Using Polypropylene Bags for Long-Term Storage of Smoked Dried Freshwater Garfish *Xenentodon cancila* (Hamilton, 1822)

Junsuda Tepmuangkhun and Somsamorn Gawborisut*

ABSTRACT

Smoked dried freshwater garfish *Xenentodon cancila* (Hamilton, 1822), a high-priced delicacy, is manufactured by small-scale smoked fish producers in Thailand. The traditional method of storage of smoked dried freshwater garfish (SDFG) involves stacking the product in plastic or bamboo threshing baskets, leaving the SDFG exposed to atmospheric moisture, which is absorbed by the product, causing mould proliferation and a short shelf life. Our experiment aimed to minimise deterioration of the product by keeping the SDFG in polypropylene bags, an affordable option recommended for packing dried foods. The experiment compared food-quality parameters of SDFG stored using the traditional method (TM) to those of SDFG stored in polypropylene bags (PP). SDFG samples kept in TM and PP were sampled at 0, 2, 4, and 6 months and evaluated for yeast and mould count (YM), total plate count (TPC), thiobarbituric acid reactive substances (TBARS), non-enzymatic browning, water activity (a_w), moisture content, CIE colour values (L*, a*, and b*), and sensory scores (general appearance, colour, odour, and taste). The results showed that PP yielded lower YM, TPC, non-enzymatic browning, a_w and moisture content compared to TM; thus, PP provided better storage. PP also provided a higher L* value in month 6 compared to TM, indicating a brighter coloured product. PP scored higher in general appearance and colour compared to TM. However, PP and TM were not significantly different in terms of TBARS, odour, or taste. In conclusion, PP offered better protection and is recommended for long-term storage of SDFG.

Keywords: Fish smoking, Plastic packaging bag, Quality parameter, Smoking-drying process, Storage method

INTRODUCTION

Fish smoking is practised worldwide, especially in developing countries (Adeyeye, 2019). Nadeeshani *et al*. (2020) described three types of smoked fish: cold smoking at a temperature of 30 °C, hot smoking at temperatures of 65-100 ºC, and dry smoking at temperatures of 45-85 ºC for 12-18 h. Traditional Thai smoked fish relies on the dry-smoking process. Smoked dried freshwater garfish (SDFG) is manufactured from *Xenentodon cancila* (Hamilton, 1822), a fish species commonly found in inland water bodies throughout Thailand. SDFG is a high-priced delicacy, and it is mostly produced in areas close to Nam-oun Dam, Sakon Nakhon Province, Thailand. Despite its high price, the product lacks proper packaging. It is simply stacked in plastic or bamboo threshing baskets and thus the product is easily contaminated. In addition, SDFG is often exposed to atmospheric moisture, which is absorbed by the product, causing mould proliferation. The lack of proper packaging for smoked dried fish is a problem in developing countries around the world, as reported by Adeyeye *et al*. (2015), Olayemi *et al*. (2015), Tapotubun *et al*. (2017), Ahmed (2019), and Sakyi *et al*. (2019).

Fish Processing Laboratory, Department of Fisheries, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand
* Corresponding author. E-mail address: somgaw@kku.ac.th
Received 14 January 2021 / Accepted 8 June 2021

Packing smoked dried fish in plastic bags is an affordable method for small-scale producers in developing countries. Most studies of smoked dried fish have been conducted using polyethylene bags (PE) (Nurullah *et al*., 2007; Al-Reza *et al*., 2015; Nahid *et al*., 2016; Kelechi *et al*., 2017; Ahmed, 2019; Ricketts, 2019). Polypropylene bags (PP), composed of thick plastic (0.075 mm), may also protect SDFG from environmental influences. Although PP bags are widely used in Thailand and neighbouring countries for storing dried foods and snacks, their use for storing smoked dried fish has not been scientifically evaluated. Demonstrating the effective use of PP bags for smoked dried fish may promote the use of proper packaging and improve the protection of the product in Thailand and other places where PP bags are available and affordable. The objective of this study is to compare the food-quality parameters of SDFG kept traditionally in baskets to those packed in PP bags for long-term storage.

MATERIALS AND METHODS

Drying and smoking process

Wild-caught freshwater garfish, captured from Nam-oun Dam (Sakon Nakhon Province, Thailand) during March-April 2015, was used for the experiment. Iced garfish purchased from local fishers were graded and sized. Fish with body weight of 17-25 g were selected. These were washed twice, frozen, and transported to the Department of Fisheries, Khon Kaen University. Upon arrival, the fish were kept in a freezer at -20 °C until the experiment in June 2015. Five hundred grams of fish was thawed and determined for proximate compositions; the sample contained 76.15 % moisture, 17.81 % protein, 1.33 % fat, and 4.68 % ash.

To prepare freshwater garfish for the smoking-drying process, the fish were thawed overnight in a refrigerator at 4 °C, the jaw was removed, and the body was butterflied by cutting through the belly towards the head. The head, backbone and ribs were left intact. The innards were removed, and the head was split lengthwise. The fish was gently pounded with a knife to flatten the body and then washed.

Five kilograms (200-294 fish) of the prepared garfish were then hand-mixed with seasonings (10 g salt, 10 g sugar, 50 g minced peeled garlic, and 250 g potable water) and allowed to marinate for 15 min at 4 ºC in a refrigerator. Four fish were arranged as a set. The fish were placed skin down into a single layer on drying racks, with the ends of the fish overlapping. All sets of fish were placed in a hot air oven (KWF-SOV-70B hot air oven, Beijing KWF Sci-tech Development Co., Ltd., China) and dried at 50 ºC for 12 h. The dried fish was then smoked in a traditional iron sheet oven at 90-100 °C for 2 h. Natural smoke was produced by smouldering hardwood sawdust. Smoked dried freshwater garfish (Figure 1) was then ready for use in the storage experiment.

Storage methods

Smoked dried freshwater garfish was divided into eight portions (250 g·portion^{-1}) for the experiment. Two storage methods (TM and PP) and four storage times (0, 2, 4 and 6 months) were investigated. The eight treatment combinations (2 storage methods × 4 storage times) were randomly assigned to the eight portions of SDFG. To store the product using TM, each portion of SDFG was placed in a plastic basket. The basket was kept in a well-aerated room at ambient temperature. To store the product using PP bags, each portion of SDFG was placed in a PP bag with a thickness of 0.075 mm (Maneemongkol Import-Export Co. Ltd., Bangkok, Thailand). The oxygen transmission rate of these bags at 23 °C and 0 % relative humidity is 1,245 cm^3·m^{-2}·d^{-1}·bar^{-1}. The water vapour transmission rate at 37.8 °C and 90 % relative humidity is 5.89 g·m^{-2}·d^{-1}. The bags were sealed using a PFS-200 impulse sealer (Hualian Zhejiang, China). The samples in PP bags were placed in a plastic basket and kept in the same room as the fish stored in the TM treatment.

The samples were stored for six months from June–December 2015. Months 0-5 of the experiment were in the rainy season (June–October). Ambient temperature and relative humidity in the storage room were 28-31 °C and 79-83 %, respectively. Month 6 of the experiment (November) was in early winter. Ambient temperature and relative humidity were 20-25 °C and <75 %, respectively. The stored samples were analysed for food-quality parameters at 0, 2, 4, and 6 months.

Food-quality parameter analyses

Microbial analyses

Determination of YM and TPC were carried out according to Oksuz *et al*. (2008) and Al-Harbi and Uddin (2005), respectively. SDFG was aseptically pulverised, then 25 g of the pulverised sample was combined with 225 mL of sterilised 0.1% peptone water (10^{-1} dilution) and mixed for 60 s using a Stomacher 3500 Jumbo blender (Seward Laboratory Systems Inc., Bohemia, NY, USA). After that, serial dilutions (10^{-2}-10^{-7}) were performed. Appropriate dilutions (10^{-1}-10^{-6}) (0.1 mL) were spread onto acidified potato dextrose agar to enumerate and incubate YM at 23±1 °C for five days. One millimetre of the appropriate dilution (10^{-3}-10^{-7}) was enumerated for TPC in standard plate count agar (BBL, Spark, MD, USA) at 30±1 °C for 48 h. The YM and TPC counts were expressed in log CFU·g^{-1}.

Chemical analyses

The parameter TBARS was measured according to Mol *et al*. (2012). Ten grams of pulverised SDFG was combined with 97.5 mL distilled water, 2.5 mL of 4 N hydrochloric acid, three drops of anti-foaming agent, and four glass beads in a 250 mL Kjeldahl flask. The contents were immediately distilled using a Kjeltec™ 8100 (Foss, Hilleroed, Denmark) distillation unit. Fifty millilitres of condensate liquid was collected, of which 5 mL was mixed thoroughly with 5 mL TBA reagent in a tube. This reagent was prepared by dissolving 0.02 M thiobarbituric acid in 90% glacial acetic acid. The tube was capped, incubated in boiling water for 30 min, and ice cooled. The

Figure 1. Smoked dried freshwater garfish.

solution was measured at 538 nm for absorbance using a Spectronic 15 spectrophotometer (Thermo Fisher Scientific Pvt. Ltd., India). The TBARS value was calculated according to the following formula:

$$\text{TBARS (mg malonaldehyde} \cdot \text{kg}^{-1} \text{ sample)} = 7.8 \times \text{O.D.},$$

Where 7.8 is a constant value and O.D. is optical density at 538 nm.

Non-enzymatic browning was analysed using a method modified from Dissaraphong *et al*. (2006). Five grams of pulverised SDFG was combined with 50 mL of 50 % ethanol (v/v). The mixture was extracted for 60 min at 400 rpm using a magnetic stirrer (MS300HS, Misung Scientific Co. Ltd., Korean) and filtrated through Whatman No. 1 filter paper. The collected supernatant was measured at 420 nm for its absorbance using a Spectronic 15 spectrophotometer (Thermo Fisher Scientific Pvt. Ltd, India).

Physical analyses

The value of water activity (a_W) of SDFG was measured using an Aqua Lab Series 4TEV water activity meter (Aqua Lab, Pullman, WA, USA).

Moisture content was determined using an oven-drying method according to Al-Reza *et al*. (2015). Five grams of SDFG was dried in an electric oven at 100±2 °C for 16-18 h and kept in a desiccator until weighing with a digital balance. The weight loss was expressed as % moisture content in the sample.

The International Commission on Illumination (CIE) colour values (L*, a*, and b*) were determined under a D65 artificial daylight bulb at 10^o standard angle using a Konica Minolta CM-2600d spectrophotometer (Konica Minolta, Inc., Japan). Surface colour of the meat on the bone side was subjected to colour determination. The belly flap with a silver membrane and the backbone were avoided. The L*, a*, and b* represent lightness, redness-greenness, and yellowness-blueness, respectively.

Sensory evaluation

Sensory attributes (general appearance, colour, odour, and taste) were evaluated according to Thai Community Products Standard No. 151/2546 for grilled-dried fish (Tepmuangkhun *et al*., 2019). The attributes were rated by five experienced panellists with scores of 1 to 4 (1 = poor/needs improvement, 2 = fair, 3 = good, and 4 = very good). The score was judged according to the criteria shown in Table 1.

Statistical analysis and experimental design

The experimental design was a 2×4 factorial arrangement in a randomised complete block design (RCBD). Two storage methods (TM and PP) and four storage times (0, 2, 4, and 6 months) were investigated. The experiment was repeated three times using three batches (5 kg·batch^{-1}) of freshwater garfish obtained from three different fishers. The data were analysed using analysis of variance. Means were compared using the least significant difference (LSD). Statistical analysis was conducted using the IBM SPSS Statistics 21 program (IBM, Armonk, New York, USA) at a 95 % confidence level.

Table 1. Quality criteria used for rating smoked dried fish.

Attribute	Characteristics
General appearance	Appears completely dried and crispy. Contains no major breakage of product or black particles of soot on the surface.
Colour	Displays reddish brown or golden brown colour. Contains no dark burnt colour.
Odour	Exhibits natural odour of smoked dried fish without any fishy, musty, rancid, or offensive odour.
Taste	Contains natural taste typical of the fish species used in the preparation of the product.

RESULTS AND DISCUSSION

Microbial analyses

Yeast and mould count (YM)

The YM counts of SDFG are illustrated in Figure 2a. The results show that in months 0 and 4, YM levels were not significantly different between TM and PP (p>0.05). However, in months 2 and 6, PP had significantly lower YM levels compared to TM (p<0.05). YM counts of TM increased slowly during the six-month storage. However, the counts for PP fluctuated throughout the storage period. The initial count of PP in month 0 (4.39 log CFU·g^{-1}) was higher than the counts in months 2-6 (3.91-4.22 log CFU·g^{-1}).

In the present study, PP clearly contained lower YM counts in months 2 and 6 than TM. The results suggest that the PP material may protect the product from yeast and mould contaminants from the surrounding environment. Ahmed (2019) reported that plastic bags can provide protection against environmental effects, so that their impact on the quality of smoked dried fish is minimised. In addition, PP may protect SDFG from atmospheric moisture, thus lowering moisture absorption by the product and consequently reducing YM proliferation. The results show that YM counts of TM increased slowly during storage. The results are in agreement with Kelechi *et al*. (2017), who found that YM counts in smoked dried mackerel stored in cardboard boxes increased slightly from no visible growth in week 0 to levels of <28 CFU·g^{-1} in week 3. In our study, YM counts in PP fluctuated within the range of 3.91-4.39 log CFU·g^{-1} during six months of storage. Kelechi *et al*. (2017) also reported that YM counts in smoked dried mackerel stored in plastic bags (high density polyethylene) increased from no visible growth in week 0 to levels of <28 CFU·g^{-1} in week 3. After that, the counts (<28 CFU·g^{-1}) tended to remain low and stable during 3-9 weeks of storage at ambient temperatures.

Total plate count (TPC)

The TPC levels of SDFG are shown in Figure 2b. The TPCs in months 0 and 4 were not significantly different (p>0.05) between treatments. However, in months 2 and 6, PP contained significantly lower TPCs than TM (p<0.05). The TPCs obtained from both TM and PP in months 2, 4 and 6 were lower than initial counts obtained in month 0. The TPCs of TM decreased from 6.64 log CFU·g^{-1} in month 0 to 6.08 log CFU·g^{-1} in month 2. After that,

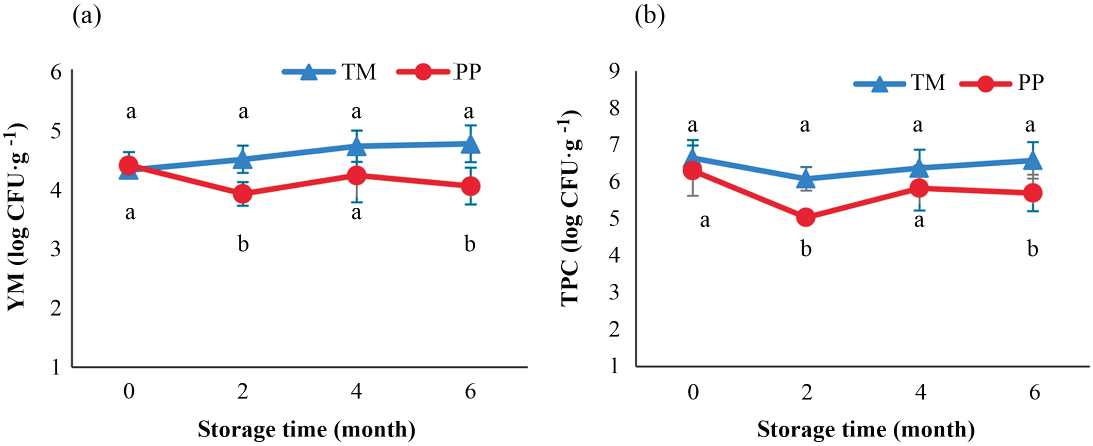

Figure 2. Yeast and mould count (YM) (a) and total plate count (TPC) (b) of smoked dried freshwater garfish as affected by storage method during six-month storage (n = 24). TM: Traditional method (stored in plastic baskets without packaging), PP: Stored in sealed polypropylene bags. Different letters above and below mean values for the same month indicate significant difference at 95 % confidence level.

the counts slowly increased to 6.58 log CFU·g^{-1} in month 6. The counts for PP decreased from 6.30 log CFU·g^{-1} in month 0 to 5.04 log CFU·g^{-1} in month 2. After that, the counts increased to 5.83 and 5.7 log CFU·g^{-1} in months 4 and 6, respectively. The sample of SDFG obtained from TM in month 0 contained the highest reading for TPC (6.64 log CFU·g^{-1}), while the lowest TPC (5.04 log CFU·g^{-1}) was found in the sample obtained from PP in month 2.

We found that during months 2 through 6, TPC was reduced in PP, indicating that this packaging protects SDFG from microbial contaminants, as previously described. In addition, the packaging minimises exposure of SDFG to atmospheric moisture, which may consequently reduce microbial proliferation. Ahmed (2019) recommended packing smoked dried fish in plastic bags because the bags can minimise atmospheric moisture absorption, thus preventing mould proliferation in the product. Our results indicate that using plastic PP bags benefits the microbial quality of SDFG. Similarly, Kelechi *et al*. (2017) found that smoked dried mackerel kept in plastic-laminated aluminium foil or high-density polyethylene bags had lower TPC counts in week 3 than the product kept in cardboard boxes. The TPCs of SDGF stored in TM and PP did not increase during storage, in contrast to Kelechi *et al*. (2017), who found that TPC in smoked dried mackerel stored in cardboard increased slowly during nine weeks of storage. Similarly, TPC of smoked dried mola (*Amblypharyngodon mola*) packed in polyethylene bags increased slowly during two months of storage (Nurullah *et al*., 2007).

Contamination of smoked dried fish may occur at smokehouses from processors and an unhygienic environment, where the product is exposed to dust and flies (Anihouvi *et al*., 2019). However, most of the contamination occurs between smokehouses and markets, and it is caused by improper packaging, such as using dirty paper to cover the product. In addition, inappropriate handling, transport and storage can contribute significantly to high levels of microbial contamination (Nunoo and Kombat, 2013; Yakubu and Ngueku, 2015). Our study demonstrates that PP bags can lower microbial counts in SDFG; thus, using the bags for storing smoked dried fish is recommended. Packing smoked dried fish in PP bags at the smokehouse in combination with good personal hygiene of processors, proper handling and appropriate transport are essential for protecting the product from contaminants.

Chemical analyses

Thiobarbituric acid reactive substances (TBARS)

TBARS is commonly used as a quality indicator in the fish and meat industries (Yang and Boyle, 2016). The TBARS values of SDFG are presented in Figure 3a, and show that PP and TM were not significantly different ($p>0.05$). The lowest value (0.06 mg malonaldehyde·kg^{-1}) was found in PP at month 0, and the highest value (0.35 mg malonaldehyde·kg^{-1}) was found in PP at month 6. In the present investigation, TBARS values were not affected by the storage methods. However, the TBARS in TM and PP increased as storage time increased. The highest TBARS value of 0.35 mg malonaldehyde·kg^{-1} was found in PP at month 6. TBARS is routinely used as an index of lipid oxidation in meat products in storage, and rancid flavour is initially detected in the products between values of 0.5 and 2.0 mg malonaldehyde·kg^{-1} (Wannasupchue *et al*., 2011). Alparslan *et al*. (2013) reported that good quality fish should contain TBARS of less than 5 mg malonaldehyde·kg^{-1}. The highest level of TBARS (0.35 mg malonaldehyde·kg^{-1}) found in any of our samples was far lower than this recommendation, indicating that oxidative rancidity may not be a quality problem in SDFG during this length of storage. Kjällstrand and Petersson (2007) stated that smoke from wood pyrolysis contains phenolic compounds that have antioxidative properties. These properties may slow the oxidation process, resulting in the low TBARS values observed in SDFG during storage.

Non-enzymatic browning

Measurements of non-enzymatic browning in SDFG are shown in Figure 3b. During the first four months, values were not significantly different between TM and PP ($p>0.05$). However, in month 6, non-enzymatic browning of TM was significantly higher than that of PP ($p<0.05$). The non-enzymatic browning of TM increased slowly during months 0-4, then with a rapid rise to 0.97 in month 6. The PP treatment showed a similar increasing trend, with a sharper increase in month 6.

It is noteworthy that TM contained higher levels of non-enzymatic browning compared to PP throughout the storage period. Maillard reactions may play a crucial role in accelerating non-enzymatic browning in TM. Lund and Ray (2017) stated that Maillard reactions are initiated by interactions of amino groups on proteins, peptides, and amino acids with carbonyl groups on reducing sugars. The likelihood of Maillard-reaction browning in a product increases as a_w increases, reaching a maximum at water activity in the range of 0.6-0.7 (Mathew *et al*., 2019). Singh and Anderson (2004) explained that non-enzymatic browning varies with a_w. A maximum rate typically occurs at a_w between 0.6 and 0.8, and lower reaction rates have been found at both higher and lower a_w values. During months 2-6, a_w levels in TM were 0.6-0.67 (Figure 4a), which is within the range of highest activity. Therefore, TM may undergo more non-enzymatic browning compared to PP, which produced a_w values in the range of 0.45-0.56. Similarly, Ibadullah *et al*. (2019) foundthat a_w played an important role in Maillard reactions developed in fish crackers during storage.

Another type of non-enzymatic browning which may occur in TM during storage is lipid browning. Nielsen *et al*. (2010) stated that lipid browning occurs when oxidised lipids and lipid-soluble compounds decompose to form browning precursors. Oxygen plays an important role in lipid browning because it causes chain reactions that produce free radicals. Hydroperoxide free radicals and reactive carbonyls produced by decomposition of hydroperoxides are the precursors of macromolecular browning pigments. TM may expose SDFG directly to atmospheric oxygen, allowing the product to undergo greater lipid oxidation and thus contain more hydroperoxide free radicals. The hydroperoxide free radicals and reactive carbonyls produced by decomposition of the free radicals may yield more macromolecular browning pigments, causing the higher level of non-enzymatic browning in SDFG using TM at month 6 as compared to the product stored in PP. PP bags may allow some oxygen passage, and thus similar lipid browning, but to a lesser degree than TM.

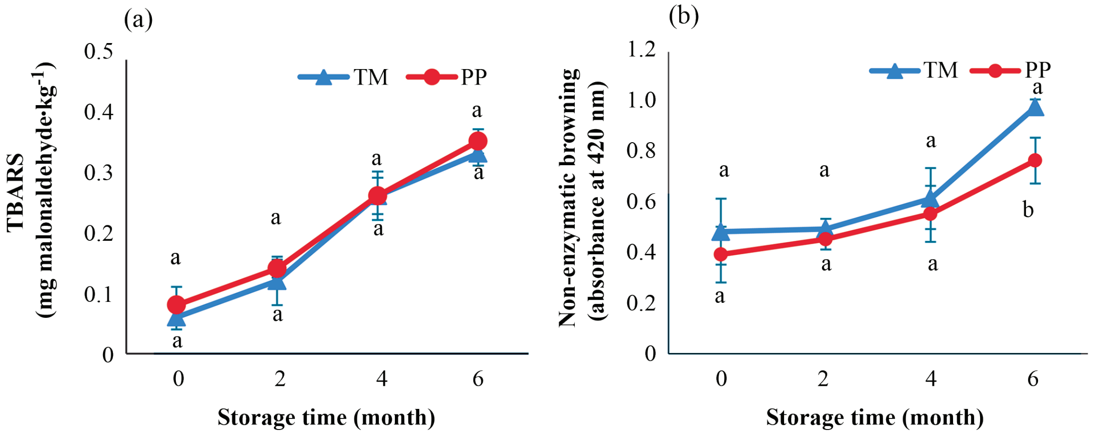

Figure 3. Thiobarbituric acid reactive substances (TBARS) (a) and non-enzymatic browning (b) of smoked dried freshwater garfish as affected by storage method during six-month storage (n = 24). TM: Traditional method (stored in baskets without packaging), PP: Stored in sealed polypropylene bags. Different letters above and below mean values for the same month indicate significant difference at 95 % confidence level.

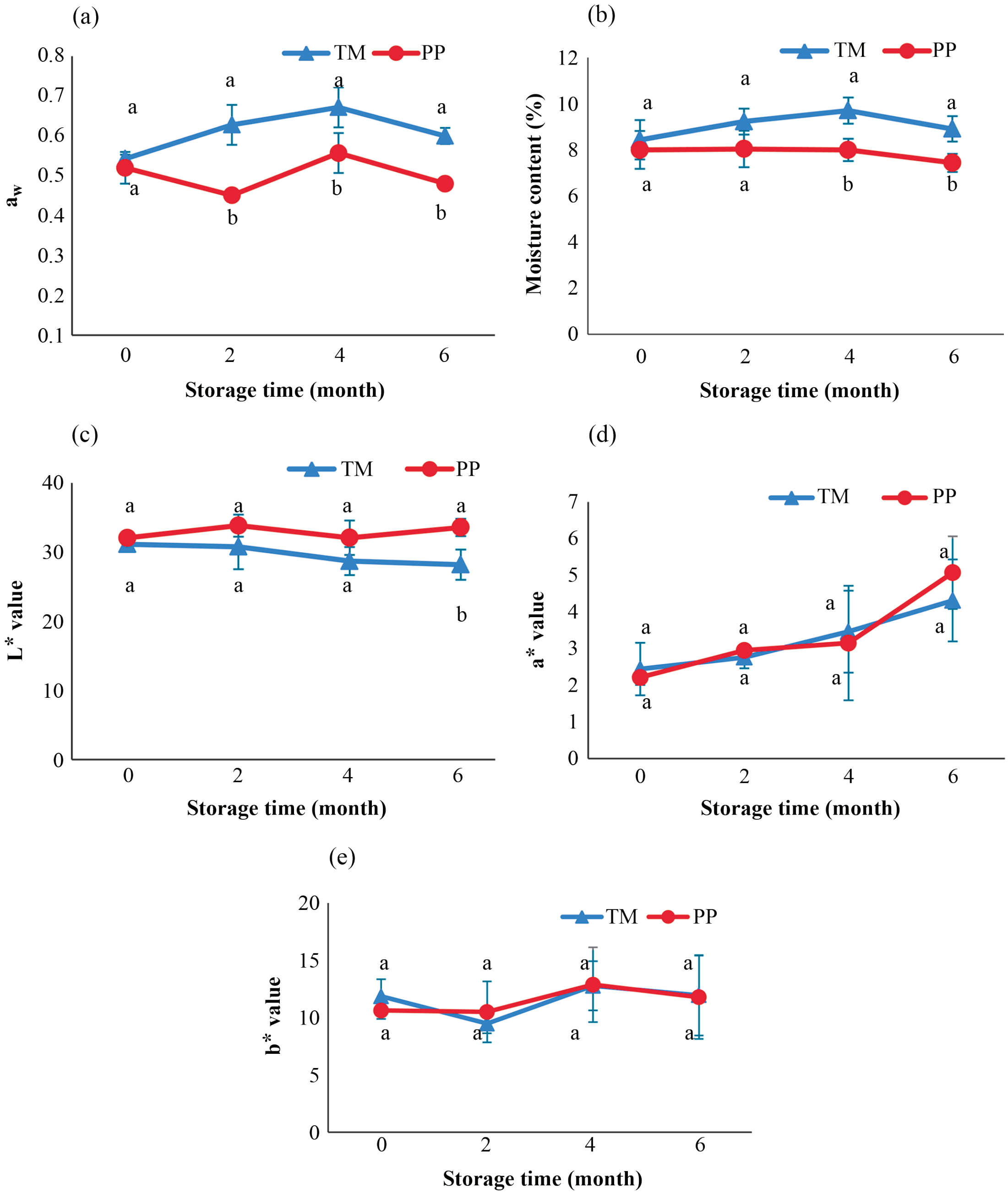

Figure 4. The a_w (a), moisture content (b), L* (c), a* (d), and b* (e) of smoked dried freshwater garfish as affected by storage method during six-month storage (n = 24). TM: traditional method (stored in plastic baskets without packaging), PP: stored in sealed polypropylene bags. Different letters above and below mean values for the same month indicate significant difference at 95 % confidence level.

Either Maillard reactions or lipid browning may be responsible for the increasing non-enzymatic browning of both treatments during storage. Ayeloja *et al*. (2020) stated that Maillard reactions increased during storage of smoked Nile tilapia *Oreochromis niloticus*, and the reactions caused reduction of amino acids in the product. Turan and Erkoyuncu (2012) and Lund and Ray (2017) stated that Maillard reactions can alter food properties such as appearance, odour, taste, texture and protein functionality. The reactions occurring during storage of SDFG may further change sensory quality of the product as storage time increases.

Physical analyses

Water activity (a_w)

Average levels of a_w in SDFG are shown in Figure 4a. The results show that during months 2 through 4, TM had significantly higher a_w compared to PP ($p<0.05$). The a_w of TM in month 0 was well below 0.6. However, during months 2 through 6, the a_w equalled or exceeded 0.6. The a_w of PP fluctuated throughout the storage period, but all measurements (0.45-0.56) were below 0.6. In months 2 and 4, a_w of TM was greater than 0.6, which fails to meet the requirement for dry foods (Chieh, 2006). Without packaging, the TM exposed SDFG directly to the high atmospheric moisture during months 2 through 4 (the rainy season). The dried fish may have picked up this moisture, causing the a_w in the product to exceed 0.6. The results show that in month 6 (November), which is early winter, the humidity was <75 % and the a_w of all samples was reduced to 0.6 (Figure 4a). Throughout the experiment, a_w values of SDFG stored in PP remained below 0.6. PP can minimise atmospheric moisture passing into the package, thus lowering moisture absorption by the product and maintaining $a_w<0.6$.

Moisture content

Moisture content in SDFG treatments are shown in Fig. 4b. The moisture content of TM and PP was not significantly different in months 0 and 2 ($p>0.05$). However, in months 4 and 6, TM had significantly higher moisture content than PP ($p<0.05$). The moisture content of TM increased slowly from 8.44 % in month 0 to 9.71 % in month 4, then fell slightly to 8.91 % in month 6. The decline in moisture in TM at month 6 (early winter) reflects the lower atmospheric humidity. The moisture content of PP was stable (8.00-8.04 %) during the first four months, then declined slightly to 7.44 % in month 6. The moisture content of PP was significantly lower than TM in months 4 and 6 because of direct exposure to the atmosphere in TM. The results suggest that PP bags may minimise passage of atmospheric moisture into the package, thus maintaining moisture content of the product during six-month storage.

A moisture content in smoked dried fish of less than 10 % or a_w to be lower than 0.75 is required by Codex Alimentarius (2013). Our study found that moisture content of both TM and PP was lower than 10 % throughout the storage period. Ibadullah *et al*. (2019) found that initial moisture content in fish crackers stored in plastic-laminated aluminium foil bags ranged between 4-5 %, and that moisture content gradually decreased during eight months of storage. Kelechi *et al*. (2017) reported that fish with moisture content of 10-15 % had a shelf-life of 3-9 months. Based on this information, SDFG may retain good quality for longer than six months of storage.

CIE colour values

The L*, a*, and b* values of SDFG are shown in Figure 4c-4e. The L* values of the samples in TM and PP treatments were not significantly different during months 0-4 ($p>0.05$) (Figure 4c). However, in month 6, the L* value of TM was significantly lower than that of PP ($p<0.05$). Also, the L* values of TM decreased as storage time increased, whereas the L* values of PP fluctuated in the range of 32.05-33.82 during the six-month storage. The reduction of L* in TM at month 6 indicates a darker colour. Increasing non-enzymatic browning in TM caused by either Maillard reactions or lipid oxidation, as previously described, may have contributed to the declining L* values in TM. The darker colour tone may have consequently reduced sensory colour scores of the product.

Although L* values of SDFG were affected by the storage method, a* values did not differ by treatment (p>0.05) (Figure 4d). The a* values were affected only by storage time (p<0.05), with values for both TM and PP increasing with storage time. The results suggest that the development of redness of SDFG progresses during long-term storage, perhaps caused by non-enzymatic browning. Although a* values of SDFG were affected by storage time, b* values were not affected by storage time or storage method (p>0.05) (Figure 4e). The b* values of TM and PP fluctuated between 9.45-12.73 and 10.46-12.83, respectively, during six-month storage. We conclude that packaging the SDFG in PP benefits the colour quality by mitigating discolouration in the product during long-term storage. Similarly, Ibadullah *et al*. (2019) reported that plastic-laminated aluminium foil bags protected the colour of fish crackers during long-term storage.

Sensory evaluation

Scores for sensory attributes (general appearance, colour, odour and taste) of SDFG are summarised in Figure 5a-5d. General appearance scores of the product during months 0-4 were not

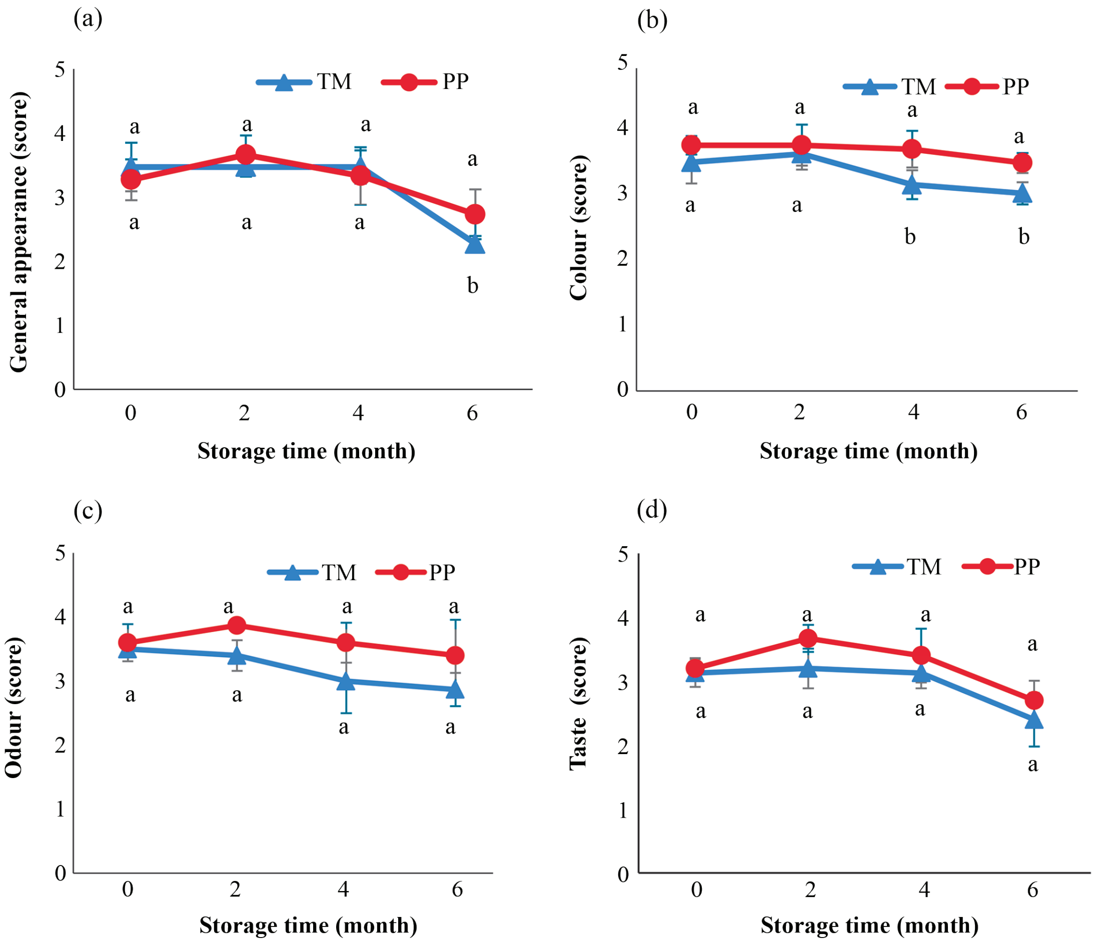

Figure 5. Sensory general appearance (a), colour (b), odour (c), and taste (d) of smoked dried freshwater garfish as affected by storage method during six-month storage (n = 24). TM: traditional method (stored in plastic baskets without packaging), PP: stored in sealed polypropylene bags. Different letters above and below mean values for the same month indicate significant difference at 95 % confidence level.

significantly different between TM and PP ($p<0.05$) (Figure 5a), and changed only slightly with storage time. However, scores at month 6 declined for PP (2.73), and declined sharply for TM (2.27), with a significant difference between treatments ($p<0.05$).

Sensory colour scores of SDFG during months 0-2 were not significantly different between TM and PP ($p>0.05$) (Figure 5b). However, during months 4-6, colour scores of TM were significantly lower than those of PP ($p<0.05$). The colour scores of TM and PP decreased gradually from month 2 to 6 (from 3.6 to 3.0 in TM; from 3.73 to 3.46 in PP).

In general, SDFG stored using TM had lower general appearance and colour scores compared to PP. The product stored using TM, having no proper packaging, can easily absorb atmospheric moisture and ambient contaminants, and consequently had higher a_w and moisture content, and contained some dirt on the surface. These undesirable characteristics caused lower general appearance scores. As mentioned previously, the a_w of TM was in a range supporting Maillard reactions throughout the experiment, and therefore exhibited a darker colour tone compared to PP and received a lower sensory colour score.

Although the storage methods affected the general appearance and colour scores of SDFG, they did not significantly affect odour or taste of the product ($p>0.05$) (Figure 5c, 5d). It is notable that odour and taste scores were mostly affected by storage time, and the scores decreased as storage time increased. Pronounced reduction of odour and taste scores was mostly found after month 2. The odour scores of TM declined from 3.40 in month 2 to 2.78 in month 6. Those of PP were reduced from 3.87 in month 2 to 3.4 in month 6. The taste scores of TM decreased sharply during months 4-6, from 3.13 to 2.4. The taste scores of PP also fell rapidly during this period, from 3.4 to 2.7. An unusual odour and taste in SDFG was noted by panellists, especially at the end of the storage period.

Non-enzymatic browning reactions (especially Maillard) during storage may have caused the unusual odour and taste, thus lowering the scores of the product. Turan and Erkoyuncu (2012) and Lund and Ray (2017) stated that Maillard reactions affect multiple food quality parameters, including organoleptic properties (colour, appearance, odour, taste, texture) and protein functionality. The reactions may be responsible for the declining odour and taste scores during storage of SDFG. Ayeloja *et al*. (2020), Moula Ali *et al*. (2020) and Li *et al*. (2020) similarly reported that Maillard reactions during storage may be responsible for the reduction of sensory scores in smoked fish, fish crackers and ready-to-eat shrimps, respectively.

From the sensory evaluation, we conclude that PP benefits the sensory quality of the SDFG. Benefits of different types of plastic and plastic-laminated aluminium foil on sensory scores of dried or smoked dried fishery products have been reported by Nurullah *et al*. (2007), Ibadullah *et al*. (2019) and Ahmed (2019). Our study shows that sensory scores of TM and PP decreased as storage time increased. However, sensory aspects of all samples were rated as higher than 2. Based on this information, shelf life of SDFG may exceed six months.

CONCLUSION

Storing SDFG in sealed PP bags yielded better results in terms of TPC, YM, a_w, moisture content, and non-enzymatic browning, as compared to stacking the product in a plastic basket without any packaging (TM). Thus, the use of PP bags for long-term storage of smoked dried fish should be recommended in Thailand and other locations where these bags are available and affordable. Using no package or an open basket for storing smoked dried fish must be avoided to minimise contamination and atmospheric moisture absorption. Our results show that shelf life of SDFG may exceed six months. Further studies focusing on food-quality changes and shelf life during twelve months of storage should be conducted.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to Khon Kaen University for research grant No. 58131 108. We also thank Mrs. Kamploy Tepmuangkhun for information about commercial production of SDFG produced by a small-scale smoked fish producer in Sakon Nakhon Province, Thailand.

LITERATURE CITED

Adeyeye, S.A.O. 2019. Smoking of fish: A critical review. **Journal of Culinary Science and Technology** 17: 559-575. DOI: 10.1080/15428052.2018.1495590.

Adeyeye, S.A.O., O.B. Oyewole, A.O. Obadina, A.M. Omemu, H.A. Oyedele and S.O. Adeogun. 2015. A survey on traditional fish smoking in Lagos State, Nigeria. **African Journal of Food Science** 9: 59-64. DOI: 10.5897/AJFS2014.1216.

Ahmed, A.A. 2019. Sensory quality of smoked *Clarias gariepinus* (Burchell, 1822) as affected by spices packaging methods. **International Journal of Food Properties** 22: 704-713. DOI: 10.1080/10942912.2019.1597880.

Al-Harbi, A.H. and M.N. Uddin. 2005. Microbiological quality changes in the intestine of hybrid tilapia (*Oreochromis niloticus* × *Oreochromis aureus*) in fresh and frozen storage condition. **Letters in Applied Microbiology** 40: 486-490. DOI: 10.1111/j. 1472-765X.2005.01716.x.

Alparslan, Y., T. Baygar, H. Hasanhocaoğlu and C. Metin. 2013. Effects of scale and skin on chemical and sensory quality of marinated sea bass filets (*Dicentrarchus labrax*, L. 1758) in sunflower oil during storage at 4 ºC. **Emirate Journal of Food and Agriculture** 25: 516-523. DOI: 10.9755/ejfa.v25i7.12666.

Al-Reza, S., S. Karmaker, M. Hasan, S. Roy, R. Hoque and N. Rahman. 2015. Effect of traditional fish processing methods on the proximate and microbiological characteristics of *Laubuka dadiburjori* during storage at room temperature. **Journal of Fisheries and Aquatic Science** 10: 232-243. DOI: 10.3923/jfas.2015.232.243.

Anihouvi, D.G.H., Y.E. Kpoclou, M.A. Massih, O.H.I. Afé, M.F. Assogba, M. Covo, M. Scippo, D.J. Hounhouigan, V. Anihouvi and J. Mahillon. 2019. Microbiological characteristic of smoked and smoked dried fish processed in Benin. **Food Science and Nutrition** 7(5): 1821-1827. DOI: 10.1002/fsn3.1030.

Ayeloja, A.A., W.A. Jimoh, M.B. Adetayo and A. Abdullahi. 2020. Effect of storage time on the quality of smoked *Oreochromis niloticus*. **Hyliyon** 6(1): e03284. DOI: 10.1016/j.heliyon.2020.e03284.

Chieh, C. 2006. **Water chemistry and biochemistry.** In: Food Biochemistry and Food Processing (ed. Y.H. Hui), pp. 103-134. Blackwell Publishing, Ames, Iowa, USA.

Codex Alimentarius. 2013. **Standard for Smoked Fish, Smoke-Flavoured Fish and Smoke-Dried Fish: Codex Stan 311-2013.** Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 9 pp.

Dissaraphong, S., S. Benjakul, W. Visessanguan and H. Kishimura. 2006. The influence of storage conditions of tuna viscera before fermentation on chemical, physical and microbiological changes in fish sauce during fermentation. **Bioresource Technology** 97: 2032-2040. DOI: 10.1016/j.biortech.2005.10.007.

Ibadullah, W.Z.W., A.A. Idris, R. Shukri, N.A. Mustapha, N. Saari and N.H.Z. Abedin. 2019. Stability of fried fish crackers as influenced by packaging material and storage temperatures. **Current Research in Nutrition and Food Science** 7: 369-381. DOI: 10.12944/CRNFSJ.7.2.07.

Kelechi, A.J., E. Fidelis and O.F. Chimezie. 2017. Storage stability of smoked mackerel fish (*Scomberomorus scombus*) as affected by selected packaging materials. **World Journal of Food Science and Technology** 1: 22-27. DOI: 10.11648/j.wjfst.20170101.14.

Kjällstrand, J. and G. Petersson. 2007. Phenolic antioxidants in wood smoke. **Science of the Total Environment** 277: 69-75. DOI: 10.1016/S0048-9697(00)00863-9.

Li, D., Z. Yuan, Z. Liu, M. Yu, Y. Guo, X. Liu, M. Zhang, H. Liu and D. Zhou. 2020. Effect of oxidation and Maillard reactions on color deterioration of ready-to-eat shrimps during storage. **LWT-Food Science and Technology** 131: 109696. DOI: 10.1016/j.lwt.2020.109696.

Lund, M.N. and C.A. Ray. 2017. Control of Maillard reactions in foods: strategies and chemical mechanisms. **Journal of Agriculture and Food Chemistry** 65: 4537-4552. DOI: 10.1021/acs.jafc.7b00882.

Mathew, S., M. Raman, M.K. Parameswaran and D.P. Rajan. 2019. **Fish and Fishery Products Analysis: A Theoretical and Practical Perspective.** Springer Nature Singapore Pte Ltd., Singapore City, Singapore. 443 pp.

Mol, S., S. Ozturan and S. Cosansu. 2012. Determination of the quality and shelf life of sous vide packaged bonito (*Sarda sarda*, Bloch, 1973) stored at 4 and 12 ºC. **Journal of Food Quality** 35: 137-143. DOI: 10.1111/j.1745-4557.2011.00430.x.

Moula Ali, A.L., K. de la Caba, T. Prodpran and S. Benjakul. 2020. Quality characteristics of fried fish crackers packaged in gelatin bags: Effect of squalene and storage time. **Food Hydrocolloids** 99: 105378. DOI: 10.1016/j.foodhyd.2019.105378.

Nadeeshani, H., N. Rajapokse and S. Kim. 2020. **Traditional and novel seafood processing techniques targeting human health promotion.** In: Encyclopedia of Marine Biotechnology (ed. S. Kim), pp. 3041-3084. John Wiley & Sons, New York, USA.

Nahid, M.N., G.A. Latifa, S.C. Chakraborty, F.B. Farid and M. Begum. 2016. Shelf-life quality of smoke-dried freshwater SIS Fish; Chapila (*Gudusia chapra*, Hamilton-Buchanan; 1822) Kaika (*Xenentodon cancila*, Hamilton-Buchanan; 1822) and Baim (*Mastacembelus pancalus*, Hamilton-Buchanan; 1822) stored at laboratory condition (26–31 ºC). **IOSR Journal of Agriculture and Veterinary Science** 9(3): 23-32. DOI: 10.9790/2380-09312332.

Nielsen, S., B. Ismail and G.D. Sadler. 2010. **Chemistry of aseptically processed food.** In: Principles of Aseptic Processing and Packaging, 3rd ed. (ed. P.E. Nelson), pp. 75-95. Purdue University Press, West Lafayette, Indiana, USA.

Nunoo, F.K.E. and E.O. Kombat. 2013. Analysis of the microbiological quality of processed *Engraulis encrasicolus* and *Sardinella aurita* obtained from processing houses and retail markets in Accra and Tema, Ghana. **World Journal of Fish and Marine Sciences** 5(6): 686-692. DOI: 10.5829/idosi.wjfms.2013.05.06.7583.

Nurullah, M., M. Kamal, M.N. Islam, C.T. Ahasan and S.H. Thilsted. 2007. Shelf life of dried products from small indigenous fish species under various packing and storage condition. **Bangladesh Journal of Fisheries Research** 11: 229-236.

Oksuz, A., G.A. Evrendilek, M.S. Calis and A. Ozeren. 2008. Production of a dry sausage from African catfish (*Clarias gariepinus*, Burchell, 1822): Microbial, chemical and sensory evaluations. **International Journal of Food Science and Technology** 43: 166-172.

Olayemi, F., M. Omodara and O. Peters. 2015. Development of appropriate packaging for shelf life extension of smoked fish in a developing economy. **International Journal of Fisheries and Aquatic Studies** 2(4S): 46-50.

Ricketts, A.O. 2019. Biochemical and microbiological assessment of smoked dried *Clarias gariepinus*. **Journal of Food Processing and Technology** 10(2): 1000775. DOI: 10.4172/2157-7110.1000775.

Sakyi, E.M., C. Jia and A. Ampofo-Yeboah. 2019. Fish smoking in Ghana: A review. **Journal of Fisheries Sciences.com** 13: 13-24. DOI: 10.36648/1307-234X.13.3.165.

Singh, R.P. and B.A. Anderson. 2004. **The major types of food spoilage: An overview.** In: Understanding and Measuring the Shelf Life of Food (ed. R. Steele), pp. 3-23. CRC Press, New York, USA.

Tapotubun, A.M., F. Reiuwpassa, Y.M.T. N. Apituley, H. Nanlohy and E.A.A. Matrutty. 2017. The quality and food safety of dry smoke garfish (*Hemirhamphus far*) product from Maluku. **IOP Conference Series: Earth and Environmental Science** 89: 012010. DOI: 10.1088/1755-1315/89/1/012010.

Tepmuangkhun, J., K. Huaisan, P. Srisakultiew, A. Srisathaporn and S. Gawborisut. 2019. Sensory quality of dried-smoked garfish (*Xenentodon cancila* (Hamilton, 1822)) during long-term storage as affected polypropylene bags and natural antioxidants. **Khon Kaen Agriculture Journal** 47 (Supplement 1): 1287-1292.

Turan, H. and I. Erkoyuncu. 2012. **Salting technology in fish processing.** In: Progress in Food Preservation (eds. R. Bhat, A.K. Alias and G. Paliyath), pp. 297-314. John Wiley & Sons, Ltd., New York, USA.

Wannasupchue, W., S. Siriamornpun, K. Huaisan, J. Huaisan and K. Meeso. 2011. Effects of adding ling-zhi (*Gannoderma lucidum*) on oxidative stability, texture and sensory properties of smoked fish sausage. **Thai Journal of Agriculture Science** 44: 505-512.

Yakubu, M.M. and B.B. Ngueku. 2015. Quality assessment of smoked dried fish from five different markets in Lifia, Nigeria. **International Journal of Fisheries and Aquatic Studies** 2(4): 135-139.

Yang, X. and R.A. Boyle. 2016. **Sensory Evaluation of oils/fats and oil/fat-based foods.** In: Oxidative Stability and Shelf Life of Foods Containing Oils and Fats (eds. M. Hue and C. Jacobsen), pp. 157-185. Elsevier, New York, USA.