chroma meter (CR-300 series; Minolta; Osaka, Japan) to obtain $L*$ (lightness), $a*$ (redness), and $b*$ (yellowness) values. The illuminant used was D65 and the standard observer position was 2°. The color was measured at five different positions on the shrimp surface. The measurement was performed on the same samples and compared with similar samples throughout storage. Hardness was measured using a texture analyzer (TA-XT plus; Stable Microsystems Ltd.; West Sussex, UK). The samples were compressed in strain mode using an aluminum cylinder probe P/50 to 50% of its height. The pre-test and test speeds were 10 mm/s and the post-test speed was 20 mm/s. Ten replicates were performed for the CIE color and hardness.

Sensory evaluation

The sensory evaluation was performed by a trained sensory panel consisting of 10 assessors (3 males and 7 females), with an average age of 23–45 yr from the Department of Food Technology and the Center of Excellence in Food Processing Pilot Plant, Faculty of Science, Chulalongkorn University, Thailand. The dried shrimp samples were individually identified using a random three-digit code. The samples were served to the panel members in a random sequence. The quality of the samples was evaluated for color, odor and overall acceptability using a 7-point-scoring system, where 7 = extremely desirable to 0 = extremely undesirable. The samples were rejected when a rating score was equal to or lower than 4.

Statistical analysis

A two-factor completely randomized design was performed. Data were analyzed using two-way analysis of variance. The results were each reported as means and standard errors of differences of the means. Duncan's new multiple range test at the 95% confidence level was applied for the calculation of significant differences using the IBM SPSS Statistics for Windows (Version 22.0. IBM Corp., Armonk, NY, USA).

Pattern recognition of dried shrimp quality

Data obtained from the chemical, physical and sensory evaluations of the packaged dried shrimp contained many analytical variables. Therefore, in such cases, evaluation of the quality and storage stability of the food is often complicated since various quality parameters must be taken into account. Consequently, in the current study, pattern recognition techniques were used, consisting of principal component analysis (PCA) and linear discriminant analysis (LDA), for the analysis of the multivariable aspects of food quality. PCA was performed to reduce the number of analytical variables of all samples. Then, LDA was performed to visualize the quality classification of all samples as a factor of the types of different packaging. The matrix calculations were carried out using the MATLAB R2018a software (MathWorks Inc.; Natick, MA, USA) and the classification was performed using the Unscrambler Software Version 10 (CAMO; Trondheim, Norway).

Results and Discussion

Effect of packaging systems on chemical properties of dried shrimp

The astaxanthin content and TBA value of dried shrimp packaged in PP, PA+V, PA+OS or AL+V and stored at 30 °C for 12 wk are presented in Fig. 1. The dried shrimp samples in PP had lower astaxanthin and higher TBA values than those in PA and AL. As shown in Table 1, the OTR of PP, PA and AL decreased in descending order and thus, oxygen was able to permeate through the PP film better than

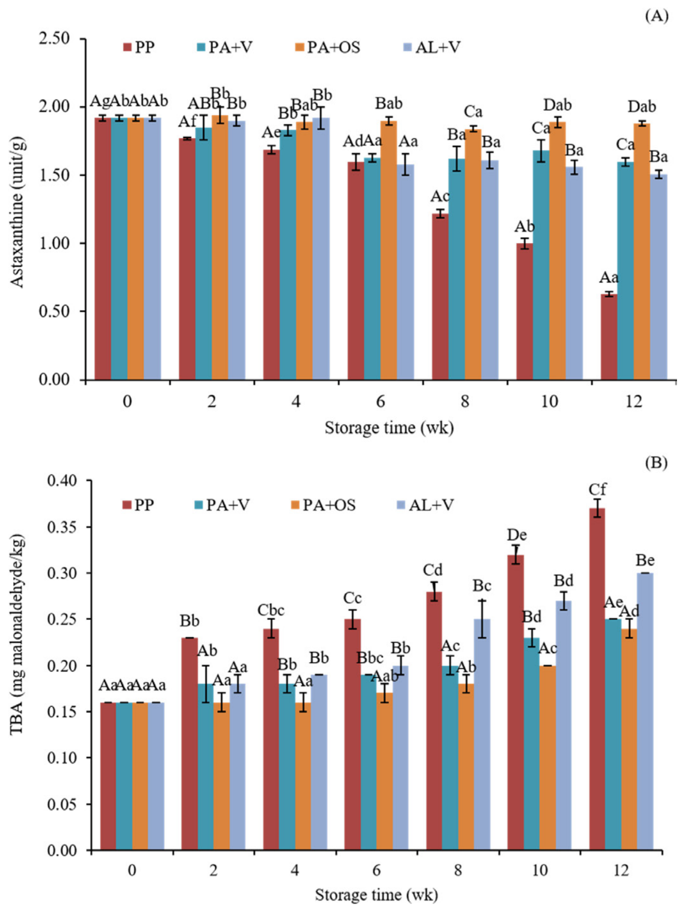

Fig. 1 Astaxanthin content (A); and thiobarbituric acid (TBA) values (B) of dried shrimp packaged in PP, PA+V, PA+OS or AL+V during storage at 30 °C, where values with different uppercase lettersindicate significant ($p < 0.05$) differences between packaging treatments within same evaluation date and values with different lowercase letters indicate significant ($p < 0.05$) differences between storage times within same packaging treatment.

PA and AL during storage. The astaxanthin content (Fig. 1A) of dried shrimp in a PP bag gradually decreased during the first 6 wk of storage, but noticeably decreased thereafter. The decrease in the astaxanthin content of the dried shrimp in all packaging systems when stored longer was probably because of the oxidation of astaxanthin when the product was exposed to oxygen during storage. These results were consistent with Ahmed et al. (2015) and Niamnuy et al. (2008) who found that the degradation of astaxanthin increased with storage time.

The TBA values (Fig. 1B), indicating lipid oxidation of the dried shrimp, in all packaging systems increased with the storage period. The PP-packaged samples had the highest TBA values followed by PA+V, AL+V and PA+OS, respectively, because shrimps have a high content of long-chain polyunsaturated fatty acids and cholesterol that are easily oxidized (Niamnuy et al., 2008; Li et al., 2019). These results agreed with Sampaio et al. (2006) who demonstrated that the amount of TBA in dried shrimp increased due to the oxidation of fatty acids and cholesterol during distribution at the local market.

Oxidation reaction is the major cause of quality degradation in dried fishery products during storage, which can lead to the losses of odor, flavor, color and nutritive values (Li et al., 2019). The dried shrimp packaged in AL+V and PA+V had lower astaxanthin degradation and TBA values than those packaged in PP because the dried shrimp was packaged under a vacuum condition, whereas the dried shrimp in PP was exposed to oxygen during the storage that caused astaxanthin and lipid oxidation. The samples packaged in PA+OS had a higher astaxanthin content and lower TBA values than those in AL+V and PA+V. PA+OS outperformed AL+V and PA+V probably because the typical non-uniform C-shape of the dried shrimps allowed air residue to remain inside the package. Although vacuum packaging can eliminate oxygen from the package before heat-sealing, the typical non-uniform C-shape of the dried shrimps allowed air residue to remain inside the package and there may also have been oxygen trapped in the food. Consequently, the vacuum packaging could not completely eliminate oxygen inside the package. In contrast, the oxygen scavenger could eliminate not only oxygen remaining in the package headspace, but also oxygen trapped in food and oxygen permeating through the packaging film during storage.

Dey and Neogi (2019) reported that conventional vacuum packaging could reduce the oxygen level in the headspace to 0.5–2 volume%, whereas oxygen scavengers could reduce the oxygen level to less than 0.1 volume%. The remaining oxygen in the vacuum packaging may cause quality degradation of the food product. The oxygen scavenger used in the current study was a sachet of iron-based active materials. The scavenging reaction between iron and oxygen, which produces an iron III oxide substance, is based on oxidation in the presence of moisture. The oxygen scavenging mechanism can be expressed using Equations 1–2 (Johnson et al., 2018; Dey and Neogi, 2019):

$$Fe + \frac{1}{2} O_2 + H_2O \rightarrow Fe(OH)_2 \quad (1)$$

$$Fe(OH)_2 + \frac{1}{2} O_2 + \frac{1}{2} H_2O \rightarrow Fe(OH)_3 \quad (2)$$

In the current study, the prevention of color changes due to astaxanthin degradation and odor changes due to lipid and cholesterol oxidation during storage were achieved by removing oxygen from the food packaging system. The oxygen scavenger reduced oxygen in the headspace and from permeating through the packaging film; thus, it retarded the degradation of astaxanthin and the oxidation of fatty acid and cholesterol (Dey and Neogi, 2019).

Effect of packaging system on physical properties of dried shrimp

The changes in the color values—L^* (light-dark), a^* (green-red) and b^* (blue-yellow)—of dried shrimp packaged in PP, PA+V, PA+OS, AL+V during storage at 30 °C for 12 wk are shown in Fig. 2. It was found that packaging system and storage time affected the L^*, a^* and b^* values. When the storage time increased, L^* values tended to increase and a^* tended to decrease, while b^* showed no obvious trend. These results indicated that the orange-red color of the product became slightly paler and greenish.

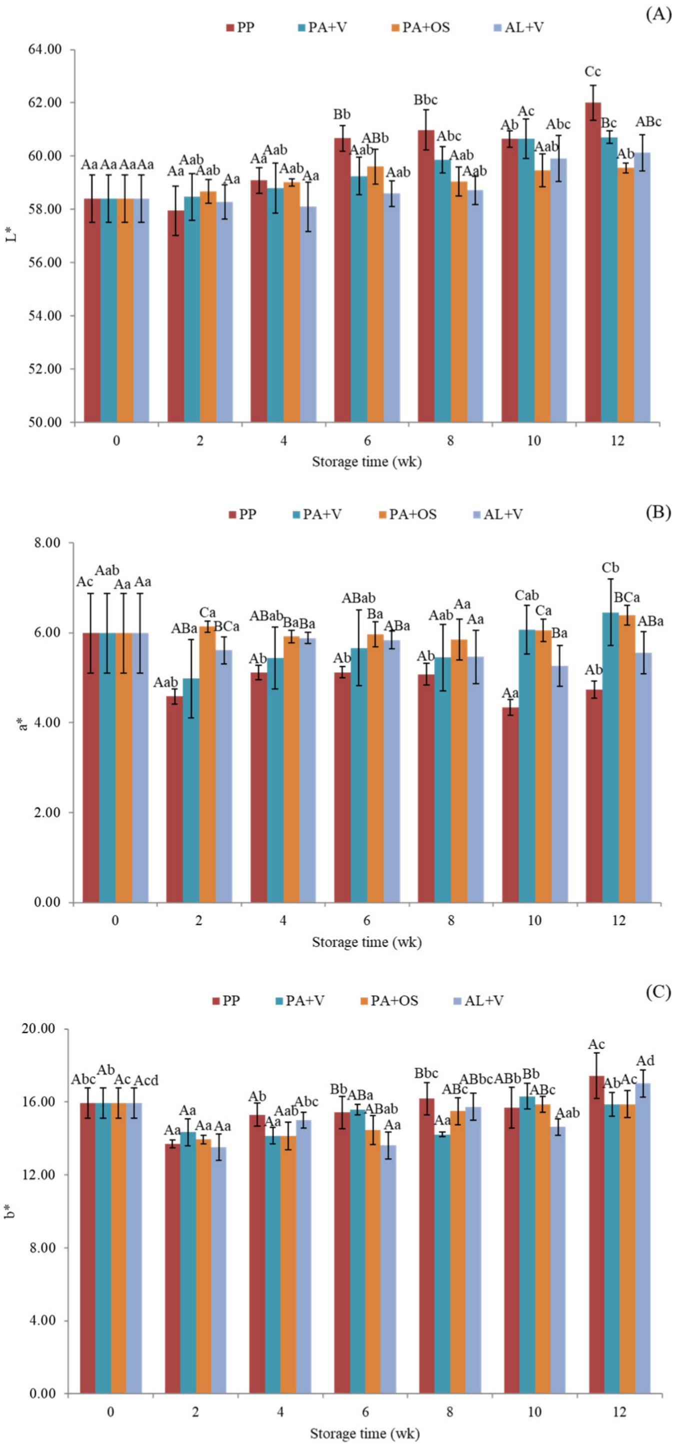

Fig. 2 *L* * (A); *a* * (B); *b** (C) color values of dried shrimp packaged in PP, PA+V, PA+OS or AL+V during storage at 30 °C where values with different uppercase letters indicate significant ($p < 0.05$) differences between the packaging treatments within the same evaluation date and values with different lowercase letters indicate significant ($p < 0.05$) differences between the storage times within the same packaging treatment.

The changes in colors of dried shrimp correlated well with the content of astaxanthin. Astaxanthin is the main pigment of dried shrimp and its reduction results in a marked color change (Becerra et al., 2014; Gómez-Estaca et al., 2017). Changes in the quality of samples packaged in PA+OS during storage were less than those packaged in AL+V, PA+V, and PP, respectively. The changes in the product color may have been due to the oxidation of carotenoid pigment, which is susceptible to oxygen and light (Naguib, 2000; Niamnuy et al., 2008). In addition, Namsanguan et al. (2004) found that astaxanthin degradation caused color changes in dried shrimp during the drying process and storage. Prevention of color changes due to astaxanthin degradation during storage can be achieved by removing oxygen from the food packaging system.

Fig. 3 shows the changes in a_w and hardness of dried shrimp during storage at 30 °C for a period of 12 wk. The a_w values

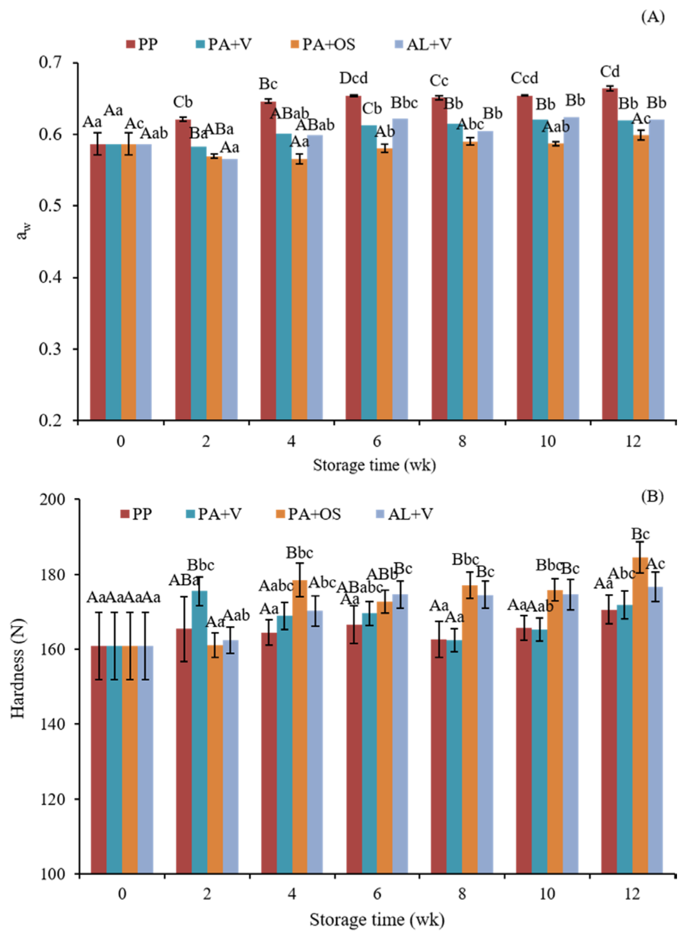

Fig. 3 a_w (A) and hardness (B) of dried shrimp packaged in PP, PA+V, PA+OS, AL+V during storage at 30 °C where values with different uppercase letters indicate significant ($p < 0.05$) differences between the packaging treatments within the same evaluation date and values with different lowercase letters indicate significant ($p < 0.05$) differences between the storage times within the same packaging treatment.

(Fig. 3A) of the dried shrimp in all packaging systems, except for PA+OS, tended to increase with storage time. The a_w values of the samples increased because the initial a_w value (0.58) of the food samples was lower than the surrounding environment (RH = 70%), causing the product to absorb moisture. The RH difference between inside and outside the package caused the outside water vapor to transport through the packaging film. The dried shrimp packaged in PP had a higher a_w value than the other types of packaging because PP has a relatively higher WVTR and thus, water vapor could more easily permeate the film during storage.

Notably, the a_w values of the samples in PA+OS decreased, whereas the a_w values for the samples in other packaging systems increased because moisture is required in the mechanism of iron-based oxygen scavenging to form iron III oxide (Dey and Neogi, 2019), as shown in Equations 1–2. Therefore, the required moisture for the scavenging reaction was taken up from food during extended storage, reducing the a_w value of the food compared to that on the initial day of storage. The a_w value affects the physical properties of food (Castañeda-López et al., 2021). The hardness of the dried shrimp in PA+OS (which had a lower a_w value) was higher than in the other packaging systems (Fig. 3B) probably because as the dried shrimp lost its moisture, it became drier and thus, the hardness increased.

Effect of packaging system on sensory quality of dried shrimp

The sensory quality of the dried shrimp packaged in different packaging systems is presented in Fig. 4. The results showed that the sensory scores for color, odor and overall acceptability of the dried shrimp in all packaging systems decreased with storage. The sensory scores of the product correlated well with the measured colors and the contents of astaxanthin and TBA. When kept longer, the product sensory scores decreased due to degradation of the astaxanthin pigment, as shown by the increase in $L*$ and the decrease in $a*$ values, and by the increase in the TBA values during storage, caused by the oxidation of fatty acid and cholesterol in the dried shrimp (Niamnuy et al., 2008).

Dried shrimp usually has an orange-red color and a smoky flavor, which are desirable in a high quality product. The different packaging systems had effects on the sensory quality of the dried shrimp. The samples packaged in PP had the lowest sensory scores. The samples packaged in PA+OS had higher sensory scores than those in vacuum packaging systems because PA+OS could effectively eliminate oxygen in the package and thus retard the oxidation of astaxanthin, fatty acid and cholesterol, which caused the color and odor changes.

The shelf life of the dried shrimp was determined based on the sensory scores, with the cut-off point for the end of shelf life defined as sensory scores less than or equal to 4. The dried shrimp packaged in PP had a shelf life of 4 wk, which lower than for PA+V, AL+V and PA+OS, whose shelf lives were up to 8 wk, 10 wk and not less than 12 wk, respectively, when stored at 30 °C.

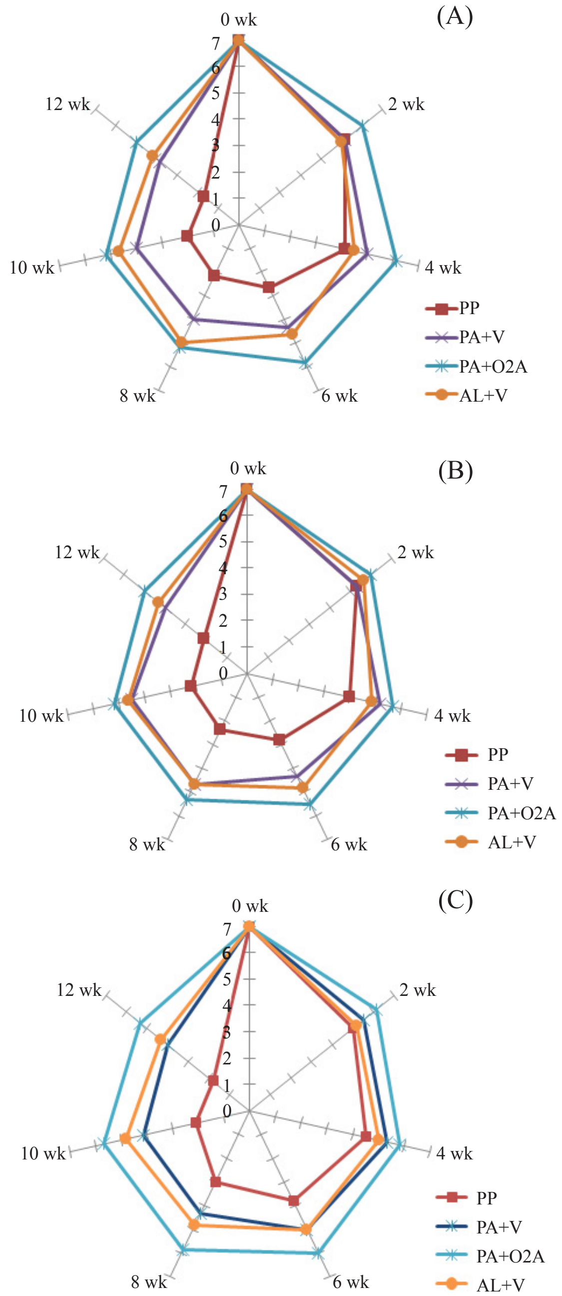

Fig. 4 Sensory scores of color (A), odor (B) and overall acceptability (C) of dried shrimp packaged in PP, PA+V, PA+OS or AL+V during storage at 30 °C

Visualization of packaging effects on dried shrimp quality

The data obtained from the evaluations of the chemical (astaxanthin content and TBA values), physical (a_w, L^*, a^*, b^* color values, and hardness) and sensory (color, odor and overall acceptability) analyses contained 10 variables. Thus, PCA was used to decompose the original complicated data matrix of 10 variables into a smaller matrix by discarding those linear combinations having small variances and retaining only those terms with large variances. PCA transformed the correlated variables into a new set of orthogonal variables called principal components (PCs; Jiarpinijnun et al., 2020). The results suggested that two PCs (PC1 and PC2) were needed for effective data representation. PC1 could explain 77% and PC2 could explain 21% of the total variance, indicating that as high as 98% of the total variance was adequately described for the samples. However, PC scores did not provide a clear quality classification of the different packaging systems (data not shown). Then, LDA-based pattern recognition was performed for sample classification using the PC scores.

LDA was used as a supervised pattern recognition technique to classify the dried shrimp samples into different groups as a factor of the packaging system. LDA provided a graphic of a two-dimensional plot which was easy to interpret (Fig. 5).

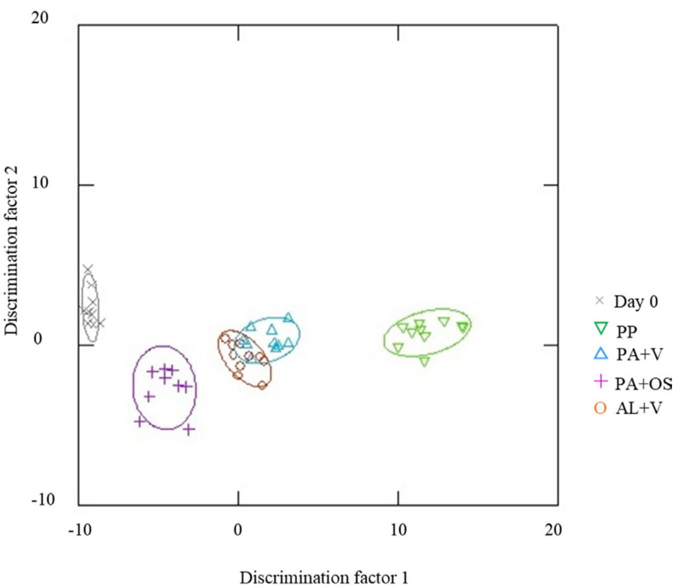

Fig. 5 LDA-based pattern recognition plot of dried shrimp at initial day (day 0) and dried shrimp packaged in PP, PA+V, PA+OS or AL+V after 12 wk storage at 30 °C

The LDA-based pattern recognition could visualize class separation between samples of different quality. There were five treatment groups (shrimp at day 0, shrimp packaged in PP, PA+V, AL+V and PA+OS after 12 wk storage). However, the data were classified into four groups based on the LDA pattern, which accounted for the different quality levels due to the different packaging systems. The samples in PA+OS were closest to the initial samples (day 0) followed by AL+V, PA+V and PP, respectively. This indicated that PA+OS was the best packaging system to maintain the quality of dried shrimp, followed by AL+V, PA+V and PP, respectively. The results suggested that oxygen scavenging was more effective at reducing oxygen inside the package than vacuum packaging. The PA+V and AL+V samples partially overlapped, indicating that the quality of dried shrimp packaged in both packaging systems had in part similar or slightly different qualities probably because both PA+V and AL+V used a vacuum condition. However, AL provided a better oxygen barrier than PA and thus, less amount of atmospheric oxygen could permeate through the AL film.

From the results, it can be concluded that the most suitable packaging system for maintaining the quality and prolonging the shelf life of dried shrimp was PA with an oxygen scavenger. The oxygen scavenger helped to eliminate oxygen in the package headspace, leading to the inhibition of lipid oxidation and astaxanthin degradation and thus preserving the product longer.

Conclusion

The LDA-based pattern recognition could visualize the effect of different packaging systems on the overall quality of dried shrimp. PA+OS was the most effective packaging system to maintain the quality and storage stability of the product, followed by AL+V, PA+V and PP, respectively. Oxygen scavenging not only reduced residual oxygen in the package more effectively than vacuum packaging, but also eliminated oxygen permeating the packaging film during storage. The low oxygen concentration retarded the astaxanthin degradation and oxidation of fatty acid and cholesterol and could preserve the quality and storage stability of the product. Furthermore, due to its transparency, the PA bag would allow consumers to see the color of the product, which is an important factor at the point of purchase. However, the iron-based oxygen scavenger, which requires moisture for its oxidation reaction, caused moisture loss of the product after extended storage. Although the optimal packaging system (PA+OS) has a higher price than the current PP package, it can provide much better protection to the product and thus reduce food spoilage and extend the shelf life, prolonging product use. A longer shelf life of this product would not only motivate more sales with less waste at retail, but also enhance product exportation. Therefore, the findings in this research can help solve the real problems of dried shrimp processors and exporters.

Conflict of Interest

The authors declared that there are no conflicts of interest.

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