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Application of the general stability index method to predict quality deterioration in bighead carp (*Aristichthys nobilis*) heads during storage at different temperatures

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ABSTRACT

A freshness index called the global stablity index (GSI) applicable to follow the variation of multi-quality indices of bighead carp (*Aristichthys nobilis*) heads during different temperatures storage was evaluated. Quality indices (sensory score, total aerobic counts, volatile base nitrogen, and K value) were estimated and calculated into the single parameter GSI at −3, 0, 3, 9 and 15 °C. GSI was then kinetically modeled to describe the dependency of GSI with temperature and storage time. The calculated data of GSI were satisfactorily described by a zero order kinetic model. The activation energy (E_A) and the corresponding pre-exponential constant (k_0) of GSI were 85.61 kJ/mol and 1.14×10^{15}, respectively. Relative errors between predicted and observed GSI values were all below 10% before the 15th day. Thus, the established model based on GSI could effectively predict the freshness of bighead carp heads at the range of −3 and 15 °C during different temperatures storage.

1. Introduction

Fish are relatively perishable, compared to other muscle foods. Quality of fish is a combination of various nutritional, microbiological, biochemical and physiochemical attributes. Moreover, the quality of fish is also dependent on the species, season, and the physiological state of the species what it has been feeding on, where it was caught, the ambient temperature, the harvesting method, and the subsequent handling and processing (Balachandran, 2001). In consequence, the evaluation of shelf-life is an arduous task. In order to determine the total food quality, many indices are needed and must be considered, since their relative importance depends on products, producer and market (Zwietering et al., 1993).

The global stability index (GSI), firstly proposed by Achour (2006) was a multi-quality index which enabled one to judge the degradation of the microbiological, physicochemical and sensory quality of food products during storage in a global fashion. Although Achour (2006) has successfully tested the stability of an orange based carbonated beverage by simultaneously considering the time variations of the brix and the CO_2 partial pressure of the drink, it is not practical when there are many quality indices affecting shelf life. A modified version of the GSI method was introduced by Ansorena et al. (2009) which could be used to determine a set of quality indices that better represent the loss of quality during storage of food products.

Traditional quality evaluations involve a large number of experimental determinations that not only consume time and trained labor but also imply high cost of experimentation. Kinetic modeling has the potential to reduce the number of experiments and gives an important tool for predicting and optimizing the quality of the processed food product during storage (Boekel, 1996). Several studies have focused on kinetic modeling of quality change of aquatic products. Yao et al. (2011) established kinetic models to predict the freshness of crucian carp (*Carassius carassius*) based on electrical conductivity and freshness indicators. Corzo et al. (2006) developed models based on the changes of sardine (*Sardinella aurita*) sheets during vacuum pulse osmotic dehydration at temperatures of 30, 32, 34, 36, and 38 °C. Tsironi et al. (2009a,b) modeled the temperature dependence of quality deterioration of frozen shrimp. However, scarce research has been conducted regarding the potential of using the Arrhenius model to predict the quality of bighead carp products in a global fashion (GSI).

Bighead carp is one of the most important commercial freshwater fish species harvested in the China. The bighead carp head is a product of high commercial value and increasing demand in China, due to its high proportion of bighead carp (approximately 34%), superior nutritional quality and delicious taste. Studies on bighead carp have been related to brine salting (Hong et al., 2012a,b), artificial breeding (Santiago and Gonzal, 2000) and microwave-vacuum heating (Zhang et al., 2007). However, little information is available on quality prediction and the preservation of bighead carp heads during the refrigerated storage.

The objectives of this study were to determine and predict quality deterioration in bighead carp heads during storage at different

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temperatures. For this purpose, organoleptic (sensory score), microbiological (total aerobic count) and physiochemical (volatile base nitrogen and *K* value) indices, which better represent the loss of quality during the shelf life of bighead carp heads, were evaluated and then transformed into the single parameter GSI. In addition to this, an Arrhenius model based on GSI was established during the product storage.

2. Materials and methods

Cultured bighead carps were purchased at an aquatic products wholesale market in Beijing, China, in July 2011 and were immediately transported to the laboratory alive. The mean weight and length of fish were 1131.86 ± 84.56 g and 40.20 ± 0.84 cm, respectively. Fish were killed by a blow to the head, scaled, gilled, gutted, and then the heads were chopped off at approximately 5 cm behind the gills. After washing, fish heads were left to drain on the sterile stainless steel wire mesh for 10 min. Then, the heads ($n = 69$) were packed in polyvinyl chloride bags and were stored at −3, 0, 3, 9 and 15 °C in refrigerators of different chambers. Samples at −3 and 0 °C were stored in partial-freezing chambers while samples at 3, 9 and 15 °C were stored in refrigerating chambers. The temperature variations were kept within ± 1 °C. Three lots were taken randomly for analysis at different intervals.

2.1. Quality analysis

2.1.1. Sensory analysis

Sensory analysis was performed according to the method of Hong et al. (2012a,b). Samples stored at −3 °C were thawed at 4 °C for 12 h prior to sensory evaluation. The fish heads were subjected to a panel consisting of nine experienced and trained assessors from the laboratory staff. Cooked fish heads were prepared by steaming for 10–20 min at 98 °C. Each assessor was requested to rate the appearance, odor, elasticity and morphology of the head muscle. A rating scale of 1–5 points was used, wherein 5 denoted "extremely desirable" and 1 denoted "extremely undesirable". Scores of separate characteristics of both fresh and cooked fish heads were summed to give an overall sensory score. A value of 12 was taken as the borderline of acceptability.

2.1.2. Microbiological analysis

The determinations of the total aerobic count (TAC) were run according to Song et al. (2011) with some modification and were as follows. Ten grams of head meat were weighed aseptically and homogenized with 90 mL sterile 0.9% physiological saline for 1 min. The homogenates and serial tenfold dilution in sterile 0.9% physiological saline were used for microbial analyses. TAC was performed using enrichment agar (5 g tryptone, 2.5 g yeast extract, 1 g glucose, 15 g agar/L medium). The pour plates of appropriate dilutions were incubated for 48 h at 30 °C. All counts were expressed as $\log_{10}$CFU/g and performed in duplicate.

2.1.3. Biochemical quality evaluation

The total volatile base nitrogen (TVB-N) analysis was carried out according to the semi-micro-titration method proposed by Zhang et al. (2011). K value was determined by a reverse-phase high-performance liquid chromatography procedure as described in Yao et al. (2011).

2.2. Modeling procedures

2.2.1. Determination of GSI

The GSI index is a mathematical expression combining several quality indicators to formulate a single quality parameter proposed by Achour (2006):

$$GSI_j = 1 - \sum_{i=1}^{n} \alpha_i V_{ij} \tag{1}$$

where *j* is the unit of storage time (day); $\sum$ is the sum of $i = 1$ to n; *n* is the total number of the quality degradation criteria; *i* is the index number; a_i is the weighing factor reflecting the relative importance of the index *i* in terms of describing the quality of the product. The variation terms (V_{ij}) are calculated as

$$V_{ij} = \frac{(C_{ij} - C_{i0})}{L_i - C_{i0}} \tag{2}$$

where C_{ij} is the measured value of the index *i* at time *j*; C_{i0} is the initial value of the criterion *i*; L_i is the threshold value of index *i*. V_{ij} describes the reported variation as compared to the maximum tolerated variation.

According to Eq. (1), GSI varies between zero and one. As GSI is closer to 1, the product is more stable, meaning its initial quality is being well preserved. As the GSI approaches zero, the quality of the product is being decayed and the product shelf life is diminishing.

In the present study, the threshold values of sensory score, TAC, TVB-N and *K* value were set by regulations or common practices. They were 12 (Zhang et al., 2011), 7 $\log_{10}$CFU/g (ICMSF, 1986), 35 mg/100 g (EC, 1995) and 70% (Saito et al., 1959), respectively. The weighting factor (α_i) means the relative importance of criterion *i* in terms of describing the quality of the product. In this work, all indices were distributed into four categories ($\alpha_A = 0.5$, $\alpha_B = 0.25$, $\alpha_C = 0.15$, $\alpha_D = 0.1$) according to Ansorena et al. (2009). Sensory score, TAC, TVB-N and *K* value belong to A, B, C and D categories, respectively, and they were arranged in order of importance of indices in response to consumer demand for freshness, safety and taste.

2.2.2. The predictive models

Loss of multi-quality characteristics of bighead carp heads as a result of storage conditions can be expressed in terms of the rate constant (k) and its dependence on temperature (E_A). The change of multi-quality index GSI with time (d [GSI]/dt) can be represented by the following kinetic equation:

$$\frac{d[GSI]}{dt} = K[GSI]^n \tag{3}$$

where *k* is the rate constant, n is the order of reaction. GSI is the value calculated from the multi-quality index of bighead carp heads after storing for time *t* (days).

In addition to describing the change in a property as a function of time at a fixed temperature, one must be able to describe the effect of temperature on the property. The Arrhenius equation is often used to describe the temperature dependence of the deterioration rate:

$$K = K_0 exp(-E_A/RT) \tag{4}$$

where k_0 is the pre-exponential constant, *R* is the gas constant [8.3144 J/(mol K)], T is the absolute temperature ($K = 273 + °C$) as the temperature used in Arrhenius equation must be in degrees Kelvin, E_A is the activation energy in kJ mol^{-1}. Substituting Eq. (4) into Eq. (3) yields

$$\frac{d[GSI]}{dt} = K_0 exp(-E_A/RT)[GSI]^n \tag{5}$$

On integration of Eq. (5) with respect to time for zero order reaction ($n = 0$) gives

$$[GSI](t) = [GSI]_0 + K_0 texp(-E_A/RT) \tag{6}$$

On integration of Eq. (3) with respect to time for first order reaction ($n = 1$) gives