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Kinetics of astaxanthin degradation and color changes of dried shrimp during storage

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Abstract

Dried shrimp is a high value fishery product of Thailand. Since it is known that drying and storage conditions affect the color changes of dried shrimp, but the quantitative information on this aspect is still very limited, the objective of the present study was to investigate the long-term effects of drying air temperature (80, 100, 120 °C) and various storage parameters, namely, storage atmosphere (air, vacuum) and storage temperature (4, 15, 25 °C), on the kinetics of astaxanthin degradation and of color changes, in terms of CIELAB parameters L^*, a^* and b^*, of dried shrimp during 16-week storage. In addition, the relationship between astaxanthin retention ratio and color retention ratio of dried shrimp was established. The degradation of astaxanthin and color loss was found to follow a first-order kinetic reaction; the temperature dependence of reaction constants was found to be well explained by the Arrhenius relationship. Drying shrimp at higher temperature led to lower astaxanthin degradation during storage than drying at lower temperatures. Storage of dried shrimp under vacuum atmosphere at low temperatures enhanced the retention of astaxanthin in dried shrimp. Good correlations between astaxanthin degradation and color changes were also observed.

Keywords: Arrhenius; Astaxanthin; Color; First-order reaction; Rate constants; Shrimp; Storage atmosphere; Temperature

1. Introduction

Dried shrimp is an important domestic and export seafood product of Thailand. The production process of dried shrimp consists of three steps: boiling shrimp in salt solution, drying and storage. The desired quality of dried shrimp includes the final moisture content of not more than 20% (w.b.) or 25% (d.b.), which is equivalent to the water activity (a_w) of not higher than 0.85. Color is nevertheless considered to be the most important sensory attribute and has a direct effect on the price of dried shrimp. Color of dried shrimp is influenced by pigments in the group of carotenoids. The main carotenoids in shrimp are astaxanthin, canthaxanthin, β-carotene and other xantophylls (Goodwin, 1984). However, since the amount of astaxanthin in shrimp (*Penaeus* species) is found to vary between 64% and 98% of the total carotenoids (Latscha, 1989), astaxanthin is usually regarded as the most important carotenoid in shrimp. In raw shrimp, astaxanthin can be found in three main forms; these are astaxanthin complexed with proteins (carotenoproteins), lipid esterified astaxanthin and non-esterified astaxanthin (free astaxanthin). Non-esterified astaxanthin is more susceptible to oxidation than esterified astaxanthin (Breithaupt, 2004).

Several works have reported the effect of drying on astaxanthin degradation and on color changes of dried shrimp. Lamberson and Braekkan (1971) reported that shrimp

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dried by vacuum drying had greater astaxanthin content than that dried by hot air drying. Posomboon (1998) investigated the effect of drying air temperature on the quality of dried shrimp. Low-temperature drying at 70 °C was recommended because the color and sensory quality of the dried shrimp were most acceptable. On the other hand, high-temperature drying at 140 °C adversely affected the color of the dried shrimp. Prachayawarakorn et al. (2002) dried shrimp using superheated steam as the drying medium and compared the results obtained with those of hot air drying. They reported that shrimp dried by superheated steam had better color than that dried by hot air. However, superheated steam drying is naturally a more complex process than hot air drying.

A jet spouted bed dryer is another alternative dryer for shrimp. Tapaneyasin et al. (2005) and Niamnuy et al. (2007a) indeed studied the effects of the size of shrimp as well as that of the inlet air temperature on the color changes of shrimp dried in a jet spouted bed dryer. It was found that the size of shrimp and inlet air temperature significantly affected the color changes of dried shrimp and the use of a constant inlet air temperature of 100–120 °C yielded dried shrimp of higher redness value.

While investigations into the effect of drying on the color changes of dried shrimp are numerous, a limited amount of information is found on the pigment stability and color changes of dried shrimp after drying and during storage. Biede et al. (1982) investigated the effect of internal package atmosphere on astaxanthin degradation of sun-dried shrimp. These investigators reported that astaxanthin degradation reached a maximum during the first four months of storage. Vacuum packaging was shown to significantly slow down the rate of degradation. Sopagdee (2001) studied the shelf life of dried shrimp in laminated packaging. It was found that storage temperature and package atmosphere significantly affected astaxanthin degradation and color changes of dried shrimp during storage. Good correlation between the astaxanthin content and color of dried shrimp was also reported.

Since very limited information is so far available on the kinetics of astaxanthin degradation and of visual color changes of dried shrimp after drying, the objectives of this study were to investigate the long-term effects of drying and storage conditions, namely, drying temperature, storage temperature and atmospheric condition in package, on the kinetics of astaxanthin degradation and of color changes of dried shrimp during storage. In addition, the relationships between carotenoids degradation and color changes of dried shrimp during storage were determined.

2. Materials and methods

2.1. Materials

Fresh wild white shrimp (*Penaeus indicus*) was obtained from a local seafood wholesaler in Samut Sakorn, Thailand with a small size (350–360 shrimp/kg). The average mass of each shrimp was 2.82 ± 0.05 g and the average equivalent diameter of shrimp was 1.63 ± 0.07 cm. After grading and washing with tap water, raw shrimp was weighed; 2.0 ± 0.1 kg of raw whole-shelled shrimp was used in each experiment. During the preparation, shrimp was kept in a polystyrene box filled with crushed ice at 2 °C. The time that shrimp was stored in crushed ice (from wholesaler to boiling) was around 5 h.

2.2. Boiling in salt solution and drying

Raw whole-shelled shrimp was first equilibrated at room temperature for 10 min prior to boiling in salt solution (NaCl solution) that was contained in a 14 cm diameter stainless steel vessel at the boiling temperature of salt solution. The boiling conditions are as follows: concentrations of salt solution of 2% (w/v), boiling time of 7 min and mass ratio of shrimp to salt solution of 1:2 on the weight basis. These boiling conditions have been reported to give good qualities of small dried shrimp (Niamnuy et al., 2007b).

After boiling, shrimp was mechanically dehydrated for 5 min in a centrifugal separator to remove excess water from its surface. The boiled shrimp was then introduced to a jet spouted bed dryer (Niamnuy et al., 2007a). An initial static bed height was set to be around 25 cm. The superficial air velocity was maintained at 2 m/s, which is 1.2 times of the minimum spouting velocity (Devahastin et al., 2006). Three different temperatures, namely, 80, 100 and 120 °C were used in the drying experiments. Shrimp was dried until it reached the final moisture content of around 15–16% (w.b.).

2.3. Storage

The package of dried shrimp was nylon/LLDPE bags, which are the conventional dried seafood package. The size of the bag is 5 in. in width and 8 in. in length with the thickness of 80 micrometers. The oxygen transmission rate of the bag at 25 °C and 0% relative humidity is 47.4 cm^3/m^2 day bar, while the water vapor transmission rate of the bag at 25 °C and 50% relative humidity is 1.26 g/m^2 day.

Shrimp (150 g samples) was packed in nylon/LLDPE bags under air or vacuum; the latter condition was achieved by a vacuum packing machine (Multivac, A300/42, Wolfertschwenden, Germany). The storage studies were conducted in dark at 4, 15 and 25 °C for up to 16 weeks. The relative humidity of the surrounding environment was controlled at 55 ± 2% in all cases (the relative humidity was controlled via the use of saturated salt solution of $Mg(NO_3)_2$) (Kaminski and Kudra, 2000). Setting up of each storage experiment was completed on the same day that the shrimp was dried.

Dried shrimp samples were taken out for astaxanthin analysis and color measurement at every two weeks. Upon collection, all samples were placed in a refrigerated storage (0 °C). Each astaxanthin analysis and color measurement