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PROPERTY PREDICTION OF DRY COMMON CARP (*CYPRINUS CARPIO*) DURING STORAGE BY KINETIC MODEL

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Abstract: Common carp (*Cyprinus carpio*) is an important food resource in European and Asian countries. Nowadays, common carp after drying process is appreciated by the transportation agency and food industry because of its low transportation cost. Changes of acid value (AV), total bacterial count (TBC), and peroxide value (PV) were reported in this study. We found that the changes of AV, TBC and PV of dry common carp fitted the first order reaction model and the reaction energies of changes of AV, TBC, and PV during storage were 4.56 kJ/mol, 2.21 kJ/mol, and 2.33 kJ/mol, respectively. This study will provide theoretical knowledge to food factories relating with dry fish storage and transportation.

Keywords: Common carp; storage; kinetics; bacteria; acid value; peroxide value

INTRODUCTION

Common carp, *Cyprinus carpio*, is a kind of freshwater fish which is widely spread in Europe and Asia (Pšenička et al., 2009). Common carp contains high content of protein and various unsaturated fatty acids which are important in human diet (Spiric et al., 2010). It was reported that common carp has been used as a kind of raw material in food industry for the

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production of protein and oil (Titoc, 2010). Furthermore, due to the good taste and cheap price, common carp has become an important part in European and Asian cuisine (Hulata et al., 1982). Therefore, now common carp is a major cultured fish in many countries, such as China, Czech, India and so on (Yeganeh et al., 2012). The property of common carp is a critical concern in food industry.

In modern food industry, to reduce the transportation cost and extend the shelf life, common carp is always dried after harvesting (Dobšíková et al., 2006; Hulata et al., 1982). Furthermore, dry common carp with special taste and flavor is favored by people in many countries. It was reported that dry fish would become more and more important in the fish processing industry (Dobšíková et al., 2006). After the drying process, the characteristics, such as water content, concentrations of some nutrients, and bacterial content, of fish would be changed a lot. Therefore, the properties and features of dry common carps are very different from those of fresh common carps. How to ensure the safety of dry common carp in transportation and storage is a critical concern in fish processing industry (Akhtar et al., 2010; Dobšíková et al., 2006). Therefore, it is significant to understand the changes of properties of dry common carp during storage and establish a system to predict the shelf life of dry common carp under different storage conditions.

The objective of this study was to establish a prediction model for the changes of some properties of common carp during storage. In the first part, the changes of acid value (AV), total bacterial count (TBC), and peroxide value (PV), under different storage conditions were analyzed. In the second part, kinetic model was employed to predict the property changes of common carp under different conditions. In the final part, a prediction model for the shelf life of dry common carp was established based on the experimental data.

MATERIALS AND METHODS

Materials and chemicals

Fresh common carps with similar size and weight were purchased from the local market. The fresh common carps were stored at 4 ^{o}C in dark until use. Agar and potassium hydroxide were obtained from Fisher Scientific Inc.

Fresh common carps were processed by the hot air dryer to a constant weight and cooling at room temperature. The packed dry common carps were stored at three different temperatures, 20 ^{o}C, 30 ^{o}C and 40 ^{o}C. Three factors, AV, TBC, and PV were evaluated every 7 days during the storage period.

Analytical methods

The analysis method for AV was described in The International Pharmacopoeia (4th Edition) from WHO. The acid value was expressed as mg KOH/g. The test of TBC was carried out according to GB 4789.2-2010. TBC was expressed as cfu/g. PV of dry common carp was tested according to ISO 3960-2007. PV was expressed as g/100g.

Establishment of kinetic model

It was reported that most physical, chemical and biological changes happened in food could be regarded as the first order reaction. Therefore, in this study, the kinetic model of first order reaction was employed in the prediction of AV, TBC, and PV of dry common carps during storage.

The first order reaction equation could be expressed as Eq. 1.

$$\mathrm{Ln}\ C = \mathrm{Ln}\ C_0 + kt \qquad \text{Eq. 1.}$$

where t is the storage time in days; k is the parameter of changes; C0 is initial value of AV, TBC, or PV; C is the actual value of AV, TBC, or PV at a certain storage time. Arrhenius equation was expressed as Eq. 2.

$$k = k_0\ \exp\left(-\frac{E_a}{RT}\right) \qquad \text{Eq. 2.}$$

where Ea is the activation energy; T is the absolute temperature (K); k is the parameter of degradation; R is the universal gas constant (8.318 kJmol-1K-1); and k0 is a constant.

The integration of Eq. 1 and Eq. 2 yields Eq. 3.

$$t = \frac{\mathrm{Ln}\left({}^{C}/_{C_0}\right)}{k_0 \exp\left({}^{-E_a}/_{RT}\right)} \qquad \text{Eq. 3.}$$

In different countries and regions, requirements on the maximum values of AV, TBC and PV have been established. Therefore, the shelf life of dry common carp could be calculated according to these requirements.

Statistical analysis

All tests in this study were performed in triplicate. The average results were shown as means ± SD. Excel ® (Microsoft) was used to analyze the variance of these results. Differences in means and F-tests were considered only when $P<0.05$.

RESULTS AND DISCUSSIONS

Changes of AV during storage

Changes of AV under different storage conditions (Figure 1) indicated that the acid value of common carp increased with the increase of storage temperature and time. During the whole storage period (56 days), the average growth rate of acidity was improved from 0.0946 mg KOH/min to 0.3125 mg KOH/min when the temperature was improved from 20 °C to 40 °C. The main factor causing the increment of AV was the hydrolysis of triglycerides which could increase the FFA (free fatty acid) content. It was reported that higher temperature could promote the hydrolysis of triglycerides (Menegazzo et al., 2014). In some parts, such as abdominal wall, of common carp, the oil content could reach 30% (Titoc, 2010). Therefore, with the increment of storage temperature, the average growth rate of acidity increased obviously.

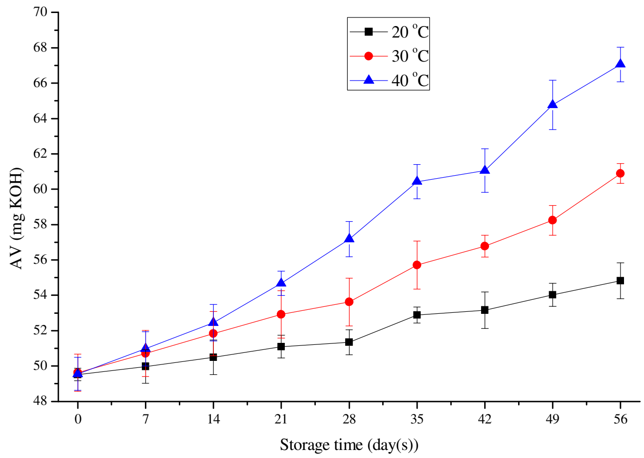


Figure 1. Changes of AV during storage

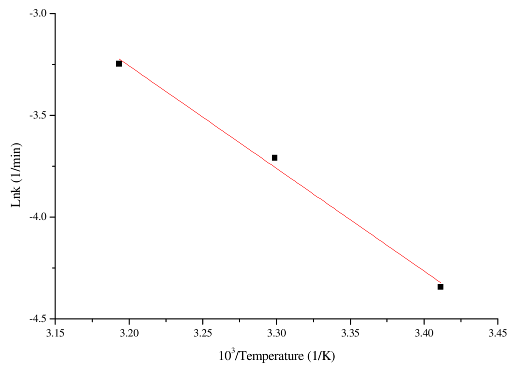
First order reaction model was used to analyze the increment kinetics of changes of AV during storage. The regression equations which reflected the relationship between LnC and storage time (t) were shown in Table 1.

Table 1. The regression equations of three factors under different storage conditions

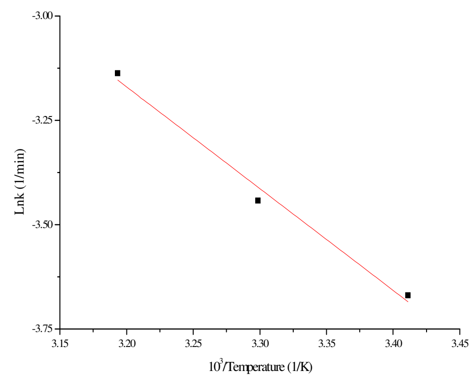
Factor	Storage temperature (°C)	Regression equation	R-squared value	k
AV	20	Y= 0.0130x + 3.8844	0.9805	0.0130
	30	Y= 0.0245x + 3.8735	0.9850	0.0245
	40	Y= 0.0389x + 3.8537	0.9919	0.0389
TBC	20	Y= 0.0255x + 1.7508	0.9822	0.0255
	30	Y= 0.0320x + 1.7569	0.9956	0.0320
	40	Y= 0.0434x + 1.7438	0.9974	0.0434
PV	20	Y= 0.0379x – 1.6743	0.9826	0.0379
	30	Y= 0.0485x – 1.6708	0.9928	0.0485
	40	Y= 0.0663x – 1.6326	0.9802	0.0663

Y is the LnC and X is the storage time t (days)

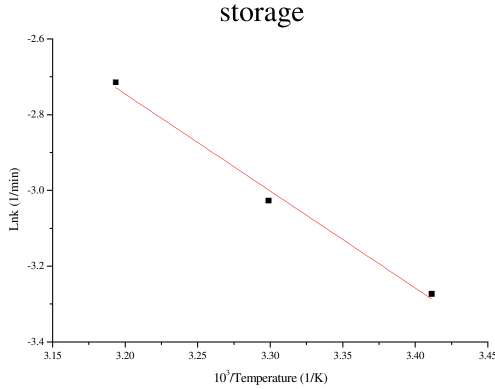
R-squared values for three equations (0.9805, 0.9850 and 0.9919) indicated that the increment of AV during storage fit the first order reaction model. Arrhenius equation of changes of AV during storage (Figure 2(a)) was $\text{Ln k} = \frac{-0.548}{T} - 2.6702$ and the R-squared value was 0.9919. Therefore, the activation energy and k_0 of AV changes during storage were 4.56 kJ/mol and $e^{-2.6702}$, respectively.



a. Arrhenius plot of changes of AV during storage



b. Arrhenius plot of changes of TBC during storage



c. Arrhenius plot of changes of PV during storage

Figure 2. Arrhenius plots of changes of three factors during storage

Changes of TBC during storage

In this section, the relationship between bacterial growth in common carp and the storage temperature was analyzed. Figure 3 reflected the changes of TBC during storage. TBC also increased with the improvement of storage temperature. In the whole storage period (56 days), the average growth rate of TBC at 20 ^{o}C was 0.02375×10^3 cfu/g/day while that at 40 ^{o}C was 0.04375×10^3 cfu/g/day. Therefore, the growth rate of TBC at 40 ^{o}C was much higher than that at 20 ^{o}C. TBC which reflects the amount of bacteria is an important concern in food storage. The bacteria in food may secret harmful chemicals, such as aflatoxin and endotoxin, which could threaten consumers' health. Furthermore, the growth of bacteria could promote the deterioration of food and reduce the shelf life (Lu et al., 2011). Therefore, to ensure the food safety, we should inspect and control TBC of fish during storage. It was reported that the growth of bacteria in food could be impacted by storage temperature, oxygen content in package, humidity, nutrients of the food, and many other factors (Abraham & Abraham, 2011). These factors could also influence the kinds of bacteria. In this study, we only focused on the total bacterial count.

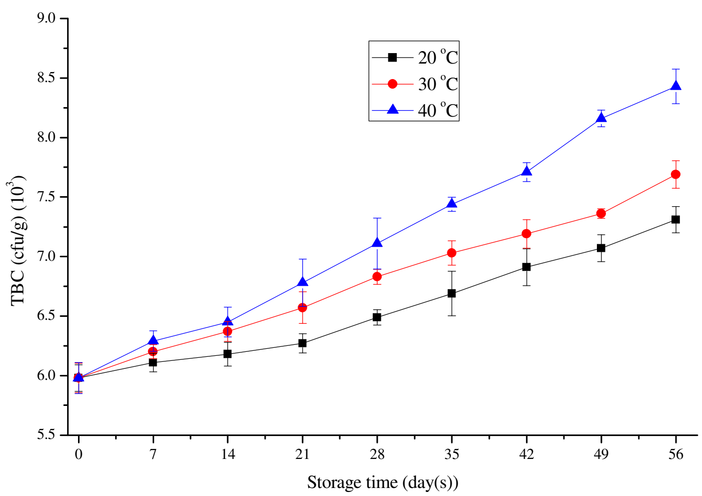


Figure 3. Changes of TBC during storage

Table 1, which reflected the first order reaction regression equation, indicated that the changes of TBC at different temperatures during storage fitted the first order reaction. The k values of the reaction at 20 °C, 30 °C, and 40 °C were 0.0255, 0.0320, and 0.0434, respectively. Arrhenius equation of changes of TBC during storage (Figure 2(b)) was $\text{Ln k} = \frac{-0.2659}{T} - 2.8849$ and the R-squared value was 0.9929. So the activation energy and k_0 of this reaction were 2.21 kJ/mol and $e^{-2.8849}$, respectively.

Changes of PV during storage

Changes of PV at different storage temperatures were shown in Figure 4. PV, which refers to the concentration of peroxide in food, could be used to evaluate the extent to which spoilage has advanced. Figure 4 indicated that during the whole experimental period the average growth rate of PV at 20 °C was 0.00116 g/100g/day while the average growth rate at 40 °C reached 0.00273 g/100g/day. High temperature could cause the deterioration of oil and fat in dry common carp and increase the PV during storage. Furthermore, in the drying process, the oxidation and deterioration of fat and oil in common carp have occurred. The free radicals presented in this process would promote the deterioration of fat and oil during storage (Bantchev et al., 2009). Therefore, compared with fresh common carp, dry common carp is more likely to have high PV.

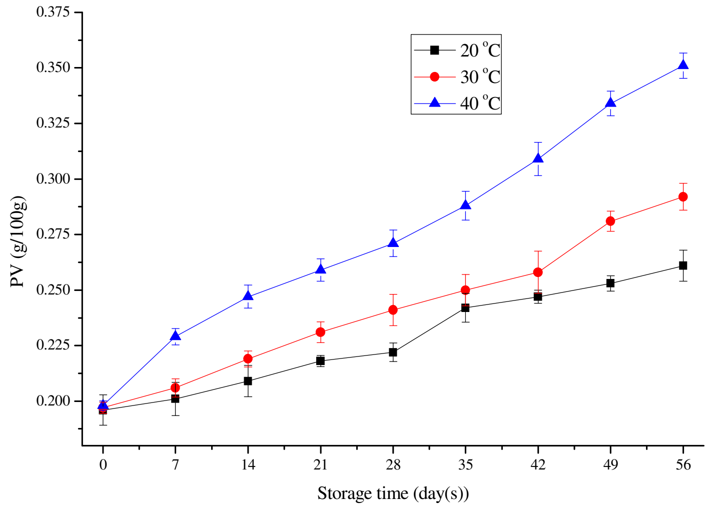


Figure 4. Changes of PV during storage

Data in Table 1 reflected that the first order reaction model could be used to describe the changes of PV during storage. The k values of the reaction at 20 °C, 30 °C, and 40 °C were 0.0379, 0.0485, and 0.0663, respectively. The Arrhenius equation of changes of PV during storage (Figure 2(c)) was $Y = \frac{-0.2796}{T} - 2.4449$ and the R-squared value was 0.9954. Therefore, the activation energy and k_0 of this reaction were 2.33 kJ/mol and $e^{-2.4449}$, respectively.

Prediction system and verification

The analysis of changes of AV, TBC and PV above indicated that first order reaction could be used to describe the changes of these three factors during storage. Therefore, prediction systems based on AV, TBC, and PV were established according to the first order reaction model and the data above. The shelf lives of dry common carp during storage based on AV, TBC and PV were shown as Eq. 4, Eq. 5, and Eq. 6, respectively.

$$\text{Shelf life (AV)} = \frac{\ln(C_{AV}/C_{0\,AV})}{e^{-2.6702} \times \exp(-4.56/RT)} \quad \text{Eq. 4.}$$

$$\text{Shelf life (TBC)} = \frac{\ln(C_{TBC}/C_{0\,TBC})}{e^{-2.8849} \times \exp(-2.21/RT)} \quad \text{Eq. 5.}$$

$$\text{Shelf life (PV)} = \frac{\ln(C_{PV}/C_{0\,PV})}{e^{-2.4449} \times \exp(-2.33/RT)} \quad \text{Eq. 6.}$$

According to the requirement of Hygienic Standard for Dried Aquatic Products (GB10144-2005), AV, TBC and PV should be controlled below 130 mg KOH/g, 30×10^3 cfu/g, and 0.60 g/100g, respectively. In this study, the average initial values of acidity, total bacterial count and peroxide of dry common carp were 49.57 mg KOH/g, 5.98×10^3 cfu/g, and 0.197 g/100g. So with the prediction model, the shelf life of dry common carp at any storage temperatures could be calculated.

Discussion

This study developed the prediction system for the shelf life of dry common carp according to the first order reaction model. Due to its low transportation cost, dry fish with low water content is highly appreciated by the food company and transportation agency. Previous studies mainly focus on the shelf life of fresh common carp or the common carp with package while neglect the development of theoretical knowledge of dry common carp, the market share of which is increasing greatly. Therefore, the findings in this study could be used to direct the work in the storage and transportation of dry fish.

There are still some weaknesses in this study. Firstly, different countries and organizations have very different regulations on the properties and shelf life of fish during storage while this study only analyzed the kinetics of changes of AV, TBC and PV. Further research should focus on other factors which could reflect the properties of common carp during storage. Secondly, during storage, different strains of bacteria may have different growth trends. This study only analyzed the changes of total bacterial count. Therefore, to understand the property changes of dry common carp during storage, other factors, besides AV, TBC and PV, relating with the shelf life and properties should be analyzed comprehensively.

CONCLUSIONS

This study established a prediction model based on AV, TBC and PV for the shelf life of dry common carp of which the consumption is great in many European and Asian countries. The result indicated that the activation energies of increment of AV, TBC and PV during storage were 4.56 kJ/mol, 2.21 kJ/mol, and 2.33 kJ/mol, respectively. This study will provide theoretical knowledge to food factories relating with dry fish storage and transportation. In the future, we should focus on details relating with the properties of dry common carp during storage. In this way, the shelf life of dry common carp could be predicted accurately.

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