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Sensory evaluation of fresh/ frozen mackerel products: A review

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Sensory evaluation of mackerel: review…

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ABSTRACT

Mackerel has received considerable attention in the global food market as one of the most important pelagic commercial fish species. The quality of mackerel is influenced by species, season, fishing area, nutritional status, catching method, handling and storage. Due to the mackerel's perishability, its quality is mainly measured by sensory procedures. Although considerable effort has been made to explore quick and reliable quality analysis, developing a practical and scientific sensory evaluation of mackerel has been an active on-going study area to meet the quality evaluation demand of the industry. Different sensory evaluation methods have been used to assess the mackerel fish quality, including Palatability and Spoilage test, Torry Scheme, EU Scheme, Quality index method, Catch damage index and Processed fish damage index, Affective test, Discriminative test and Descriptive test. Each method has its strength and weakness. Despite mackerel sensory evaluation protocols having undergone partial harmonization, specific sample process needs to be carefully followed to minimize the change during sample preparation. This review summarizes the sensory evaluation methods in mackerel research, the factors affecting sensory evaluation, and then updates the latest advances in mackerel sensory evaluation and offers guidance for presents its application in the mackerel chain. Also, each technique's advantages and limitations are discussed. In our opinion, the future trends for sensory evaluation of mackerel should be consumer-centric.

END PAGE 2

1 Introduction

Mackerel is the common name for more than 30 different species of fish, mainly those belonging to the family Scombridae (Sone, Skåra, & Olsen, 2019). As a pelagic migratory fish, mackerel is widely distributed in the world's oceans and mainly concentrated in the offshore of western Pacific and Atlantic. The currently accepted classification of the mackerels within the suborder Scombroidei is shown in Figure 1 (Collette & Chao, 1975; Collette, Reeb, & Block, 2001; Johnson, 1986; Kishinouye, 1923). The common mackerel species is Atlantic mackerel (*Scomber scombrus*), a productive and economically important species in the European fishing industry, supplied mainly by Norway, Iceland, Australia, New Zealand and the United Kingdom, which are also major suppliers to the world mackerel trade (EUMOFA, 2019). Allied to this species is chub mackerel, once separated into Atlantic chub mackerel (*S. colias*) and Pacific chub mackerel/Japanese mackerel (*S. japonicus*). Other economically important mackerels belong to the family Scombridae, *Scomberomorini, Scomberomorus* including blue mackerel/spotted mackerel (*S. australasicus*), Spanish mackerel (*S. commerson*), cero/painted mackerel (*S. regalis*) and king mackerel (*S. cavalla*) have also been reported (Anders, Eide, Lerfall, Roth, & Breen, 2020; Huang et al., 2019). Other fishes known as mackerel and belonging to the family Scombridae include Indian mackerel (*Rastrelliger kanagurta*) and frigate mackerels (*Auxis thazard thazard, Auxis thazard brachydorax*). Besides, the name mackerel is also used for certain species of tuna and bonito. Likewise, horse mackerel (*Trachurus trachurus, Trachurus japonicas*) are fishes of the family Carangidae (Collette, Carpenter, & Niem, 2001; Collette & Cornelia, 1983). Among all mackerel species, horse mackerel and chub mackerel (Atlantic and

Pacific) are currently the most frequently mentioned worldwide (Levsen, Jørgensen, & Mo, 2008; Sone et al., 2019).

Previous studies have shown that from the moment of capture, the spoilage process of mackerel begins (Martinsdóttir, 2010), as mackerel is fatty and perishable. With increasing consumer demand for fish and concern for seafood quality, especially in a market that has strict quality control, the price of mackerel is greatly influenced by sensory quality and consumers are willing to pay a higher price for high-quality fish (Sieffermann, Lopetcharat, & Pipatsattayanuwong, 2013). Therefore, for monitoring changes in mackerel quality, diverse chemical and bacteriological analyzes has been applied to the quality control of mackerel, such as Total volatile base nitrogen (TVBN) and trimethylamine (Postma, De Graaf, & Boesveldt, 2020; Agüeria, Sanzano, Vaz-Pires, Rodríguez, & Yeannes, 2015; Calanche et al., 2019; Dos Santos, Kushida, Viegas, & Lapa-Guimarães, 2014; Lanzarin et al., 2016; Ritter et al., 2016; Wu, Pu, & Sun, 2019), free fatty acids (FFAs) and peroxide values (PVs) (Okogeri & Chioma, 2016; Romotowska, Gudjonsdottir, Karlsdottir, Kristinsson, & Arason, 2017; Secci & Parisi, 2016), total viable counts (TVC) (Fuentes-Amaya, Munyard, Fernandez-Piquer, & Howieson, 2016; Jack & Read, 2008; Li et al., 2017; Sveinsdóttir, Martinsdóttir, Hyldig, Jørgensen, & Kristbergsson, 2002), or specific spoilage organisms (SSOs) (Wu et al., 2019) and K-value (Mishima et al., 2005).

Furthermore, in order to optimize quality assessment, improve consumer safety and reduce raw material losses, a number of rapid, less destructive and objective methods such as sensory bionic techniques (SBT) have been applied to the freshness evaluation of mackerel (Wu et al., 2019), comprising electronic tongue, electronic nose, computer vision techniques, Vis/NIR spectroscopy, HSI techniques and fluorescence spectroscopy, respectively (Liu, Zeng, & Sun, 2013; Menesatti, Costa, & Aguzzi, 2010; Shim & Jeong, 2019). However, the slight changes in sensory properties resulting from spoilage are difficult to be detected by instrumental (Fagan, Gormley, & Mhuicheartaigh, 2003). Hence, sensory evaluation, as a subjective test for rapid evaluation of mackerel quality, is crucial for maintaining *post-mortem* quality in the mackerel supply chain (Fagan et al., 2003; Sone et al., 2019). Cropotova et al. (2019) compared changes of hardness and drip loss of chilled (4 °C), super chilled (-37 °C for 1.5 min, -1.7 °C storage) and frozen (-27 °C) mackerel fillets during storage in relation to protease activity and protein oxidation. Sone et al. (2019) reviewed the factors affecting *post-mortem* quality, safety and storage stability of mackerel. Their review provides a comprehensive overview of intrinsic and extrinsic factors affecting quality changes in mackerel raw material from harvest/slaughter, *post-mortem* handling to storage (Sone et al., 2019). Despite the existence of extensive research as mentioned above, published reviews with a comprehensive introduction to specific operations and influencing factors of mackerel sensory evaluation are limited, thus the systematic understanding of sensory evaluation in mackerel research needs to be continuously improved. Therefore, it is necessary to review the development of sensory evaluation methods in the field related to mackerel and their application in the chain of distribution.

The purpose of this literature review is to provide an overview of sensory evaluations related to mackerel from three aspects, including applications to the transportation of mackerel chain, the main sensory evaluation methods in mackerel research, and sample preparation and experimental control of mackerel. Furthermore, the limitations and challenges of mackerel sensory evaluation are discussed and current research gap and future trends are also addressed in the conclusion section.

2 Processes affecting the quality of mackerel

2.1 *Post-mortem* quality changes

The death of mackerel is followed by a decrease in adenosine triphosphate (ATP) concentration, rapid *rigor mortis* and a drop in pH, which in turn affects the sensory quality of the mackerel after death (Boylston et al., 2012). Among ATP-related compounds, inosine monophosphate (IMP) is one of the most important components responsible for umami taste of fishery products, while inosine (HxR) and hypoxanthine (Hx) have unpleasant odor and bitter taste associated with the loss of fish freshness (Hong, Regenstein, & Luo, 2017; Li et al., 2017; Li et al., 2017; Yu et al., 2018).

Fast *rigor mortis* has been shown to be associated with the processed fish damage index (PFDi), due to the free contraction of mackerel muscles prior to *rigor mortis* and the shortening of fillets after the onset of *rigor mortis*, leading to an increased incidence of gaping (Özogul & Özogul, 2004; Sato et al., 2002). If the fish is cooked pre-rigor, the texture will be very soft and pasty. In contrast, the texture is tough but not dry when the fish is cooked in rigor, and the cooked flesh will become firm, juicy, and elastic (Boylston et al., 2012).

Glycolysis induces a pH drop in fish. It has been shown that fish with a higher pH usually contains more water than fish with a lower pH, thus, the texture of fish with a lower pH is described as firm, dry and a little tough, while the texture of fish with a higher pH is softer, juicier, and tender (Howgate, 1977). However, a different situation was observed in a study by

Anders (2020), in which no significant correlation was found between Atlantic mackerel fillets *rigor mortis* and initial muscle pH or time to maximum development of *rigor mortis* during preservation.

In addition to above mentioned changes, unsaturated fatty acids and pro-oxidants make mackerel highly susceptible to lipid oxidation (Shahidi, 2000; Shahidi & Cadwallader, 1997), and lipids readily decompose into low molecular volatile compounds such as aldehydes and ketones and produce unpleasant odors (Yu et al., 2018).

Moreover, proteolysis leads to changes in protein linkages and in the connective tissue around cells, producing textural changes (Saeed & Howell, 2002; Saeed & Howell, 2004), such as reduced fish tenderness (Cropotova et al., 2019; Lund, Luxford, Skibsted, & Davies, 2008). Furthermore, enzymatic activity or oxidation reactions can also cause discoloration of fish, such as an increase of yellowing and/or reddening (Hong, Leblanc, Hawrysh, & Hardin, 1996). With the decarboxylation of large amounts of free histidine via the action of bacteria to produce histamine, the increase in sulfur compounds and acids may give rise to off-flavor in fish. In particular, the increase of dimethyl disulfide can lead to further degradation of its sensory qualities, such as the development of off-flavors and texture softening. These changes are influenced by fishing, handling and preservation method throughout the production and distribution process (Alasalvar, Quantick & Grigor, 1997; Cropotova et al., 2019; Erkan, Özden, & Inuğur, 2007; Jhaveri, Leu, & Constantinides, 1982).

2.2 Factors affecting the quality of mackerel

2.2.1 Biological and nutritional

The quality of mackerel is influenced by species, season, fishing area, nutritional status, catching method, handling and storage. The quality of the mackerel varied considerably between species, e.g., during storage at 4 °C, the muscles of spotted mackerel were softer than that of chub mackerel, which may be related to its lower collagen content and thinner connective tissue (Hashimoto, Kobayashi, & Yamashita, 2016). Due to the migratory nature of mackerel, whose dietary composition varies regionally and seasonally, stomach contents may promote proteolytic activity to accelerate *post-mortem* degradation of muscles, such as during the period of heavy feeding, the muscles of mackerel may be sensitive to processing and transport conditions, resulting in product quality problems such as gaping and texture (EC, 1996; Prokopchuk & Sentyabov, 2006; Sone et al., 2019). Meanwhile, the effect of different fishing seasons, fishing areas and nutritional status on mackerel quality may be reflected in the muscle fat content and lipid composition of mackerel, with higher fat content likely to maintain muscle structure and firmness of texture better than lean mackerel during frozen storage (Sone et al., 2019). For example, the fat content of Atlantic mackerel is about 10-15% in June, and reaches 25-30% in September (Romotowska et al., 2017; Romotowska et al., 2016a; Romotowska, Karlsdóttir, Gudjónsdóttir, Kristinsson, & Arason, 2016b; Romotowska, Karlsdóttir, Gudjónsdóttir, Kristinsson, & Arason, 2016c). Moreover, the variation of unsaturated fatty acid content directly affected the degree of lipid oxidation of mackerel during refrigeration, and its content was affected by the harvest season (Bae & Lim, 2012; Bandarra, Batista, Nunes, & Empis, 2001; Romotowska et al., 2016b; Romotowska et al., 2016c). For example, the unsaturated fatty acid content of Atlantic mackerel caught in July was higher than that of Atlantic mackerel caught in September (Romotowska et al., 2017). The effect of the exercise required by the living environment may be directly reflected in the texture of the mackerel, e.g. mackerel caught in areas with high water velocity have a higher collagen content in the muscle and firmer meat texture (Ando et al., 2001). In addition to the above factors, the quality of mackerel is also affected by the way it is caught, handled and preserved. This section focused on the effects of these treatments on the sensory quality of mackerel in the mackerel supply chain.

2.2.2 Fishing methods

Different fishing methods have different effects on the sensory quality of mackerel. The methods of mackerel fishing include trawling, longlining, gillnetting and purse seining (Misund & Beltestad, 2000). Very little is known about the earliest methods of catching mackerel. Stansby and Lemon (1941) mentioned that between 1815 and 1860, mackerel fishing was essentially hook, line and gill-nets.

As mackerel are schooling fish, these fishing methods were gradually replaced by the more efficient trawling. However, the process of trawling often originates injuries to the fish, occurring as a result of contact with other fish, debris or the gear itself during the operation of the gear. In fact, most of the caught fish had physical injuries such as marks on the fish due to the net being tangled together (Purbayantoz, & Sondita, 2008). Some fish lose their upper body and fight back when they are wounded while being entangled.

Compared to trawling, purse seining tends to have less skin-/scale- damage and higher survival rates (Misund et al., 2000). Hence, over the past 60 years, purse seining has been the most productive fishing method in the world, accounting for about one third of global catches by weight. Also, due to the phototaxis of mackerel, light seining is widely used in the mackerel fishery (Watson, Revenga, & Kura, 2006). Indicators to assess the organoleptic quality of mackerel in purse seine fisheries include mortality, mechanical injury, pressure injury, bleeding and other quality losses, are important factors affecting fish quality (Botta, Bonnell, & Squires, 1987; Digre, Hansen, & Erikson, 2010; Digre, Tveit, Solvang-Garten, Eilertsen & Aursand, 2016; Esaiassen et al., 2004; Margeirsson, Nielsen, Jonsson, & Arason, 2006; Olsen, Oppedal, Tenningen, & Vold, 2012; Rotabakk, Skipnes, Akse, & Birkeland, 2011). It has been shown that rough handling during catch and catch handling while the fish is still alive, such as in the net (long trawl times and very large catches) or on the deck (fishermen stepping on the fish or throwing boxes, containers, and other items on the fish), may cause bruises, ruptured blood vessels, and blood oozing into muscle tissue (hematomas), resulting in discoloration of the fillets (Boylston et al., 2012). Thus, handling on board fishing vessels, such as pumping, fishing time, etc., can result in quality loss of mackerel such as increased gaping, discoloration, and texture softening (Digre et al., 2016; Kraus, Hardy, & Whittle, 1992; Sone et al., 2019). It has been shown that due to the large catch of mackerel, the roundup time is long and most of the fish die after 20 to 60 min. Due to the shorter squeeze time suffered by fish pumped to the main vessel, these fish have a significantly higher survival rate than those pumped to the by-catch vessel (Digre et al., 2016).

In addition, intense swimming during crowding means intensive use of white muscle. Therefore, anaerobic glycolysis is increased as lactic acid is produced and muscle pH is lowered. If the fish can recover from the intense activity, lactic acid production and lower muscle pH will increase. The acid produced will be removed from the blood and muscles (Milligan, 1996; Poli, Parisi, Scappini, & Zampacavallo, 2005). Tamotsu et al. (2012) indicated that spotted mackerel after 9 h of resting at 5 °C temperature had significantly higher muscle elastic strength than that of the capture fish. It has been shown that starvation (i.e., 1-3 days depending on water temperature) ensure complete gut emptying, reducing the charge of spoilage organisms and contributing to the quality and preservation of the fish (Boylston et al., 2012; Digre et al., 2016). Conversely, if fish have been starved or starved to death for an extended period of time, their glycogen reserves are depleted and *rigor mortis* begins immediately or shortly after death (Boylston et al., 2012).

2.2.3 Slaughtering

Studies have shown that quality loss of mackerel is associated with *antemortem* stress brought about by slaughter methods, such as reduced texture hardness, increased incidence of gaping, and faster onset of *rigor mortis* in Atlantic mackerel and other mackerel genus members including spotted mackerel, chub mackerel (Ando et al., 2001; Miyazaki et al., 2018; Mochizuki & Sato, 1996; Ogata, Koike, Kimura, & Yuan, 2016; Sato et al., 2002; Tamotsu et al., 2012).

Struggle and stress have been shown to accelerate *postmortem* quality loss in mackerel. First, struggle leads to accelerated degradation of nucleotides (ATP, IMP, phosphocreatine, K value) in fish, which accelerated the onset of *rigor mortis* of the mackerel (Sone et al., 2019). Also, during struggling, physical shocks lead to the release of cathepsin L and Ca^{2+}, which promote accelerated collagen fiber disintegration and weaken the binding of connective tissue around cells, such as the dissolution of V collagen in struggling chub mackerel during ice storage and the decrease in tyrosine content in collagen fibers occur more rapidly than in unstruggled fish, and these causes may also induce muscle softening in mackerel (Ando et al., 2001; Sato et al., 2002) and even earlier odor (Özogul et al., 2004; Sone et al., 2019). Secondly, high external stress can also lead to a decrease in pH, which can affect the appearance of the fish, resulting in a lighter and more transparent appearance (Anders et al., 2020; Robb, 2001).

Different slaughter methods result in varied degrees of struggle and external stress, thus affecting the sensory quality of mackerel. Methods of fish slaughter include death in ice slurry, electrical stunning and electrocution, carbon dioxide narcosis, knocking and spiking (Bagni, Priori, Finoia, Bossu , & Marino, 2002; Concollato et al., 2019; Huidobro, Mendes, & Nunes, 2001; Marx, Brunner, Weinzierl, Hoffman, & Stolle, 1997; Poli et al., 2005; Sigholt, Erikson, & Rustad, 1997; Zampacavallo et al., 2003). Electrocution is an efficient method, but causes a violent reaction in the fish, resulting in opening of the mouth and gills, blood spots in the muscles and vertebral fractures (Marx et al., 1997). Compared to electrocution, carbon dioxide narcosis, although it reduces the struggle of the fish, results in a high slaughter pressure, and its treatment causes lower pH and weaker muscle water holding capacity. Knocking and spiking induce less slaughter pressure (Mochizuki & Sato, 1996) and better muscle texture of the fish (Sigholt et al., 1997), but are not applicable to the treatment of large catch of mackerel. For purse seine species like mackerel, ice slurry is the most common treatment. Ice slurry is when a fish is caught and placed directly into a water/ice slurry container to make liquid ice by adjusting the water/ice ratio. This method is simple and quick, and the quality and shelf life of the ice-dead-treated fish is improved due to the rapid reduction in core body temperature, improving the quality and shelf life of mackerel (Bagni et al., 2002; Mochizuki & Sato, 1996; Sone et al., 2019; Zampacavallo et al., 2003).

In addition, bleeding can slow the development of mackerel decay and is an important part of the treatment process that affects the organoleptic quality of mackerel after slaughter (Richards & Hultin, 2003). The possible reason is that pro-oxidants including heme pigments (e.g., haemoglobin (Hb), myoglobin (Mb)), metal ions (e.g., iron and copper), and enzymes (e.g., lipoxygenase) is highly susceptible to lipid oxidation due to low *postmortem* pH and high polyunsaturated fatty acids (PUFA) content (Banerjee, Khokhar, & Apenten, 2002; Decker & Hultin, 1990; Richards & Hultin, 2003). It has been shown that after 5 days of storage at 0 °C, lipid oxidation was higher in blooded chub mackerel than unbleeding fish (Sakai & Terayama, 2008). Sone et al. (2019) presented in their review the effect of gill cut bleeding versus tail-cut bleeding on the quality of mackerel and noted that preservation methods can also affect the quality of mackerel.

2.2.4 Preservation

Due to the combined actions of endogenous enzymes, spoilage bacteria and chemical reactions, protein degradation, nucleotide breakdown and lipid oxidation in mackerel, these changes contribute to the quality loss of mackerel during storage, mainly including drip loss, discoloration, softening of texture and off-flavors (Puolanne & Halonen, 2010; Wang, Vang, Pedersen, Martinez, & Olsen, 2011; Yu et al., 2019). Drip loss affects the juiciness, flavor and texture of the fish (Nielsen & Green, 2007), and accelerates quality degradation by providing a moist nutrient medium for bacterial growth.

The common methods of preserving mackerel are chilling and freezing, which are different but aim at reducing the rate of enzymatic protein decomposition, lipid oxidation and microbial degradation through low temperature to slow and restrain the deterioration of fish in terms of color, taste and texture (Nielsen et al., 2007). The key factors in freezing effectiveness are freezing rate and freezing temperature. As far as freezing rate is concerned, ice crystals formed during freezing destroy mackerel cells leading to drip loss and the release of various pro-oxidants (H_2O_2, iron, myoglobin, etc.), which further increase the oxidation state of the fish during the thawing phase (Standal et al., 2018). It has been shown that rapid freezing forms smaller-sized ice crystals that reduce drip loss (Vidaček, Medić, Marušić, Tonković, & Petrak, 2012). Moreover, freezing rate can be increased by immersion in salt solutions, but it has been shown that dipping the fish in a salt solution before freezing makes the muscles of mackerel more susceptible to fat oxidation (Aubourg & Ugliano, 2002), which accelerates the development of rancid freeze house taste due to the presence of cis-4-Heptenal formed by oxidation of n-3 fatty acids (Hyldig, Nielsen, Jacobsen, & Nielsen, 2012).

As far as storage temperature is concerned, 5 °C or less is considered beneficial for maintaining the muscle breaking strength of mackerel (horse mackerel, chub mackerel) (Mishima et al., 2005; Mochizuki, 1999). However, a decrease in freezing temperature is not necessarily beneficial for preserving the sensory quality of mackerel, and when the temperature of frozen fish goes above the freezing point of salt (-21.6 °C), the enzyme activity increases dramatically leading to peritoneum deterioration (Jiang, Ho, & Lee, 1985; Romotowska et al., 2017). Notably, temperature fluctuations may lead to recrystallization and further growth of ice crystals inside the fish muscle (Hashimoto, Kawashima, Yoshino, Shirai, & Takiguchi, 2015), which may further cause cell damage, resulting in increased gaping. Therefore, during the freezing process of mackerel, the freezing rate must be fast, the temperature must be low and constant, and fluctuations must be avoided during transportation and storage (Hyldig et al., 2012; Romotowska et al., 2017).

Cropotova et al. (2019) compared the application of freezing and super chilling methods in mackerel preservation and showed that super chilled effectively maintains the integrity of the fish's muscles from structural damage; compared to other methods, super chilling has the least adverse effect on drip loss and softening of fish tissues and is a preferred method for mackerel preservation.

To extend the shelf-life of mackerel, some methods include ice coating/glazing, edible coating, adding antioxidants, and vacuum packaging have been applied to mackerel products (Goulas & Kontominas, 2007; Jamróz, Kulawik, Guzik & Duda, 2019; Quitral et al., 2009). Glazing protects the surface of the fish from oxidation and dehydration by limiting the chance of oxidation by air (Popelka et al., 2012). Edible coatings such as chitosan-citrus composite coating can inhibit the growth of microorganisms and mitigate the production of lipid oxidation and peroxide in Pacific mackerel, resulting high preferred appearance, odor and organization over the untreated samples. However, at the beginning of storage, the coating caused a citrus taste (Li et al., 2019). Antioxidants such as grape seed extract (GSE), papaya seed extract (PSE), sea weed extract (*Fucus serratus* and *Polysiphonia fucoides*) can restrain microbial growth and alleviate lipid oxidation and proteolysis (Babakhani, Farvin & Jacobsen, 2015; Sofi, Raju, Lakshmisha & Singh, 2016). The combination of vacuum packaging and low-dose irradiation reduced biogenic amine formation has been shown to improve sensory properties, and extend the shelf life of mackerel stored in 7-day refrigerated storage (Mbarki, Miloud, Selmi, Dhib & Sadok, 2009). Moreover, a high hydrostatic pressure of 150 MPa has been proved to inhibit the growth of harmful microorganisms, as well as maintain the sensory characteristics (water holding, color and texture) (Aubourg, Torres, Saraiva, Guerra-Rodríguez, & Vázquez, 2013). Moreover, for ready-to-eat mackerel products, microwave-treated fillets were superior to the other two methods in maintaining the organoleptic properties of mackerel fillets (Fiore et al., 2019).

3 Relevant sensory evaluation methods in mackerel research

In the last three decades, different sensory evaluation methods have been applied in the evaluation of raw material quality of mackerel, preservation studies, and market research. As shown in Figure 2, these methods have different applications and can play complementary roles in the quality evaluation of mackerel. From the moment of harvest, the fishing crew can use basic sensory evaluation to quickly assess the injury and appearance of the caught fish, for instance Catch damage index (CDi) (Esaiassen, Akse, & Joensen, 2013). At the same time, palatability test can be applied to evaluate the appearance of fresh fish and the quality of the fish after cooking. In addition, spoilage test can be used to assess the quality of the fish's preservation on-board the vessel. During processing and storage, various sensory evaluation methods are carried out to assess the sensory quality of mackerel. Consumer tests such as preference tests are used to gather consumer attitudes towards mackerel products before they are placed on the market and in retail. Table 1 provides a summary of mackerel studies published in the past 30 years (1990-2020), in which the effects of different variables on the sensory characteristics of mackerel. The advantages and disadvantages of various sensory methods are summarized in Table 2.

3.1 Palatability and Spoilage test

Following death, several changes occur in sensory properties of mackerel, including appearance, color, texture, odor and taste. Palatability was regarded as an important criterion for the quality of mackerel as early as 1941 (Stansby, 1951; Stansby & Lemon, 1941).

The most important aspects of palatability judging included the following conditions: (a) the presence of normal flavor, texture, and appearance; (b) the absence of abnormal flavor, texture, and appearance (Stansby, 1951). This method was more concerned with the appearance of the fish at the time of sale, hence indicators such as clear eyes and bright red gills were used as the first criteria for judging the quality of the fish (Tomiyasu & Zenitani, 1957). However, such method was not suitable for shelf-life assessment of mackerel. Simidu and Hibiki (1954) compared the sensory qualities of mackerel and yellow tail through a spoilage test to provide a reference for determining the shelf-life of mackerel. However, considering food safety, the test did not include any measurement of taste, flavor and culinary properties, only the color of the meat was considered. Since the various methods could provide complementary results, the combination of palatability and spoilage tests expanded their application and opened new possibilities for research. In fact, the results of both palatability test and spoilage test were essentially ordinal data (Martinsdóttir, Schelvis, Hyldig, & Sveinsdóttir, 2009), which meant that such scoring is a ranking of fish quality. These methods were used in the past along with bacterial counts to assess the level of fish spoilage (Otero, Pérez-Mateos, Holgado, Márquez-Ruiz, & López-Caballero, 2018), and in general, both palatability test and spoilage test focused on mackerel defect grading.

Such methods have the advantage of considering changes in the fish during preparation, but have the disadvantage of being relatively complex for the consumer. Therefore, they have been gradually replaced by other more simplified sensory evaluation methods, such as the Torry Scheme, EU Scheme, and Quality Index Method (QIM).

3.2 Torry Scheme

In order to improve the efficiency of producers and consumers in assessing the quality of mackerel, a more simplified sensory evaluation method, the Torry Scheme, was introduced in 1953 (Martinsdóttir, 2002). Keay (1979) tested the quality of mackerel by using the Torry scheme, a 10-point scale based methodology where 10 indicated very fresh, 3 meant spoiled, and an average of 5.5 points represented the minimum consumption value. This scheme could be used by both consumers and producers.

The Torry Scheme can be used not only for raw fish but also for post-cooking fish samples, making it the most widely used method for assessing post-cooking fresh fish quality (Alasalvar et al., 1997). A limitation of this method, though, is that its scales provide limited information on how individual fish characteristics change over storage time. Hence, the Torry Scheme is gradually being replaced by QIM, or its shortcomings are being compensated for by combining it with other methods.

To further facilitate the use of this method, the Torry Research Center developed the Torrymeter in 1976 (Botta, 1994), a hand-held electronic instrument with measurement criteria that follow the Torry Scheme. The Torrymeter detects deterioration of chilled fish by measuring changes in dielectric properties on the fish skin or fillet. Although it needs to be further refined in the future, this approach links an objective, instrumental method to sensory evaluation.

3.3 EU Scheme

Since the main suppliers of the world mackerel trade were in Europe, EU scheme was established in 1996 to standardize the freshness assessment of mackerel (Commission Regulation (EC), 1996). In this grading evaluation procedure, four categories were established: highest quality (E), good quality (A), fair quality (B) and reject-able quality (C) (EC, 1996). Compared with palatability test, spoilage test and Torry scheme, this method is more inclined to evaluate the freshness of raw fish. Inácio et al. (2003) applied a combination of the EU scheme and the Torrymeter method for the sensory evaluation of fish, along with QIM and microbiological tests. The results showed that the cleaning process (fish were kept inside a box with bottom drainage and washed by running tap water/treated sea water for 5 min with low pressure volume system) seemed to interfere with the properties of the fish skin cells, resulting in instrumental detection of degrees that can be affected by the cleaning operation. Conversely, the sensory evaluation of the fish in this study was consistent with the microbiological result. In 2004, the EU scheme was used to evaluate the sensory quality of mackerel by Aubourg et al (2004a). They examined raw mackerel fillets, including its general appearance, odor and color. The sensory attributes of whole mackerel were more than those of raw fillet. The quality of odor, texture and surface mucus were classified into four sections, each of which is assessed using four levels of criteria. So far, the EU scheme has been widely used for sensory evaluation of raw whole fish and fish fillets because it is highly efficient; besides, in the EU it is a regulated mandatory method used by the competent authorities at several stages of the commercial circuit (mostly at first sale/auction) (Howard, 1992).

Nevertheless, the limitation of this approach is that it does not consider differences between fish species, with a mixture of subjective and objective answers, and therefore can only be used to measure general aspects of fish (Boylston et al., 2012). Hence, EU scheme is often used in conjunction with QIM.

3.4 Quality index method (QIM)

The Quality Index Method (QIM) was originally developed by Tasmanian Food Research Unit (Bremner, 1985), and was further developed in the Nordic countries thereafter (Larsen, Heldbo, Jespersen, & Nielsen, 1992; Warm, 1998). As an accurate and objective method for determining fish freshness, QIM becomes the main reference method for evaluating the quality of fresh fish in Europe.

More than 80 studies on the QIM have been published to date (Esteves et al., 2020). Olafsdóttir (1997) developed a freshness quality grading of small pelagic species of Atlantic mackerel via the QIM, which consisted of three steps, two for the training and validation of assessors and the third for the validation of the QI protocol. Moreover, a simplified QIM method, also known as the Consumer Quality Index Method (C-QIM), which can relate the results of QIM to consumer perceptions (Hyldig & Larsen, 2003). C-QIM was developed using an external panel testing their own vocabulary against expert QIM terminology (Nielsen, Hyldig, & Larsen, 2002), which involved scoring 0-3 demerit points in appearance, smell, texture, etc. (higher scores indicated poorer quality), as well as scoring sum of demerit points (SDPs). However, C-QIM is not an acceptance test, but rather a consumer test of the Decision-making tools for buying fish in markets or from fishmongers (Nielsen et al., 2002). Bernardi et al. (2009) refined the QIM for the preservation of fish in ice. Alfama et al. (2009) established QIM for frozen-thawed Atlantic Mackerel stored in ice. Thereafter, QIM has been increasingly used for sensory evaluation of raw fish (Mai, Martinsdóttir, Sveinsdóttir, Olafsdóttir, & Arason, 2009). The application of the QIM method in the shelf life was described in detail in the study by Ritter et al. (2016). The method used a score system from 0 to 3 demerit points to evaluate the quality of fish involving characteristics such as appearance, eyes, gills, texture, surface mucus, odor, texture, among other characteristics (Ritter et al., 2016; Bernardi et al., 2013; Boylston et al., 2012; Sveinsdottir, Hyldig, Martinsdottir, Jorgensen, & Kristbergsson, 2003).

The QIM scheme has the unique advantage of preserving the integrity of the sample (Araújo, De-Lima, Peixoto-Joele, & Lourenço, 2017; Ritter et al., 2016). Meanwhile, the method allows estimation of the remaining shelf life by means of a linear relationship between QI and storage time (Esteves et al., 2020). Due to the inherent differences between fish species, it is necessary to develop QIM programs for each species. In this way, one of the basic principles of QIM (species specificity) seems to be a disadvantage, since it limits the procedure to qualify the species to which it is applied and does not allow generalization of the results (Bernardo, Rosario, Delgado, & Conte - Junior, 2020).

3.5 Catch damage index and Processed fish damage index

Catch damage index (CDi) initially elaborated for gadoids by Esaiassen et al. (2013; 2004) and adapted for flatfish with the following minor adaptations, focuses on visual evaluation, including the live state of the fish and the visible damage of whole fish and fillets. The CDi scheme lists damages caused by fishing gear and handling onboard together with scores relative to the severity of the damage and its influence on the quality of the raw material. The scores for each attribute in the CDi scheme ranged from 0 for flawless to 2 for most severe.

Compared with all above mentioned methods, CDi is the only method to assess the sensory quality on live fish species. In 2016, the Atlantic mackerel (*Scomber scombrus*) CDi was established by Digre et al. (2016). In this study, mackerel live state was rated as the highest priority to be evaluated, followed by mackerel injury. Mackerel damage involves the damage of its skin, fins, and eyes of mackerel, which can be assessed by rating gear damage, crush injuries, blood trauma (eyes, skin, gills, and fins). In addition, blood spots, consistency, and parasites in fish fillets are important indicators for evaluating the quality of fish fillets.

Also, in 2016, the processed fish damage index (PFDi) was developed by Savina et al. (2016) and is used by exporters and processing companies to assess the quality of fish as it enters the industry. The score for each attribute in the PFDi scheme ranges from 0 to 2. Finally, the scores for all attributes are summed to calculate the PFDi for each fish. The PFDi scores ranged from 0 for perfection to 6 for the most severe. The assessment consisted of three processing steps, whole fish, post-skinning and post-slicing.

The two methods are suitable for different scenarios: the CDi scheme can easily be implemented on board a fishing vessel and requires inspection within 12-24 hours of capture, while the PFDi scheme is suitable for inspection of fish the day after landing and storage and is easier to implement in a fish factory.

Compared to the EU scheme, PFDi provides a finer degree of differentiation than the currently used EU quality grading scheme, e.g. gaping is a very important indicator of back cracks, and this indicator can be used to predict possible mechanical damage. During the assessment of fish quality, it is possible to identify some problems that are not reflected on the whole fish, the absence of which can affect the quality of the fillets (Digre et al., 2016).

3.6 Affective test

Affective tests have been widely used by consumers to determine and quantify their level of preference. They have proven to be very effective as a tool for designing products and services and are often used for consumer insights (Meilgaard, Civille, & Carr, 2015). The choice of methodology affects the efficiency of the test. Two of the key considerations in these methodologies are: 1). the selection of panelists, and 2). the use of scales. In fact, assessors can be classified into six categories (Naïve consumer, product user, naïve co-worker, product expert, general trained descriptive panelist, trained descriptive expert panelist) based on their experience (ASTM Committee E-18 on Sensory Evaluation of Materials and Products, 1992).

If targeting concept alignment and analytic approaches, then about 10 assessors are more appropriate. Earlier tests of preference and acceptance tended to use about 10 trained panelists, the purpose of which was to validate the results of microbiological and physicochemical tests (Alasalvar et al., 1997; Erkan et al., 2007; Goulas et al., 2007). For example, Bennour et al. (1991) conducted a quality assessment of the acceptability of Atlantic mackerel (*Scomber scombrus*) stored in ice. The Acceptance question in this study had a simpler form and only required assessors to judge the acceptability of the product, which led to limitations in understanding the sensory evaluation results, and making the analysis of the results more reliant on microbiological indicators. To obtain more consistent results, some researchers emphasized assessors training and process control (ISO, 2012). For instance, Fagan et al. (2003) conducted experimental design to standardize the manipulation of sensory evaluation. Goulas et al. (2007) reported in detail on panel screening in sensory evaluation of Pacific mackerel (*S. japonicus*), which first used Triangle test to screen panelists for the ability to identify undesirable odors. Moreover, some researchers insisted on using internal trained panelists for hedonic test, as can be seen specifically in the mackerel-related studies that were reported between 2008-2016 (Albertos et al., 2015; Alfaro et al., 2013; Aubourg et al., 2013; Erkan et al., 2010; Lakshmisha et al., 2008; Medina et al., 2009; Ozogul et al., 2013; Popelka et al., 2012; Sofi et al., 2016; Sofi et al., 2014; Uçak et al., 2011; Viji et al., 2016; Wu et al., 2016). One possible reason was for better integration of sensory attribute strength results with attitudinal results, and another possible reason was practical cost.

From an economic point of view, it would be much better to minimize the number of assessors. Nonetheless, the information that comes with training can influence the assessor's judgment of preference. However, this approach does not take into account the difference between the results given by a small number of trained panelists and those given by "Naïve consumer" (Sofi et al., 2016; Viji et al., 2016). Therefore, from 2007 to the date, researchers tend to select product users, Naïve consumers and Naïve co-workers as candidates for affective test (Fattouch et al., 2008; Mbarki et al., 2009).

The choice of scale needs to be based on the purpose of the test and the panel's situation. Different types of scales such as category, line scales, or magnitude estimation scales can be used to measure the degree of liking for a product. Early researchers used a 10-point scale, such as Alasalvar et al. (1997) applied the 10-point hedonic test to the Atlantic mackerel (*Scomber scombrus*). However, the outcome data collected by this method is not continuous type data. Fagan et al. (2003) conducted a mackerel acceptance test using linear scoring instead of a 10-point hedonic scale in order to collect continuous-type data results. In order to make it easier for untrained consumers to make a choice, Fattouch et al. (2008) used a 5-point scale instead of the previous 10-point scale. It can be seen from Table 3 that the 9-point hedonic test has become a common scoring form used by researchers in mackerel sensory tests for the purpose of detecting preference or acceptance over the last 30 years.

However, alternative scales were selected based on the type of assessor, e.g. Murali et al. (2019) used a 7-point hedonic test for evaluation in order to make the choice of scales easier for semi-trained panel to score. For special panelists such as children, Alfaro et al. (2020) used a 5-point smiley face hedonic scale for sensory evaluation with 277 children, which helped children to better understand the scale. Furthermore, the advantage of choosing an already established approach are obvious. The validity and reliability of the method has been continuously tested, and external stakeholders with knowledge of the method can easily understand how results were generated (Dehlholm, 2012; Dehlholm, Brockhoff, & Bredie, 2012; Dehlholm, Brockhoff, Meinert, Aaslyng, & Bredie, 2012). But there are still some weaknesses in these methods, such as the high cost of extensive research (Rickertsen et al., 2017), the difficulty of controlling the quality of cooked fish, and the reliability of internal expert scoring. Thus, several rapid methods have been used to study mackerel, e.g., Daltoe´ (2017) used Projective mapping to study the attitudes of school-aged children towards fish products in three different age groups. Alfaro et al. (2020) used a time-saving shortcut to solve the problem of cooking mackerel samples by using photographs instead of products to distribute to consumers and then sorting and scoring them. However, this method needs to be carefully considered if other sensory attributes of the fish and their influence on the overall quality are considered. This is because the photographic form of product presentation may only be suitable for the evaluation of appearance attributes.

3.7 Discriminative test and Descriptive test

Popelka et al. (2012) applied the Paired Comparison test to the study of frozen Atlantic mackerel cooking methods. Discriminative sensory tests began to be used to evaluate assessors' ability to identify off-flavors and screen cooking methods. Goulas et al. (2007) used a triangle test to test assessors' odor discrimination in the evaluation of fresh and chilled chub mackerel. The quality of fresh and chilled Pacific mackerel (*S. japonicus*) was compared using Same-Different Rating by Mbarki et al. (2009). Discriminative test is a fast way to determine the quality of mackerel, but it cannot quantify the differences between the sensory attributes.

There are still some researchers prefer descriptive sensory evaluation methods to obtain more information about sensory attributes (Mai et al., 2009; Nielsen & Green, 2007; Rodrigues et al., 2016; Sykes et al., 2009). Descriptive analysis is very useful in research and industrial product development. Hong et al. (1996) constituted a panel of 10 trained assessors to evaluate the odor and texture of frozen Atlantic mackerel by using a 15-cm scale. In fact, descriptive analysis can be used to evaluate single attributes, for instance Aubourg et al. (2002) used 100 points scale to describe the rancid odor of frozen horse mackerel. It can also be used to evaluate many sensory attributes of each sample, such as Goulas et al. (2007) used descriptive analysis for the sensory evaluation of fresh and chilled chub mackerel. The advantage of descriptive analysis is the high degree of species specificity for a thorough description of product qualities such as appearance, texture, and flavor (Nielsen, Hyldig, & Larsen, 2002). Also, descriptive analysis can be applied for the evaluation of both raw fish and cooked fish. In addition, descriptive analysis can be used to determine the maximum shelf life of fish. Nielsen et al. (2007) used a common descriptive method, quantitative descriptive analysis (QDA), for the evaluation of cooked fish and QIM for the evaluation of raw fish. Their study used the combination of QDA and QIM to evaluate both the quality of raw fish and its quality after cooking to more scientifically determine the maximum shelf life of fish (Nielsen et al., 2007).

However, the reliability and accuracy of descriptive methods are closely related to the selection of their attributes, and trained panelists are often at risk of forgetting attributes or failing to identify them when performing descriptive analyzes. Lazo et al. (2016) overcame this risk by using free-choice profiling and Check-All-That-Apply (CATA) association to build sensory profiles of fresh and frozen mackerel. This method offers a new option for research institutions or companies without trained panelists due to the high similarity between CATA (untrained panelists (n=44)) and QIM (trained panel (n=5-9)) sample results (Tiyo de Godoy, Veneziano, Da Cunha Rodrigues, Schoffen Enke, & Lapa‐Guimarães, 2019). In addition, Word association (WA) was another useful method to evaluate raw fish evaluations by untrained panel, although its ability to discriminate samples was weaker than CATA under the same conditions (Tiyo de Godoy et al., 2019).

As more descriptive methods have been applied to fish research, descriptive methods can be classified into time-static methods and time-dynamics methods based on the way they are evaluated. Time-static methods include: Flavor Profile, Texture Profile, QDA®, Quantitative Flavor Profiling (QFP®), Spectrum™, Free-choice profiling, Optimized Descriptive Profile, Flash Profiling and Ideal Profile Method. Nowadays, QDA® is widely used to study freshness before and after frozen storage, affecting the quality and sensory characteristics of fish for different commercial presentations (Rodrigues et al., 2016). However, this method is time consuming and it would lead to the fatigue of the sensory panelists. Therefore, this method is not suitable for handling large collection of samples. Some similarity sorting-based methods such as Sorting, Labeled Sorting/Sorted Napping, Napping®, Projective mapping and Ultra-Flash Profiling provide a global view of similarity sorting between samples and require less training of analysts, which are an effective class of methods. Daltoe´ (2017) used Projective mapping to evaluate a large number of fish stickers. However, these methods are more demanding for product preparation and are not suitable for cooked fish samples (Dehlholm, 2012; Dehlholm, Brockhoff, & Bredie, 2012; Dehlholm, Brockhoff, Meinert, et al., 2012). In addition, CATA, Free listings, and Rate-All-That-Apply, based on the Pick-any method, have recently received attention in sensory studies (Oppermann, de Graaf, Scholten, Stieger, & Piqueras-Fiszman, 2017; Tiyo de Godoy et al., 2019).

Time-dynamics methods focus on human perceptual processes during sensory evaluation. For example, temporal dynamics descriptive tests can evaluate the sensations of food change during chewing. Albert et al. (2012) compared the temporal dominance of sensation (TDS) and key-attribute sensory profiling (KASP) used to evaluate fish sticks and found that the results obtained from the TDS and KASP scores were very similar. It is worth noticing that TDS using an untrained panel was able to attain similar results, saving time and effort in comparison with KASP. Moreover, TDS can monitor the appearance and evolution of different attributes over time of consumption. Currently, methods such as TDS (Albert et al., 2012; Pineau, Cordelle, & Schlich, 2003), Dynamic Flavor Profile (DFP) (De-Rovira & Mermelstein, 1996), Progressive Profiling (Jack, Piggott, & Paterson, 1994), Sequential Profiling and Temporal Order of Sensations (TOS) are widely applied in sensory evaluation (Methven et al., 2010; Pecore, Rathjen-Nowak, & Tamminen, 2011). Among these methods, TDS has received the most attention. This approach focuses more on the complexity and interactivity of perceived sensations, requiring the assessors to evaluate the most dominant attribute (Pineau et al., 2003). While DFP requires the assessors to draw TI curves independently and finally construct a 3D spider plot for multiple attributes (Dehlholm, 2012; De-Rovira et al., 1996). Unlike two previously mentioned methods, sequential profiling tends to study repeated exposure. TOS is faster than TDS because this method removes intensity assessment and focus on the selection of temporal attributes only (Dehlholm, 2012; Pecore et al., 2011). However, these methods have not been used to assess the quality of mackerel. Perhaps the choice of specific sensory evaluation methods will be limited by the content of the study, and these methods still provide additional options for the analysis of sensory quality in mackerel.

4 Sample preparation and evaluation of mackerel during process control

In the commercial environment, sensory evaluation is prevalent in the harvesting, processing and marketing of mackerel and is a very important part of the quality control of mackerel (Howgate, 2013). See Figure 2 for the main evaluation methods in the distribution chain of mackerel. Since sensory evaluation is a test based on the subjective attitude of assessors, there are many factors that affect the accuracy of the results, such as the training and selection of assessors, sample preparation and process control. Therefore, this part focuses on the preparation of mackerel samples and process control methods in different stages of mackerel supply chain.

4.1 Sample preparation of raw mackerel

Most mackerel studies show that the time of acquisition of mackerel samples is 8 to 10 h after fishing (Aubourg, 2001; Erkan et al., 2010; Jhaveri et al., 1982; Mbarki et al., 2009). There are also studies that reduced acquisition period to 4-6 hours, or extended to 24-48 hours. Although lipid oxidation in mackerel has been extensively studied, few authors have been able to draw on any systematic study to examine the effect of sample acquisition time on mackerel quality (Alasalvar et al., 1997; Alfaro et al., 2013; Aubourg et al., 2013; Bennour et al., 1991; Chun et al., 2014; Fattouch et al., 2008). Mackerel are usually preserved in ice and packed in boxes or sealed bags. The transportation temperature of mackerel will vary according to different research purposes. Generally, the transportation temperature of mackerel is controlled at 0-2 °C (Alasalvar et al., 1997), whereas the temperature of non-frozen mackerel samples is generally controlled at 4 °C (Babakhani et al., 2015). During mackerel transportation, commonly used containers include: plastic lined polyfoam box, polystyrene box, rigid plastic bags, polyethylene bag, sealed foamed box, cardboard box and wooden box (Aubourg et al., 2005; Aubourg et al., 2006; Chen et al., 2019; Erkan et al., 2010; Fattouch et al., 2008; Fiore et al., 2019; Hong et al., 1996; Icekson et al., 1998; Wu et al., 2016).

On arrival in the laboratory, some basic information of mackerel samples will be recorded according to the purpose of the research. Previous research has established that the sensory characteristics of fish are affected by its species, fishing ground, fishing season, fish batch and maturation of fish gonads. In most of the mackerel research articles related to sensory evaluation, mackerel species, origin, average length and average weight were recorded, but only a few indicate the harvest time and the gonad maturity of mackerel samples (Aubourg et al., 2005; Aubourg et al., 2006). The processing of whole mackerel includes heading, eviscerating, washing and filleting and hand filleted (Jhaveri et al., 1982). Then cut the mackerel into small (e.g. 2.54 x 3.81 cm (Jiang et al., 1985) or 20 g (Jhaveri et al., 1982) pieces) or large (8 x 4 x 2 cm or 75 g) (Boylston et al., 2012) pieces to assess the sensory quality of the sample. It is worth noting that the mackerel skin and brown muscle can be removed or retained depending on the purpose of the study due to their strong flavor (Boylston et al., 2012). Since the homogeneity and consistency of the product is very important in the evaluation of the senses, it is also possible to make minced fish if the texture is not considered. The sample preparation procedure of raw mackerel is shown in Figure 3. In addition, mackerel is prone to spoilage due to its high fat content. In order to prevent temperature induced disturbances, the study by Tzikas et al. (2009) required the frozen material to be thawed overnight in a refrigerator set at 2 ± 2 °C before sensory evaluation.

4.2 Sample preparation of cooked mackerel

Sudip et al. (1982) used steaming (10 min with samples wrapped aluminum foil) to ensure uniform heating of Atlantic mackerel. In another major study, Alsalvar et al. (1997) preferred to cook Atlantic mackerel in steam for 15 min in a covered aluminum pan. Both studies used steam to minimize cooking loss and ensure heating uniformity. Hong et al. (1996) proposed a formula, cooking time = raw weight x 0.00633 min / g, and that internal temperature needed to be recorded at 1-5 min intervals. In 2012, Popelka et al. (2012) preferred the hot steaming method to control the center temperature rather than the control time, and in their experiment the steaming time was preferable with the sample center temperature reaching 65°C.

Water bath is another heating method which can retain the juice and flavor to the maximum extent. Honikel (1998) suggested cooking sample inside a plastic bag by water bath until a final temperature of 75 °C in geometric center is reached. In a study of horse mackerel, Aubourg et al. (2002) also preferred this heating method. Mbarkei et al. (2009) chose microwave oven (600 w) as the heating treatment method to prepare chub mackerel samples. From the heat transfer point of view, the traditional steam heating and water bath heating methods transfer heat from the outside to the inside slowly thus are time-consuming. The microwave heating method converts electrical energy into high-frequency microwaves that directly penetrate the interior of the material and heat the entire material at the same time (Hailong et al., 2020). Therefore, compared with steam and water bath heating, microwave heating has high conversion efficiency, uniform heating and is easy-to-control. However, microwave heating method, unlike traditional consumer cooking, cannot induce the roasted aroma produced by the grilling method. Fagan et al (2003) treated mackerel samples by grilling for 6 minutes, and although the study conducted five repeat tastings, the flavor control of the samples could still be inconsistent as grilling relies mainly on heat transfer and it is too difficult to control the desired uniform quality and cooking losses. Aubourg et al. (2013) used the grill conditions to (200 °C, 10 min) and set the center temperature cooking standard for fish to 68 °C, recommending more repeated trials of grill-treated mackerel samples. The sample preparation procedure of cooked mackerel is shown in Table 4.

4.3 Test control

During the sensory evaluation of mackerel, certain process controls are carried out in order to prevent interference from other factors in the sensory test, for example, the samples are required to be divided equally with same container and 3-digital numbers, the samples tissue need to be homogenized with consistent temperature. Jia et al. (1996) stated that mackerel samples should be warmed to room temperature prior to evaluation for reducing temperature-induced sample flavor errors. Moreover, in order to prevent the color of the samples from affecting the assessor's evaluation of off-flavor, red shielded lights were applied in this study. Furthermore, due to the perishability of mackerel, Fagan et al. (2003) made restrictions on the taste time when they conducted sensory evaluation of mackerel, i.e., all fresh mackerel fillets need to be tested within 6 h to avoid possible errors. Due to the large individual variation of fresh mackerel, in order to obtain as stable samples as possible, Hyldig et al. (2012) required that each assessor should evaluate the samples at the same position of each fillet. Babakhani et al. (2015) more explicitly controlled the evaluation of mackerel samples. In their study, the samples were served in randomized order after incubation for 1 h at 5 °C.

5 Conclusion and future research

This review emphasizes the importance of sensory evaluation for mackerel research, provides critical evaluation of currently available sensory methods, and offers guidance for future research and industrial application of sensory methods for quality control of mackerel products. However, it is true that the variability of handling procedures and the complexity of quality attributes of mackerel products pose a great challenge for the assessment and control of mackerel quality. In reviewing previous studies, we identified at least three research gaps. The first gap is the lack of assessment of the sensory quality of mackerel in terms of temporal dynamics, which leaves a gap in research on the release of flavor during chewing; the second gap is the lack of research on the effects of some processing steps, such as slaughter, transportation, on the sensory quality of mackerel; the third gap is the lack of research on the mechanisms of flavor, especially odor production, in mackerel.

As one of the most important products in the food trade, mackerel is very susceptible to spoilage and quality deterioration, which determines quality control must be handled in a timely manner. Therefore, sensory evaluation is considered as the main method to determine the quality of mackerel. While most of the current sensory evaluation techniques for mackerel are focused on EU schemes, QIM, hedonic test and descriptive analysis, some profiling techniques using untrained panel will be used more widely in the aquatic sector to gather information directly from consumers. These include free-choice profiling, sorting, projective mapping, flash profiling, and CATA (Lazo, Claret, & Guerrero, 2016). In practice, quality control of aquatic products must consider the needs of consumers, and it is of great importance to understand and satisfy their needs for sensory properties of delicious food. Therefore, in the future, sensory evaluation will remain consumer-centered.

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The authors declare no conflict of interest.

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Sensory evaluation of fresh/ frozen mackerel products: A review

Table 1

Note. This summary table includes the author, year, country, specie, sample preparation and sensory information (data collection, tool or method). Sensory evaluation of mackerel can be divided into off-odor identification, acceptance/preference testing and sensory characterization depending on the purpose.

Table 1 Mackerel studies published in the past 30 years (1990-2020)

Species	**Country**	**Purpose**	**Sample preparation**	**Method**	**Sensory data collected from**	**Attribute**	**Reference**
Atlantic Mackerel	MOROCCO	Ice: fish ratio	Raw fish	X	X	Acceptance	(Bennour, Marrakchp, Bouchritf, Hamama, & Ouadaa, 1991)
Atlantic Mackerel	CANADA	CO_2 MAP storage	Raw/Cooked (Baked)	15 cm scale	10 trained assessors	Appearance, odor, texture	(Hong et al., 1996)
Atlantic Mackerel	USA	Glutathione system	Raw minced	9-point scale	6 trained assessors	Off-flavor	(Jia et al., 1996)
Atlantic Mackerel	UK	Aroma	Raw fillet Cooked (steamed)	FTRU scheme Torry scheme 10-point hedonic test	10 trained assessors	Freshness Acceptance	(Alasalvar et al., 1997)
Atlantic Mackerel	ISRAEL	Lipid oxidation	Fillet	X	X	X	(Icekson, Drabkin, Aizendorf, & Gelman, 1998)
Horse mackerel	SPAIN	Ice shelf-life	Whole fish Fillet	EU scheme	5 trained assessors	Off-flavor	(Aubourg, 2001)
Pacific mackerel	USA	Histamine	X	X	X	Appearance, texture, odor	(Kim, Field, Chang, Wei, & An, 2001)
Horse mackerel	SPAIN	Pre-chilled storage	Water bath cooked fillet.	100 score	6-9 trained assessors	Rancid odor	(Aubourg, Lehmann, & Gallardo, 2002)
Horse mackerel	SPAIN	Brine pre-treatment	Whole fish	X	X	X	(Aubourg et al., 2002)
Atlantic Mackerel	USA	Hemolysate	X	10 scale	5-8 trained assessors	Rancid odor	(Richards et al., 2003)
Atlantic Mackerel	IRELAND	Freeze-chilling	Cooked fillet (baked)	6 cm	25 untrained assessors	Acceptance	(Fagan et al., 2003)
Horse mackerel	PORTUGAL	Tap and treated seawater washing	Raw whole fish	EU scheme QIM scheme	3 experienced assessors	Appearance, eye, cover, gill, abdomen, vent	(Inácio, Bernardo, & Vaz-Pires, 2003)
Horse mackerel	SPAIN	12 months of frozen storage	Raw whole fish and fillet.	EU scheme	5 selected assessors	General aspect, odor, and color	(Aubourg, Piñeiro, & González, 2004b)
Atlantic Mackerel	SPAIN	Catching season	Whole fish fillet	EU scheme	5 selected assessors	Skin, gills, eyes	(Aubourg, Rodríguez, & Gallardo, 2005)
Atlantic Mackerel	SPAIN	Flax seed soaking treatment	Fillet	EU scheme	5 trained assessors	General aspect, odor, color	(Aubourg, Stodolnik, Stawicka, & Szczepanik, 2006)
Chub Mackerel	GREECE	MAP, VP package	Fresh fish 12hr of the catch, raw fillet	Triangle test 10 intensity scale	7 trained assessors	Off-flavor/Sensory profile/acceptance	(Goulas et al., 2007)
Chub Mackerel	TURKEY	MAP, VP package	Cooked fillet	10 scale	5 trained assessors	Acceptance	(Erkan et al., 2007)
Atlantic Mackerel	TUNISIA	Quince polyphenolic extract presoaking	Smoked fillets	5-point hedonic test	70 consumers	Odor, taste, color, firmness	(Fattouch, Sadok, Raboudi-Fattouch, & Slama, 2008)

Table 1 (continued)

Species	Country	Purpose	Sample preparation	Method	Sensory data collected from	Attribute	Reference
Atlantic Mackerel	UK	Instant green tea	Minced	X	X	X	(Alghazeer, Saeed, & Howell, 2008)
Indian Mackerel	INDIA	Freezing Time	Cooked (boiled 10 min)	10-point hedonic test	10 trained assessors	Appearance, color, odor, flavor, taste, texture/acceptance	(Lakshmisha, Ravishankar, Ninan, Mohan, & Gopal, 2008)
Chub Mackerel	TUNISIA	VP and low-dose irradiation	Cooked (microwave oven)	Same-difference rating 9-point hedonic test	120-consumer	Acceptance	(Mbarki et al., 2009)
Horse mackerel	SPAIN	Hydroxycinnamic acids	Minced	8-point scale	4 trained assessors	Off-flavor	(Medina, González, Iglesias, & Hedges, 2009)
Atlantic Mackerel	CROATIA	Endotoxin and biogenic amine levels	X	X	X	Texture, odor	(Prester et al., 2009)
Horse mackerel	GREECE	Vacuum storage	Raw fillet Cooked fillet	EU scheme 5-point descriptive scale	8 trained assessors	General aspect, odor, color	(Tzikas, Papavergou, Soultos, Ambrosiadis, & Georgakis, 2009)
Chub Mackerel	TURKEY	Essential oils treatment	Cooked fillet (microwave oven)	9-point scale	5 trained assessors	Odor, taste, texture/Acceptance	(Erkan & Bilen, 2010)
Atlantic Mackerel	ROMANIA	Quality control	Frozen Smoke Canned	Romanian guidelines	X	Skin, external odor, consistency, flesh odor	(Dobrinas, Stanciu, Soceanu, Epure, & Bold, 2011)
Horse mackerel	SPAIN	Lipid damage	Raw and cooked	EU scheme	5 trained assessors	Appearance, odor	(Sanjuás-Rey, Barros-Velázquez, & Aubourg, 2011)
Atlantic Mackerel	TURKEY	Rosemary extract combination with VP	Fish burgers	9-point scale 9-point hedonic test	6 trained assessors	Appearance, odor, flavor and texture	(Uçak, Özogul, & Durmuş, 2011)
Atlantic Mackerel	SLOVAKIA REPUBLIC	Glaze and storage temperature	Cooked (steam vs bake)	Paired comparison test 5-point scale	6 trained assessors	Taste, aroma, texture, juiciness and appearance	(Popelka et al., 2012)
Atlantic Mackerel	TURKEY	Borage-containing film	Smoked	9-point hedonic test	6 trained assessors	Appearance, odor, flavor, texture/Acceptance	(Ozogul & Balikci, 2013)
Horse mackerel	SPAIN	MAP Different Temperature	Raw fillets	5-point scale	6-8 trained assessors	Freshness (Appearance, odor, color, firmness)	(Alfaro, Hernandez, Balino-Zuazo, & Barranco, 2013)
Atlantic Mackerel	SPAIN	HPP pre-treatments	Cooked baked	5 point-Hedonic tests 6 point-Sensory profile	10 trained assessors	Sensory profile/acceptance	(Aubourg et al., 2013)
Korea Mackerel	KOREA	Storage Conditions	X	X	X	Freshness	(Chun, Cho, & Shin, 2014)
Horse mackerel	INDIA	Pre-washing with Tannic Acid	Raw minced	9-point hedonic test	7 trained assessors	Sensory profile/acceptance	(Sofi, Zofair, Surasani, Nissar, & Singh, 2014)

Table 1 (continued)

Species	Country	Purpose	Sample preparation	Method	Sensory data collected from	Attribute	Reference
Atlantic Mackerel	DENMARK	Seaweed extract	Raw minced	9-point scale	4 trained assessors	Off-flavor	(Babakhani et al., 2015)
Atlantic Mackerel	NORWAY	Purse seiner	Raw whole fish Raw fillet	Total catch damage index	X	Injuries, blood, gap, consistency	(Digre et al., 2016)
Indian mackerel	INDIA	Antioxidants	Raw whole fish	9-point hedonic test	12 trained assessors	Appearance, color, taste, texture, odor /acceptance	(Sofi et al., 2016)
Indian mackerel	INDIA	VP mint extract	Raw and cooked	9-point hedonic test	6 trained assessors	Sensory profile/acceptanc e	(Viji et al., 2016)
Pacific mackerel	CHINA	Chitosan-Gallic Acid Coating	fillet	9-point hedonic test	7 trained assessors	Sensory profile/acceptanc e	(Wu et al., 2016)
Chub Mackerel	CHINA	Atmospheric cold plasma (ACP)	fillet	9-point hedonic test	50 assessors	Preference and acceptance	(Chen et al., 2019)
Atlantic Mackerel	ITALY	HP, CB and MWB	Fillet	9-point hedonic test	10 trained assessors	appearance, texture, odor, off-odor and taste	(Fiore et al., 2019)
Atlantic Mackerel	POLAND	furcellaran films with plant extracts	Fillet	5-point scale	5 trained assessors	Freshness/accept ance	(Jamróz, Kulawik, Guzik, & Duda, 2019)
Pacific mackerel	CHINA	chitosan–citrus essential oil coating	Fillet	9-point hedonic test	37 trained assessors	Appearance, odor	(Li, Wu, Wu, Yuan, & Hu, 2019)
Indian Mackerel	INDIA	solar–electrical hybrid dryer (S-EHD)	Dried	7-point hedonic test	10 semi-trained assessors	Color, texture, appearance, odor/acceptabilit y	(Murali, Sathish Kumar, Alfiya, Delfiya, & Samuel, 2019)
Indian Mackerel	SPAIN	Children's preference	Color photographs	Sorting 5-point hedonic smiley-scales	277 children	Preference Concept	(Alfaro, Rios, Arranz, & Varela, 2020)

Table 2

Table 2 Advantages and disadvantages of various sensory methods.

Sensory method	Advantage	Disadvantage	Reference
Palatability test	This method takes into account the changes in the fish during preparation and during the cooking process.	The terminology in the method tends more towards the appearance at the time of sale and more towards collecting the results of consumer experience rather than the description of the sensory characteristics of the product; it is not suitable for shelf-life assessment of mackerel.	(Stansby et al., 1941)
Spoilage test	This method can provide a reference for the determination of the shelf life of mackerel.	This method has limitations in conducting sample evaluation including only appearance and odor due to safety issues; it is not suitable for describing product characteristics.	(Dyer, Sigurdsson, & Wood, 1944)
Catch damage index (CDi)	This method is suitable for fishing vessel operations and for rapid evaluation of whole fish damage.	This method requires testing within 12-24 hours of capture; not suitable for shelf-life testing.	(Esaiassen et al., 2013)
Processed fish damage index (PFDi)	This method is suitable for the detection of stored fish after landing; it can be used to predict possible mechanical damage.	It is not suitable for shelf-life assessment of mackerel.	(Savina et al., 2016)
EU scheme	Highly efficient; It is a regulated mandatory method used by the competent authorities at several stages of the commercial circuit (mostly at first sale/auction).	It is not suitable for shelf-life assessment of mackerel.	(EC, 1996)
Torry scheme	This method is applicable to the evaluation of raw and cooked fish.	This method is not suitable for evaluating large quantities of fish because there is not enough time to score the fish according to the Torry procedures.	(Howgate, 2013)
Quality index method (QIM & C-QIM)	This method is applicable to the sensory evaluation of raw fish; it is suitable for detecting trends in sensory quality during the shelf life.	Differences between species are not taken into account (as it only uses general parameters to group species), this method mixes subjective and objective sensory methods, it requires trained and experienced assessors, and it does not provide information on the remaining shelf life of the fish.	(Esteves et al., 2020)
Discriminative test	It can be done quickly by the assessors; the method is simple and easy to understand.	It is not possible to quantify the differences between the sensory attributes of mackerel.	(ISO, 2019)
Descriptive test	The high degree of species specificity for a thorough description of product qualities such as appearance, texture, and flavor.	The reliability and accuracy of the test are closely related to the choice of its attributes, and trained panel often run the risk of forgetting attributes or failing to identify them when performing descriptive analysis.	(ISO, 2016)
Affective test	Widely used by consumers to determine and quantify the degree of consumer preference for a given product.	High cost; difficult to control the quality of cooked fish.	(ISO, 2014)

Table 3

Table 3 Application of sensory technology to mackerel preference and acceptance.

Mackerel Species	Sensory Technique	Reference
Atlantic mackerel	15cm lime scale (intensity test)	(Hong et al., 1996)
	10-point hedonic test	(Alasalvar et al., 1997)
	6cm lime scale (intensity test)	(Fagan et al., 2003)
		(Uçak et al., 2011)
	9-point hedonic test	(Ozogul et al., 2013)
		(Aubourg et al., 2013)
	5-point hedonic test	(Jamróz et al., 2019)
Pacific chub mackerel	10-point intensity test	(Goulas et al., 2007; Erkan et al., 2007)
		(Mbarki et al., 2009)
	9-point hedonic test	(Wu et al., 2016)
		(Erkan et al., 2007)
		(Chen et al., 2019)
Indian mackerel	10-point hedonic test	(Lakshmisha et al., 2008)
	9-point hedonic test	(Sofi et al., 2016)
		(Viji et al., 2016)
	7-point hedonic test	(Murali et al., 2019)
Horse mackerel	9-point hedonic test	(Sofi et al., 2014)

Table 4

Table 4 Sample preparation of cooked mackerel

Cooking methods	Advantage	Disadvantage	Reference
Steaming	This method minimizes cooking loss and ensures uniform heating.	Time consuming.	(Sudip et al., 1982)
Water bathing	This method retains the maximum amount of juice and flavor.	Time consuming.	(Aubourg et al., 2002)
Microwaving	The method is characterized by high conversion efficiency, uniform heating and easy-to-control.	Cannot induce the roasted aroma.	(Mbarkei et al., 2009)
Grilling/roasting	This method contributes to unique baking flavors and textures of foods.	Difficult to control flavor and cooking loss. Time consuming.	(Aubourg et al., 2013)

Figure 1

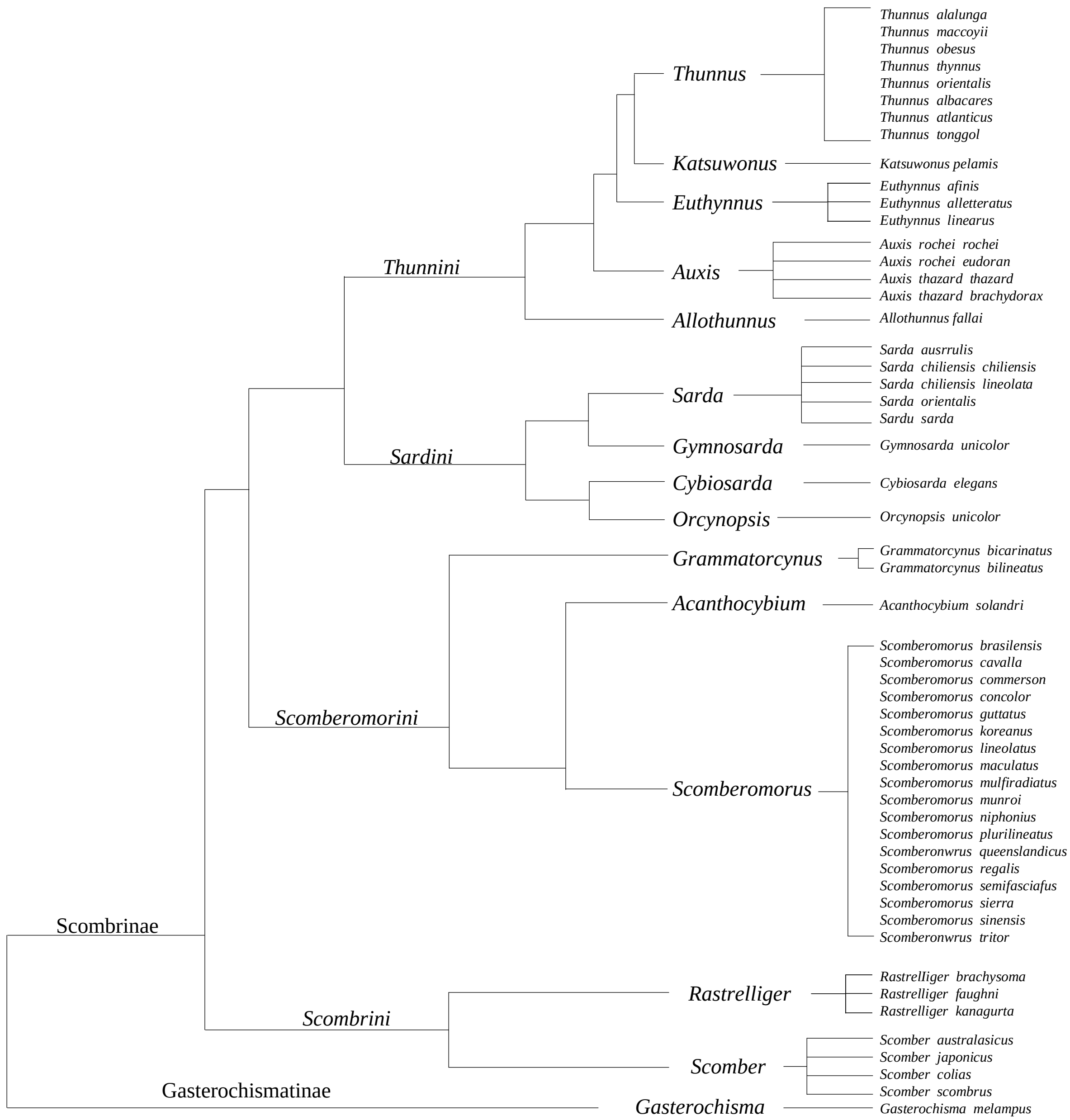

Figure 1. Classification and taxonomy tree of the family Scombridae (Collette et al., 2001)

Figure 2

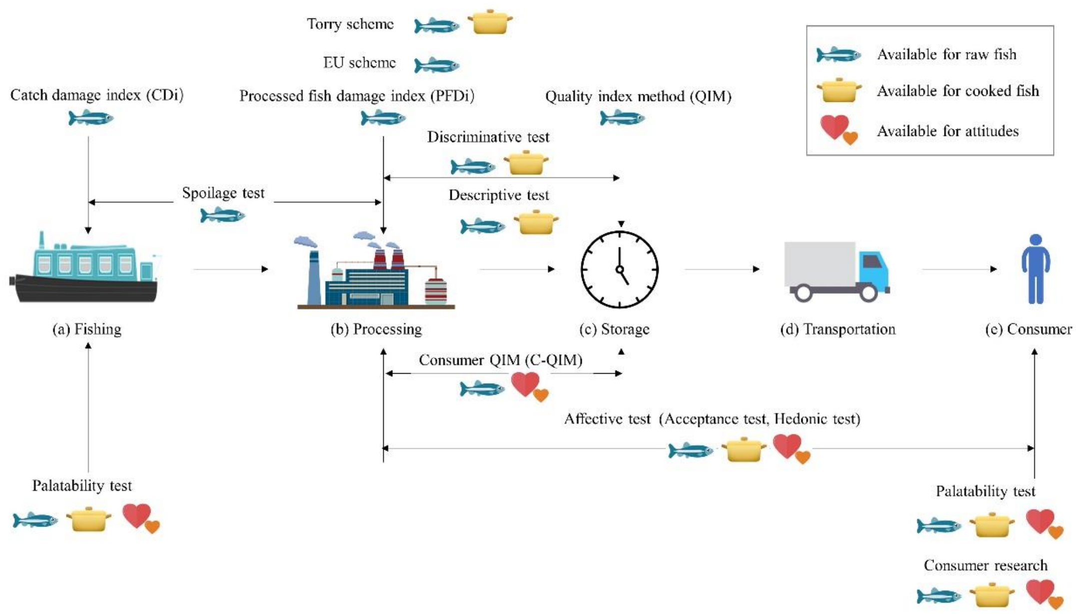

Figure 2 A general view of the range of applications of sensory evaluation methods for mackerel.

Note. The main links in the mackerel chain are listed in (a) to (e). Relevant sensory evaluation methods are listed in the figure, and the sample forms that can be used for evaluation are indicated by the symbols of fish and pot for raw fish and cooked fish, respectively. Moreover, some of the methods that can be used to measure subjective attitudes are marked by heart symbols.

Figure 3

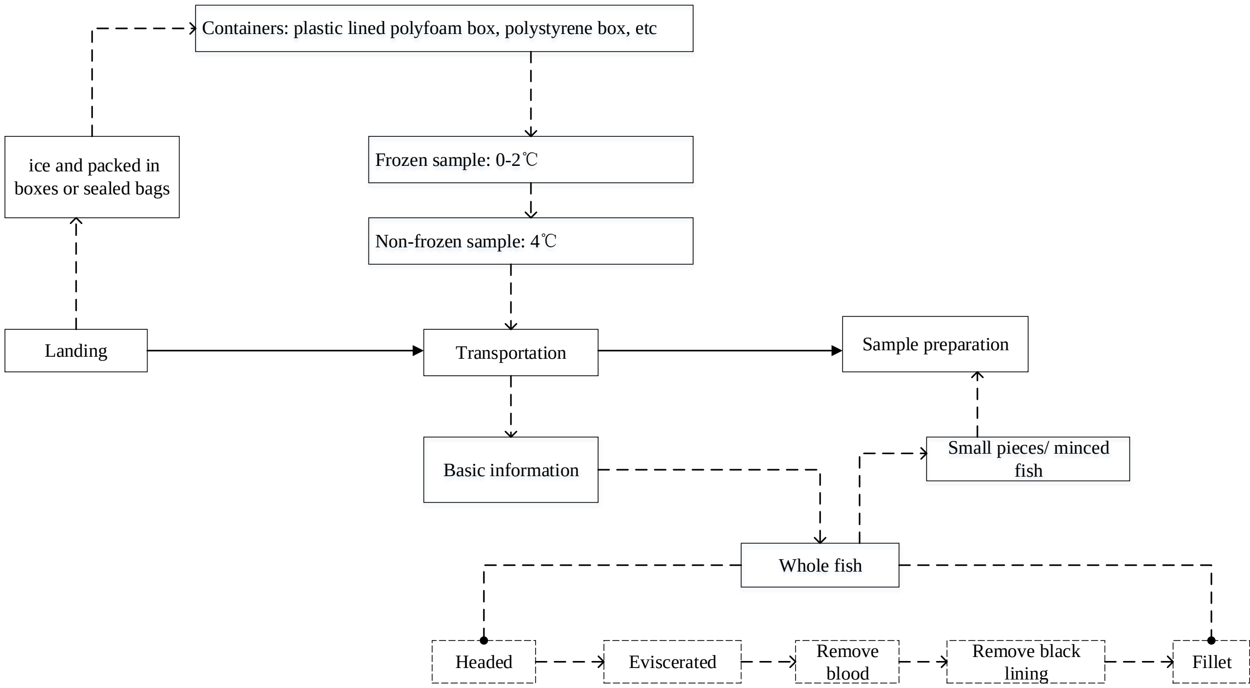

Figure 3 Sample preparation of raw mackerel.

Note. After landing, the fish will be packed in boxes or sealed bags and then put into containers for transportation at 0-2 °C or 4 °C. Upon arrival at the laboratory or processing plant, the fish will be headed, eviscerated, washed to remove blood and the black lining in the gut cavity, and hand filleted. Moreover, fillets will be cut into pieces or minced for sensory evaluation.

1410