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# Effects of Different Freshness on the Quality of Cooked Tuna Steak

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**Abstract**

The variation in quality of yellowfin tuna (*Thunnus albacares*) steaks of different freshness after cooking were studied by analyzing *K* value, adenosine triphosphate (ATP)-related compounds content, histamine content, sensory quality, E-nose and E-tongue analysis. The results indicated that when the freshness of raw tuna steak decreased from sashimi grade to cooking grade, IMP content significantly decreased whereas HxR content significantly increased after cooking. With the decrease of freshness, *K* value of the 4th day sashimi-grade tuna and the 6th day cooking-grade tuna increased from 18% and 24% to 27% and 45% respectively after cooking. The higher histamine content in raw tuna steak, the more significantly increased histamine level of cooked tuna was observed. Raw tuna steaks with sashimi grade have significant variation from those with cooking grade in odor and taste by E-nose and E-tongue analysis after cooking The sensory evaluation showed that the freshness of tuna steak significantly influence the cooking quality ($p<0.05$).

***Keywords:***

Yellowfin tuna (*Thunnus albacares*), *K* value, Cooking quality, ATP-related compounds, histamine, sensory quality

**Industrial relevance**

Tuna is well appreciated worldwide because of its high nutritional value and potential health benefits. Canned tuna is one of the most widespread and recognized fish commodities in the world. The species utilized commonly for canning are skipjack, yellowfin and albacore tuna. Cooking tuna steak is normally used as semi-manufactured products in canned tuna industry. Control of the cooking unit operation is critically important to producing cooked muscle for tuna industry. However, freshness of raw tuna steak may have close connection with the quality of cooked tuna steak. This research paper presents the effects of different freshness on the cooking quality of tuna steak. Finding in this research showed primary knowledge of mastering the freshness of raw tuna steak for ensuring the quality of cooked tuna steaks in canned tuna industry.

## 1. Introduction

Tuna is greatly appreciated worldwide and recommended by International Union of Nutritional Sciences because of its excellent nutritional value and sensory characteristics. The main processing methods of tuna are the fresh, frozen and canned after thermal processing (Catarci, 2005). The species utilized commonly for canning are skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and albacore (*Thunnus alalunga*) tuna. Very high quality tuna steak can be destined for the sashimi market. However, when freshness of tuna steak gets decreased and unsuitable for sashimi, it can continue to be consumed after thermal processing (Mullon et al.,2016). Aquatic foods are highly perishable and usually spoil faster than other muscle products. In fish tissues, autolytic reactions controlled by native enzymes take place immediately after death, leading to the formation of adenosine triphosphate (ATP) breakdown compounds, which can be used as an index of freshness (Kamalakanth et al., 2011). *K* value as an important chemical index has been widely used for fish freshness assessment based on nucleotide degradation. The *K* value is the ratio of the sum of inosine (HxR) and hypoxhantine (Hx) to the sum of ATP and its related degradation products (Mendes et al., 2001; Saito et al., 1959). Generally, tuna with a *K* value of less than 20% is considered to be of 'sashimi grade' and can be consumed in raw condition. When the *K* value reaches 50%, the edible freshness touches the limit (Widiastuti et al., 2013), which can be called cooking-graded tuna. Among the ATP-related compounds, it is known that inosine monophosphate (IMP) is the main

component responsible for fish umami and the desirable fresh fish flavor. On the other hand, the accumulation of Hx is the characteristic index of fresh fish flavor loss (Nakatani et al., 2005). The *K* value and the ATP-related compounds could be the important indexes of the taste and the umami of tuna.

Histamine is a biogenic amine present in high levels in muscle tissues of scombroid fishes, such as tuna, bonito, mackerel and saury (Vitali et al., 2013). High levels of histamine have been known as the causative agent of scombroid food poisoning. The formation of histamine is commonly related to the free histidine content of the fish muscle, the presence of exogenous microbial decarboxylases and certain environmental conditions (Tsai et al., 2005). A variety of microorganisms are known to possess histidine decarboxylase and have the ability to produce histamine (Silva et al., 2011). In freshly harvested fishes, histamine will be absent. Histamine content change could be a consequence of storage and processing of tuna. Histamine determination is of great importance from the point of tuna safety and quality.

Cooking process has the great effects on the quality of product. The previous studies of fish cooking process focused on the effect of different cooking methods on the changes of the components and quality characteristics of different fish species (Bauchart et al., 2007; Hosseini et al., 2014; Neff et al., 2014; Oz & Kotan, 2016; Türkkan et al, 2008) and fish product (Pérez-Palacios et al., 2013). Mohan et al. (2015) reported the effects of different filling medium on cooking time and quality of yellowfin tuna during canning.

Fish tissues are more vulnerable to post-mortem deterioration than other meats. In

addition, during the cooking process, the components of fish have biochemical reactions as other meat (Lagares, 2010; Webb & O'neill, 2008). The combined actions of the lipid oxidation, protein denaturation, and the formation of flavor substances on the senses, color, flavor and texture of fish lead to the changes of fish quality after cooking process (Weber et al., 2008). In view of the problems associated with storage and handling of fresh fish and hence lead to difference in freshness, quality of cooked tuna may be eventually affected.

Thus the present study aimed to study the influence of freshness on the umami and sensory quality after cooking process in canned tuna industry. The combination of electronic nose and tongue applied in this study to assess comprehensive sensory changes of tuna. The quality relevance of the freshness of the raw tuna and the cooking tuna were discussed.

## 2. Material and Method

### *2.1 Fish samples and chemicals*

Frozen yellowfin tuna , which had been skinned and finely chopped were supplied by Zhongshui Fisheries General Corporation (China) kept at -60°C. Samples were made into cubes (3 × 3 × 2 cm3) and wrapped with polyethylene film, packed individually in zip-lock packets and stored at -60°C until use. Frozen samples were placed in a fridge at 4 °C and triplicate samples were taken for analysis every 2 days to get the

tunas with different freshness. All chemicals used in the experiments were of analytical grade and purchased from Guoyao Chemical Reagent Co., Ltd., Shanghai, China.

*2.2 Cooking methods*

The yellowfin tuna blocks of different freshness were put into the steamer, and the temperature probes of the thermocouple are placed into the geometric center of the tuna blocks. The tuna blocks were heated in water-jacket heating mode, meanwhile, the changes of the center temperature were observed. When the center temperature of tuna blocks reached 65 °C, heating was stopped immediately and tuna blocks were quickly removed to make it cool naturally. When the center temperature dropped below 30 °C, the samples were subjected to the following experiments.

*2.3 Determination of K value and the content of ATP-related substances*

Referring to the method of Ryder (1985), the *K* value of tuna with different freshness and the contents of ATP-related substances (adenosine-5'-triphosphate (ATP), adenosine-5'-diphosphate (ADP), adenosine-5'-monophosphate (AMP), inosine-5'-monophosphate (IMP), inosine (HxR) and hypoxhantine (Hx)) before and after cooking were determined by HPLC (LC-20A,Shimadzu,Japan). Each measurement was reported as the mean value of three independent experiments.

*2.4 Determination of Histamine*

Referring to the Chinese official SN/T 2209-2008 export-and-import trade standard method SN/T (2209-2008, 2008), the histamine contents of tuna with different freshness before and after cooking were determined by HPLC (LC-20A, Shimadzu, Japan). Each measurement was reported as the mean value of three independent experiments.

*2.5 Sensory evaluation*

A Quality Index Method (QIM) scheme for the sensory evaluation of tuna was designed (Table 1). Tuna with the same freshness was divided into two parts. One part was kept raw, and the other part was cooked. The sensory evaluation was conducted separately. Added all the results of the evaluation index and get the Quality Index (QI) value. The QI value being 0 represented the best tuna quality. The rise of QI value represented the increasing deterioration of tuna. Sensory evaluation of tuna samples before and after cooking was carried out by a 6 member trained sensory panel.

Table 1 QIM sensory evaluation on tuna steak

| | Index | Characteristics | QIM score |
|---|---|---|---|
| | colour | Red | 0 |
| | | Dark red | 1 |

| | | | |
|---|---|---|---|
| | | Reddish brown | 2 |
| | | brown | 3 |
| Before cooking | odour | Very fresh | 0 |
| | | Fresh | 1 |
| | | Neutral | 2 |
| | texture | elastic, finger mark disappears rapidly | 0 |
| | | less elastic, finger mark delays disappear | 1 |
| | taste | Umami | 0 |
| | | Light fishy | 1 |
| | | fishy | 2 |
| | chewiness | Elastic | 0 |
| | | Less elastic | 1 |
| | | soft | 2 |
| | colour | Ordinary | 0 |
| | | dim | 1 |
| After cooking | odour | Very fresh | 0 |
| | | Fresh | 1 |
| | | Neutral | 2 |
| | taste | Umami | 0 |
| | | Light fishy | 1 |
| | | fishy | 2 |
| | chewiness | Elastic | 0 |
| | | Less elastic | 1 |
| | | soft | 2 |

QI value:0-10(before cooking); 0-7(After cooking)

*2.6 E-nose analysis*

Fish samples were further analyzed by a FOXα 4000 sensor array system (Alpha M.O.S France) to distinguish discrepancies between the aroma profiles of various fish samples. Tuna sample of 0.5g was loaded into a glass vessel. The vessel was then sealed with screw cap immediately and placed in a specimen tray for detection. The vessel was first equilibrated to 40 °C (tuna before cooking) and 60 °C (tuna after cooking) for 600 s before injection, and then 2000μL (tuna before cooking) and

1000μL (tuna after cooking) of headspace gas was injected into the sensor chamber at 2500μL/s. The data acquisition period lasted for 120s. For each sample, E-nose detection was repeated seven times under the same conditions.

*2.7 E-tongue analysis*

Fish samples were analyzed by using ASTREE (Alpha M.O.S France). From each sample, 100 ml deionized water was added to 7 g tuna and homogenized. The mixture was kept for 5 minutes and centrifuged at 5000 rpm for 10 min. The supernatant was filtered and the filtrate of tuna before and after cooking was analyzed by E-tongue.

The experiment was carried out with tuna filtrate, which was used to avoid the influence caused by solid particles. The measurement time was set to 120 s for each sample, which was long enough for sensors to reach stable signal values. For each sample, e-tongue detection was repeated six times under the same conditions.

*2.8 Statistical analysis*

Experimental data were analyzed using the software Microsoft Excel 2003 and SPSS 18.0. The diagram was handled in Origin 8.0. For data analysis, mean, standard deviation and analysis of variance (ANOVA) were used. Significance of differences was defined at $p < 0.05$.

## 3. Results and Discussion

### *3.1 Determination of the freshness of tuna*

Table 2 *K* value of tuna steak during storage at 4 °C

| Storage time (d) | 0 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|
| *K* value (%) | 4.08 ± 0.25 | 11.81 ± 0.08 | 18.03 ± 0.40 | 24.28 ± 1.84 | 41.01 ± 4.27 |

Table 2 summarizes the *K* values obtained for tuna stored at 4 °C for 8 days. The *K value* of tuna steak changed during storage. The initial *K* value for tuna was 4.08%, which indicated that samples were extremely fresh. The *K* value in the study was relative lower than the previous reports (Guizani et al., 2005; Kamalakanth et al., 2011). The *K value* increased linearly at a slow rate during the first 6 days storage reaching the value of 24.28% on the day $6^{th}$ day. Then the *K* value increased more rapidly and reached 41.01% on the $8^{th}$ day. The *K* value was found to be strongly affected by the decomposition of IMP, which is formed by the activity of 5-nucleotidase. The relatively low increase of K value in this study could be explained by the low temperature (4 °C) to inhibit the activity of 5-nucleotidase. The rapid increase in *K* values after 6 days storage could be explained by the depletion of IMP. With the extension of cold storage time, the K value of tuna steak increased. This is in agreement with those reported by (Guizani et al., 2005) for yellowfin tuna at chill-storage.

The *K* value is the important index to evaluate the freshness of fish. The lower the *K* value, the higher the freshness of the fish. It is generally agreed that fishing products with K values lower than 20% as very fresh ones, less than 50% as moderately fresh, and higher than 70% as not fresh (Saito et al., 1959). Based on these *K* value categories, the tuna steak under the experimental conditions of this study can be considered moderately good until the end of the storage. In the initial 4 days, tuna steaks had good freshness and were suitable for consumption in the format of sashimi. After 4 days, the tuna steak was not suitable for raw consumption, but it was still edible after cooking process.

Generally, a *K*-value of less than 20% is considered to be of excellent 'sashimi grade' and 20-50% is considered to be of 'cooking grade'. Thus in this study, keeping freshness period of tuna on "sashimi" grade and "cooking" grade with *K*-value of below 20% and below 50% was found in 4 and 8 days, respectively.

*3.2 Determination of ATP-related substances*

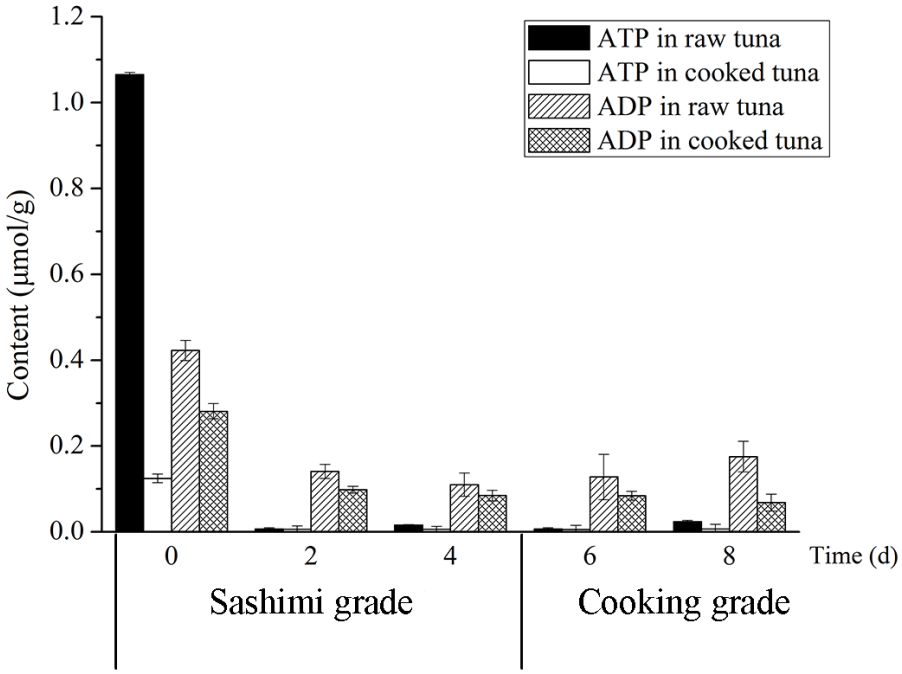


Fig.1 ATP and ADP content of raw and cooked tuna with different freshness. Data points are the mean of n = 3 for each sampling day. Bars represent the standard deviation of the mean. ATP = adenosine-5'-triphosphate, ADP = adenosine-5'-diphosphate.

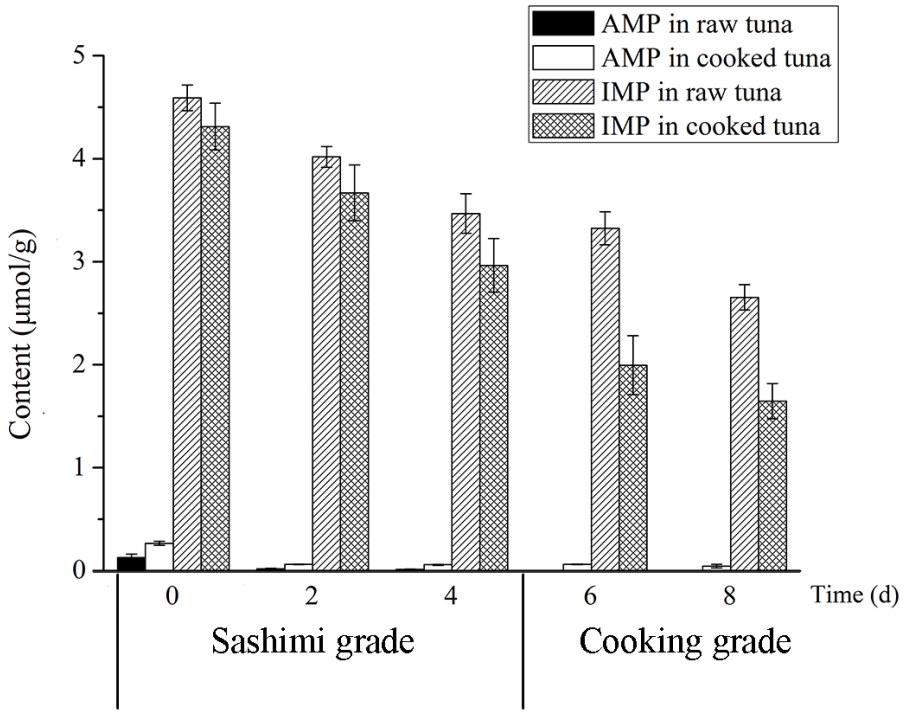


Fig.2 AMP and IMP content of raw and cooked tuna with different freshness. Data points are the mean of n = 3 for each sampling day. Bars represent the standard deviation of the mean. AMP = adenosine-5'-monophosphate, IMP = inosine-5'-monophosphate.

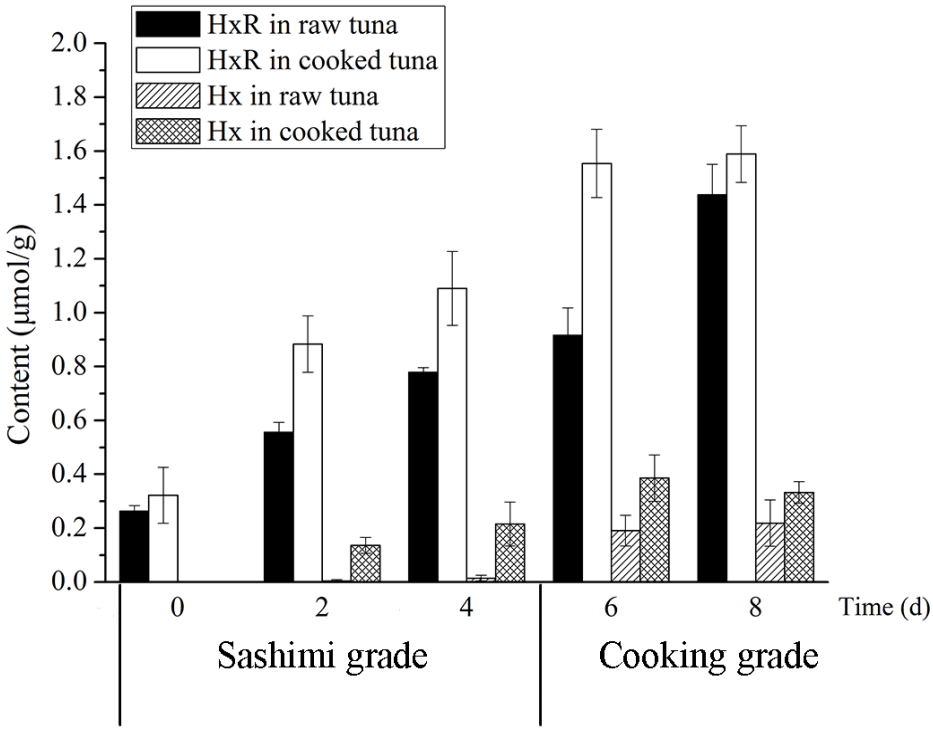


Fig.3 HxR and Hx content of raw and cooked tuna with different freshness. Data points are the mean of n = 3 for each sampling day. Bars represent the standard deviation of the mean. HxR = inosine and Hx = hypoxantine.

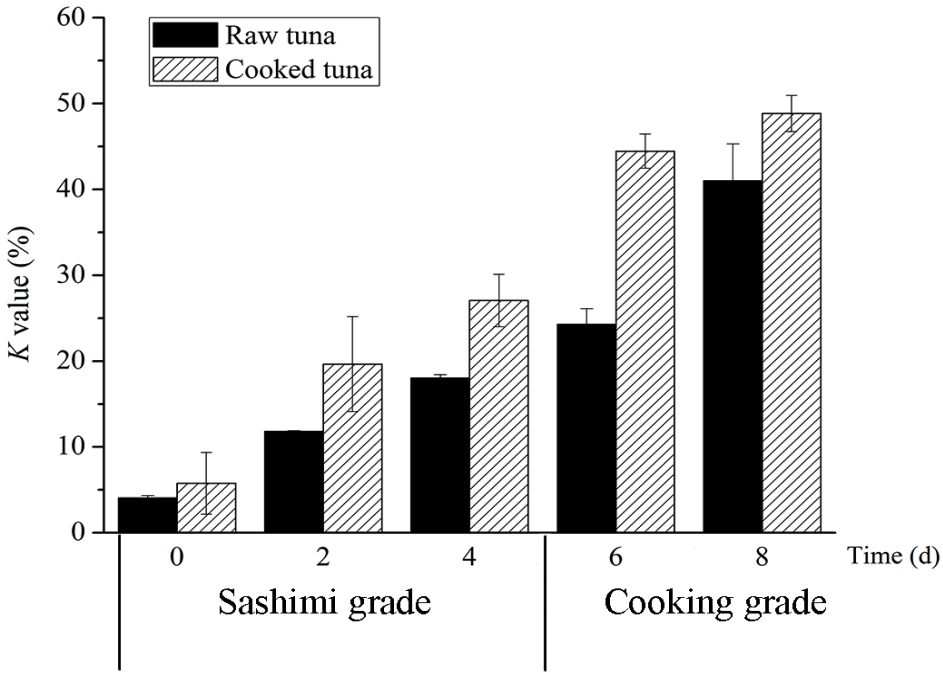


Fig.4 *K* value of raw and cooked tuna with different freshness.

Figures 1-3 illustrate the contents of ATP-related substances in raw and cooked tuna from different freshness. The values for ATP and ADP were initially high and decreased similarly for both raw and cooked tuna. Most of the ATP was degraded within 2 days. The ATP, ADP and AMP levels of both raw and cooked tuna decreased dramatically during the first 2 days and tended to remain stable over the storage from 4-8 days. The level of ATP in raw and cooked tuna fell from 1.065 and 0.125 μmol/g to below 0.007 μmol/g and 0.003 μmol/g, respectively, at 2 days of storage.

During the storage, the IMP content of tuna showed a downward trend, whereas HxR and Hx content showed upward trend. IMP content in cooked tuna was significantly lower than that of the raw tuna ($p$<0.05). HxR and Hx contents in all samples showed remarkable growth as storage time increased and the cooked tuna exhibited

greater increase than the tuna without thermal processing. As the degradation of nucleotides processed, HxR and then Hx, which has a bitter flavour, were produced. An increase in the HxR and Hx was observed with increasing storage time. The cooking process, at each point of storage, resulted in the significant decrease of IMP and significant increase in the levels of HxR and Hx compared with the raw tuna steaks. The result of cooking process of tuna obtained in the present study is similar to that reported by (Ocaño-Higuera et al., 2011), who have reported that the degradation of IMP and accumulation of HxR and/or Hx prove to be a good indicator of freshness reduction in raw fish. In addition, when the freshness of raw tuna decreased from sashimi grade to cooking grade, the IMP content significantly decreased and HxR content significantly increased after cooking.

Fig.4 shows the changes of *K* value of tuna steak before and after cooking. After cooking, *K* value of tuna steak increased significantly ($p<0.05$). With the decrease of freshness, *K* value presented an upward trend. After cooking, *K* value of sashimi grade tuna (day 4) and cooking grade (day 6) increased from 18% to 27% and 24% to 45%, respectively. It can be assumed that when the freshness of tuna changes from sashimi grade to cooking grade, it will result in the significant changes in freshness quality after cooking. Similar research has also been reported about effects of freshness on ATP-related compounds in retorted chub mackerel (Kuda et al., 2007) and indicated that that the measurement of ATP-related compounds in retorted fish products may estimate the freshness in raw materials, the product quality and manufacture practices.

*3.3 Determination of Histamine*

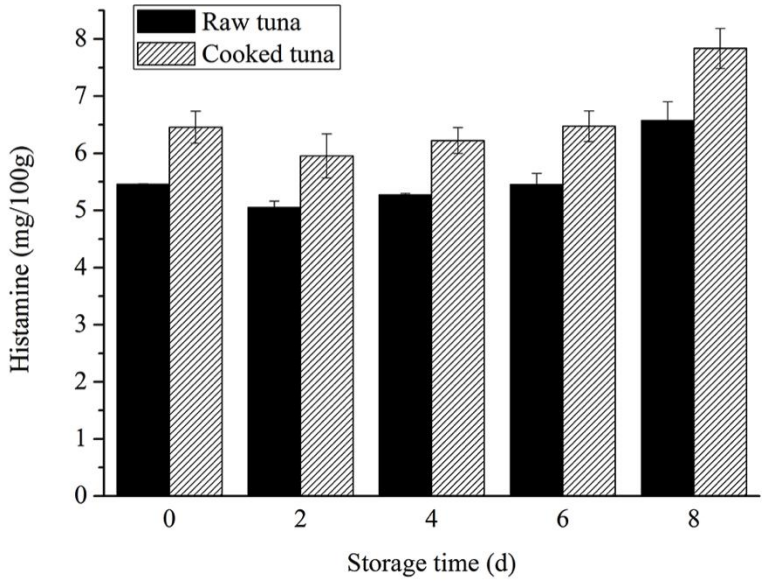


Fig.5 Changes in histamine content of tuna steaks of different freshness before and after cooking

Changes in histamine content of tuna steaks of different freshness before and after cooking are shown in Fig.5. During cold storage, with the decrease of tuna freshness, histamine content presented a trend that first decreased and then increased. Histamine in raw tuna was detected on day 0 with a level of 5.46 mg/100g tuna. Nevertheless, the formation of histamine at refrigeration temperature (4 $^{o}$C) showed some fluctuation. The histamine level decreased to 5.05 mg/100g on the 2$^{nd}$ day, and then gradually increased to 6.57 mg/100g on the 8$^{th}$ day. In the case of cooked tuna, thermal process significantly increased the histamine level, and the histamine content reached to 7.83 mg/100g on the 8$^{th}$ day, which was below the maximum permissible

limit of histamine in fish and fish products in Canada, Switzerland, Brazil and Mercosur of 10 mg/100g (Tarliane et al., 2011). Therefore, safety, with respect to histamine, of tuna with or without thermal processing, was maintained for 8 days.

Histamine generates postmortem by bacterial action on the amino acid. Histamine is formed mainly through the decarboxylation of specific free amino acid by exogenous decarboxylases released by the microbial species associated with the aquatic products (Evangelista et al., 2016). Several factors (the temperature, the pH and oxygen supply, and so on) are known to affect decarboxylase activity and formation of histamine (da Silva et al., 2002). Previous studies had shown that the suitable growth temperature of histamine producing bacteria was 20-25 $^{o}$C, and histamine had the fastest formation rate at 20 $^{o}$C, while the suitable growth temperature of decomposing bacteria was 0 $^{o}$C (Guizani et al., 2005). In low temperature environment, the activity of histamine producing bacteria was inhibited, while the activity of histamine decomposing bacteria was enhanced. If the decomposition rate were greater than the formation rate, the histamine content would decrease. Fig.5 shows that during the first 2 days of cold storage, histamine content of tuna steak declined. It was probably due to the temperature shift of tuna steaks transferred from -60 $^{o}$C ultra low temperature to 4 $^{o}$C cold storage environment. During the course, the activity of histamine producing bacteria was inhibited. When the temperature reached 0 $^{o}$C, the activity of histamine decomposing bacteria was enhanced, resulting in the rapid decomposition of histamine and the decrease of content.

The cooking process resulted in the remarkable increase of histamine in tuna steak ($p$<0.05). With the decrease of tuna freshness, the histamine content presented a trend that first decreased and then increased and reached the highest of 19.20% on the day 8. The results indicated that the histamine level in cooked tuna was highly dependent on the freshness and quality of raw tuna. The higher the histamine content of the raw tuna steaks, the more significantly increased histamine level of cooked tuna would be observed. Soares and Gloria (1994) demonstrated that due to the thermal stability of histamine, the levels has been used as a indicator of quality of the raw materials in the processing of fish and suggested the need for food industries to improve the quality of raw material to improve the quality of the products.

*3.4 Sensory evaluation of tuna steaks*

Table 3 QIM sensory evaluation on tuna steaks of different freshness

| | Index | Cold storage time (d) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 2 | 4 | 6 | 8 |
| Before cooking | Colour | 0.17±0.08$^{a}$ | 0.50±0.21$^{b}$ | 0.61±0.20$^{bc}$ | 0.72±0.46$^{bc}$ | 0.83±0.38$^{c}$ |
| | Odor | 0.67±0.28$^{a}$ | 0.83±0.18$^{ab}$ | 1.11±0.12$^{bc}$ | 1.33±0.28$^{cd}$ | 1.56±0.31$^{d}$ |
| | Taste | 1.17±0.28$^{a}$ | 1.28±0.36$^{a}$ | 1.33±0.28$^{a}$ | - | - |
| | chewiness | 1.50±0.31$^{a}$ | 1.67±0.28$^{a}$ | 1.67±0.28$^{a}$ | - | - |
| | QI value | 3.67±0.72$^{a}$ | 4.61±0.77$^{b}$ | 5.17±0.58$^{b}$ | - | - |
| After cooking | Colour | 0.17±0.08$^{a}$ | 0.22±0.12$^{a}$ | 0.28±0.16$^{ab}$ | 0.56±0.21$^{bc}$ | 0.67±0.18$^{c}$ |
| | Odor | 0.72±0.26$^{a}$ | 0.83±0.18$^{a}$ | 0.94±0.03$^{ab}$ | 1.17±0.18$^{b}$ | 1.17±0.18$^{b}$ |
| | Taste | 0.83±0.18$^{a}$ | 0.83±0.31$^{a}$ | 0.94±0.14$^{ab}$ | 1.17±0.18$^{bc}$ | 1.33±0.28$^{c}$ |
| | chewiness | 0.50±0.21$^{a}$ | 0.72±0.16$^{ab}$ | 0.89±0.17$^{b}$ | 1.22±0.12$^{c}$ | 1.50±0.21$^{c}$ |
| | QI value | 2.22±0.48$^{a}$ | 2.61±0.50$^{b}$ | 3.06±0.33$^{c}$ | 4.11±0.47$^{d}$ | 4.67±0.56$^{e}$ |

Note: Within each row, values with different letters are significantly different ($p$<0.05)

Quality index method (QIM) sensory evaluation of tuna steaks of different freshness before and after cooking is shown in Table 3. QIM is a tool to assess the sensory properties of fish with specific aspects for each species. Researchers have presented a list with fish species for which QIM schemes had been developed (Barbosa & Vaz-Pires, 2004; dos Santos et al., 2014; Lanzarin et al., 2016; Ritter et al., 2016; Sant'Ana et al., 2011). With the decrease of freshness, the color of tuna steaks gradually turned from red to dark red. The color of tuna steak on 0 d is significantly different from those after 0 d ($p$<0.05). In the first grade of freshness ($K$ value < 20%), there was no significant difference ($p$>0.05) in the taste and chewiness of tuna steaks with different freshness. The colour, odour, and taste of tuna steaks after cooking did not significant changes ($p$>0.05). The QI value of tuna steaks gradually increased after cooking with the decrease of freshness and had significant difference ($p$<0.05). This result indicated that the cooking quality of tuna steaks has high correlation with the freshness, and the decrease of freshness will result in the significant deterioration of cooking quality from the view of QI value.

*3.5 E-nose-based PCA*

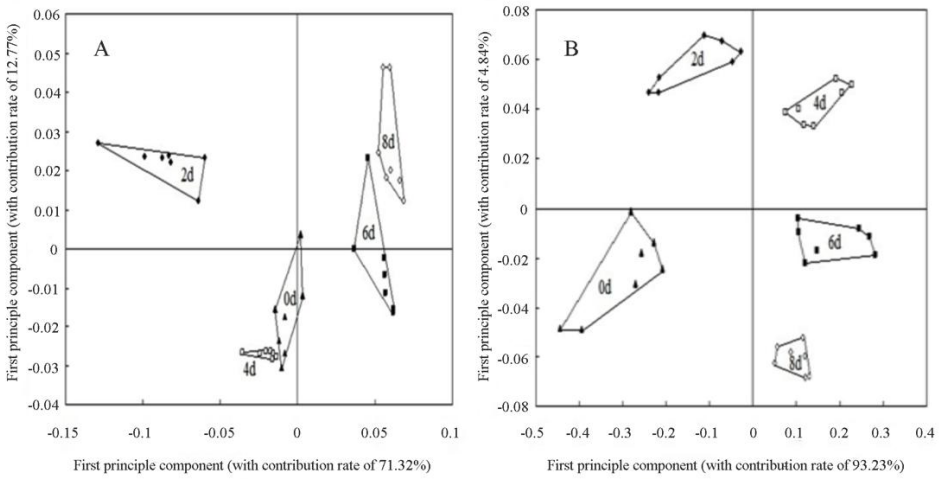


Fig.6 Principal component analysis plot for electronic nose data of raw tuna steaks (A) and cooked tuna steaks (B) with different freshness.

Results of principal component analysis for E-nose data of raw and cooked tuna steaks of different freshness were shown in Fig.6. As shown in the figure, there was a notable cluster tends for the five groups of raw tuna with different freshness, indicating the successfully differentiation of the different samples. Analogously, the aroma of cooked tuna can also be discriminated based on the aroma profiles obtained by E-nose combind with PCA analysis. For raw tuna steaks, the PC1 and PC2 explained 84.09% of the total variation (71.32% for PC1 and 12.77% for PC2). The contribution rate of PC1 of the tuna steaks after cooking reached 93.23%, and that of PC2 was 4.84%. The PC1 and PC2 explained 98.07% of the total variation. The volatile odor of tuna steaks after cooking gradually changed with the freshness of tuna steaks. The result of cooked tuna proved that the direction of the principal components of the odor changed significantly on the $4^{th}$ day, turning from right along PC1 axial and upward along PC2 axial to downward along PC2 axial. Therefore, in

the first grade freshness (*K* value <20%), the odor of tuna steaks after cooking was obviously different from that of tuna steaks with k value higher than 20%. It was also reported that E-nose detection, as observed for sensory evaluation, could help reach a decision on freshness of fish (Güney & Atasoy, 2015; Zhou et al., 2016).

*3.6 E-tongue-based PCA*

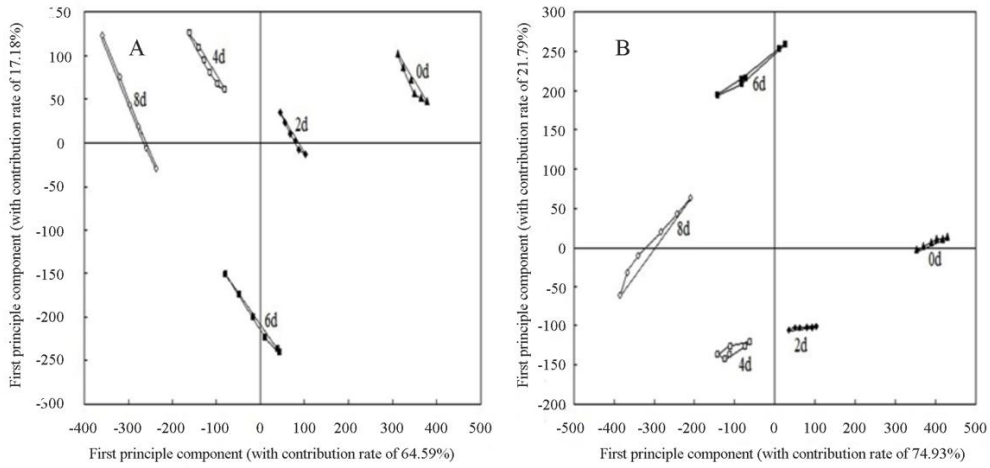


Fig.7 Principal component analysis plot for electronic tongue data of raw tuna steaks (A) and cooked tuna steaks (B) with different freshness.

E-tongue data, collected on six tuna steaks, were processed by PCA. Fig.7 shows the score plot of raw and cooked tuna steaks with different freshness. Examining the score plot, a clear separation of both raw and cooked tuna samples into five groups according to the variety was found. For raw tuna steaks, the PC1 and PC2 explained 81.77% of the total variation (64.59% for PC1 and 17.18% for PC2).

The principal component scores of tuna steaks of different freshness were distributed in different regions and there was no interference among them. Meanwhile, Distinction degree obtained by software analysis was 96, which proved that there was significant difference between the tastes of tuna steaks of different freshness. By observing the change trend of the distribution area of principal component score with the cold storage time, it was found that with the extension of cold storage time, the direction of the principal component first went left along the PC1 axial, from the $4^{th}$ day went right along the PC1 axial and went down along PC2 axial. This change demonstrated that the content and composition of the taste components have significant change from the $4^{th}$ day to the $6^{th}$ day. It probably owing to that the quality of tuna steak in cold storage has an apparent change on the $4^{th}$ day. The result also agreed well with that obtained by sensory evaluation.

The contribution rate of PC1 of the tuna steaks after cooking reached 74.93%, and that of PC2 was 21.79%. The PC1 and PC2 explained 96.73% of the total variation.

By observing the distribution area of principal component score of the tuna steaks of different freshness, it was found that with the decrease of the freshness, the score of the principal component of taste changes gradually. The principal components went left along PC1 axial and downward along PC2 in the first 4 days. The significant changes occur from the $4^{th}$ day. The principal components gradually went upward along PC2 axial from the $4^{th}$ day to $6^{th}$, and from the $6^{th}$ day to $8^{th}$ day went left along PC1 axial and downward along PC2 axial again. This result showed the higher correlation with sensory evaluation. Comparing Fig.7 (A) and Fig.7 (B), significant

change from the 4th day to 6th day proved that the content and composition of taste components of tuna steaks of different freshness after cooking depended on the quality of the tuna steaks before cooking. It was reported that the relationship between sensory attribute and analytical measurement performed by E-tongue was investigated in order to develop a rapid method for the assessment of umami taste (Bagnasco et al., 2014).

## 4. Conclusions

This paper mainly aimed at the effects of different freshness on the *K* value, ATP-related substances, histamine, sensory quality and E-nose and E-tongue analysis after cooking process of tuna steak. The results showed that when the freshness of tuna steaks turned from sashimi grade to cooking grade, there was an apparent change in freshness quality after cooking. When the sashimi-grade tuna steaks degraded to cooking-grade, the decrease amplitude of the content of IMP before and after cooking increased significantly and was consistent with the change of taste in sensory evaluation. Therefore, the differences in sashimi-grade and cooking-grade tuna steaks resulted in the significant difference of the freshness quality of cooked tuna. The content of histamine of tuna steaks after cooking mainly depended on that of raw tuna steaks. Good correlation was obtained between the changes of sensory quality and the results of E-nose and E-tongue analysis. PCA-score plots of E-nose and E-tongue revealed a satisfactory distribution of the samples by the first two principal components. They all proved that when the sashimi-grade tuna steaks degrade to the

cooking-grade, the quality of tuna steaks after cooking had a significant transition. The freshness of raw tuna steaks significantly affect the quality of tuna steaks after cooking process. Especially in the freshness range of 18%-24%, degrading from sashimi grade to cooking grade, a small increase of *K* value of raw tuna steaks would result in an obvious deterioration in quality after cooking. In the cooking process of tuna products, mastering the freshness of raw tuna steaks was an important factor for ensuring the quality of tuna steaks after cooking.

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## Highlights

- Freshness and quality of raw and cooked tuna were analyzed.
- ATP-related compounds in raw tuna may estimate the quality in cooked products.
- Decrease in *K* value of raw tuna resulted in obvious deteriorations in cooked tuna.
- E-nose and E-tongue effectively distinguished tuna steaks with different freshness.
- The freshness of raw meat is important for ensuring the quality of cooked tuna.