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REVIEW

Effects of frying on fish, fish products and frying oil – a review

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Abstract

Fish and fish products contain important source of nutrient that provides benefits upon consumption. The increasing demand and high utilization of fish have caused a market shift in the fishery industry. Although fish is nutritious, some consumers do not prefer to consume fish in its original form because of its fishy taste, fishy odour and it is highly perishable. To further promote the consumption of fish, the production of fish products and frying are applied to suit consumers' preferences. Frying is commonly used in various food premises as it changes the characteristics of the fish and fish products, especially the taste and texture. However, the increase in awareness has changed the perception of the consumer as they prefer healthier food in their lifestyle. Despite the increase in awareness, some consumers still prefer fried foods and food products due to their unique sensory properties and texture. To understand the effects of frying on foods, several parameters during frying are studied. Frying temperature, frying cycle, frying time, frying techniques and frying oils used are parameters that could affect the physicochemical and sensory attributes of the fish and fish products. Repetitive frying could cause the formation of toxins and alter the fatty acid content in the fish, fish products and frying oils. This changes the taste and alters the composition of the foods. Meanwhile, different frying times, oil and techniques cause significant changes to the chemical composition, sensory attributes, lipid oxidation, fat content, oil absorption and fatty acid profiles of the fish and fish product. This review aimed to gather information specifically on the changes in fish and fish products upon frying at different frying cycles, time, temperature, oils, and techniques.

1. Introduction

Fish is one of the significant protein contributors to our daily diet, and it is consumed globally due to its high protein content, high polyunsaturated fatty acids (PUFA), minerals, and vitamins (Abraha *et al.*, 2018). Fish contains high omega-3 polyunsaturated fatty acids which help in preventing heart disease and decreasing the risk of certain cancer and other diseases such as cancer, hypertension, and atherosclerosis (Domingo, 2014; Kannaiyan *et al.,* 2019). Besides that, moderate fish intake also benefits mothers during pregnancy (Gil and Gil, 2015). According to the Food and Agriculture Organization of the United Nations Yearbook of Fishery and Aquaculture Statistics (FAO, 2018), fish utilisation for human consumption increased from 2011 to 2016. Malaysia is considered one of the top Asian countries with a high percentage of fish consumers as Malaysian's annual per capita fish is the second-highest after Japan among Asian nations and ranked fifth throughout the world (York and Grossard, 2004). The average growth of fish consumption has continuously increased since 2000, about 1.6% annually in Malaysia (Ibrahim *et al.*, 2014). The Food and Agriculture Organization (2018) reports that the entire fish and fishery products reached about 1,760,371 tonnes in 2013. Nevertheless, fish are not often consumed by some consumers in their fresh form due to oxidisation, spoilage, odour and off flavours (Sampels, 2015). Therefore, to promote the consumption of fish, fish are processed to produce high-quality fish products whilst maintaining their nutritional value of the fish (Hall, 2012).

Frying is considered one of the popular processes used in the food industry to provide unique sensory and change the physical properties of the food products (Ghidurus *et al.,* 2010; Karizaki *et al.,* 2013; Zarulakmam *et al.,* 2021). Frying applies heat and mass transfer equilibrium, causing the oil to be transferred into

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the products while the water exudes from the food product into the oil (Khazaei *et al.,* 2016; Yu *et al.,* 2020; Dehghannya *et al.,* 2021). High protein food such as fish is susceptible to heat causing major changes in protein such as the loss of soluble proteins. Absorption of oil could contribute to the high amount of fatty acids in the fish and increase the hydrophobic interaction which causes water to exude out from the fish. According to Nieva-Echevarría *et al.* (2016), frying is used to cook food above water boiling point either by partially or fully immersing the foods in liquid-state oils or fats. The frying process is usually influenced by several factors such as the type of oil and temperature used during frying (Oluwaniyi *et al.,* 2010; Oke *et al.,* 2018; Zhang, Chen, Yue *et al.,* 2020). Various frying techniques such as vacuum frying, deep frying and stir-frying were designed according to several parameters that include the frying medium and frying mechanisms to produce better quality end products (Arslan *et al.,* 2018). Fried fish products with coatings and other ingredients are more acceptable and have higher sensory scores. However, several factors cause a shift in the sensory attributes such as the temperature of frying, frying cycle and frying oil used (Kilincceker and Hepseg, 2011; Tadesse *et al.*, 2020).

The primary objective of frying was to increase food acceptability and develop desirable sensory characteristics (Ghidurus *et al.,* 2010). Frying repetitively using the same oil has been adapted by industries to save costs. However, the repetitive frying process has its limitation as it can cause the formation of toxins with an increased amount of frying cycle. Furthermore, the selection of frying oil during frying must be appropriate and suitable to ensure no lipid oxidation by-products were produced that could contribute to health risks. Another limitation of frying is the frying technique. Research and data on other cooking methods, such as stir-frying and pan-frying, that were commonly used in Asia have not been thoroughly and majorly investigated. Moreover, the research study about frying techniques especially the deep-fat frying technique and its effect on fish and fish products were challenging to find. Furthermore, consumer nowadays preferred healthy food as their lifestyle, thus, the tendency for consumers to seek more nutritious food alternatives are higher compared to consuming high-fat content fried food (Zaghi *et al.,* 2019). Many frying technologies have been introduced especially frying techniques that could lower the absorption of oil intake and maintain the palatable sensory properties of the food (Vieira *et al.,* 2018; Fang *et al.,* 2021). According to Fang *et al.* (2021), some new frying techniques such as air frying and vacuum frying have been developed. Nowadays, air frying techniques have become a trend used in frying food, especially in Malaysia, as they become more aware of the food composition and health benefits. This was also supported by Vieira *et al.* (2018), as consumers gain a new technology called air frying; it becomes more popular because it provides similar characteristics to fried products with less amount of oil. However, research on the application of air frying on fish and fish products was still scarce. According to Ferreira *et al.* (2017), research studies regarding the degradation of lipids using air frying is still scarce. This was also supported by Sansano *et al.* (2015) where the researcher reported that there was a lack of research that provides scientific information regarding the effect of using air frying on the initiation of acrylamide. Hence, the objectives of this study were to review the effect of different frying cycles, frying time, frying oil and frying techniques on the properties of fish and fish products.

2. Fish and fish products

Fish is a significant contributor of protein for humans, and it is consumed globally due to its high content of nutrients. Fish contain high omega-3 polyunsaturated fatty acids that can help prevent diseases especially cardiovascular diseases (CVD) such as heart disease and hypertension (Domingo, 2014; Kannaiyan *et al.,* 2019). Therefore, the increase in demand and the benefit of consuming fish has changed the fish industry, especially fish product processing.

Fish can be sold in various forms such as frozen fish, dried fish, smoked fish, canned fish, pre-cooked fish, salt -cured fish, marinades fish, fermented fish products, and processed fish products such as fish balls (Cutting and Spencer, 2012). Fish can also be processed into surimi products, fish oil and fish meal as a by-product of fish processing (Jayathilakan *et al.,* 2011). The diverse fish product produced is determined by the technology used during processing (Hall, 2012). Cooking, drying, freezing, chilling, fermenting, frying, canning, modern fish processing and by-product processing were methods involved in producing different types of fish products (Hall, 2012; Yongsawatdigul *et al.,* 2014). The benefit of processing fish and fish products depends on the processing mechanism and the raw ingredient used but commonly, fish processing helps perishable ingredients to increase their shelf life, especially the frying method (Tiwari *et al.,* 2011). Other than that, fish products improve the taste and texture of the fish beside still providing the nutrients of a fish.

2.1 Composition of fish

Fish are recognized for their various nutritional composition. The composition of fish consists of 0.1-1% carbohydrate, 15-24% protein, 70-84% water, 0.1-22%

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fat and 1-2% minerals, 0.5% calcium, 0.25% phosphorus and 0.1% vitamins A, B, C and D (Abraha *et al.*, 2018). As moisture content is high in fish, a processing method that affects the moisture content will also alter the characteristics of the fish, such as gelation of protein and texture. Fish provide high protein and fat content such as omega-3 polyunsaturated fatty acids and amino acids (Suganthi *et al.*, 2015). Fatty acid composition and fat content vary within species depending on their biotic and abiotic factor such as water temperature, pH, season, type and amount of feed available (Moradi *et al.*, 2011). For example, the different season of fish contains different lipid content which can differ from four to more than 30% in mackerel and 2-25% in herring fish. It is also reported that larger fish has a higher amount of saturated fatty acid compared to medium and small size (Mekonnen *et al.*, 2020). Other than that, most marine fish had lower fat content than freshwater fish (Huynh and Kitts, 2009; Li *et al.,* 2011). The difference in fish composition causes various effects and physicochemical changes for different types of fish during processing and frying.

Fish are categorized based on their muscle tissue which are lean fish and fatty fish. Lean fish generally have more white meat with some dark muscle meat in the fish body while fatty fish have more dark muscle meat and fat content. Moreover, fatty fish meats are pigmented with yellow, grey, pink or other colours (Moradi *et al.*, 2011). These colour pigments are undesirable for fish product processing and are usually discarded during washing. Fatty fish such as tuna and salmon store lipid in the flesh while lean fish such as cod store the lipid in the liver (Calder, 2013). The lipids on fish flesh are usually composed of triacylglycerol (TAG), sterols and phospholipids (Moradi *et al.*, 2011). The triacylglycerol is responsible for the storage of lipid and increasing lipid content in the fish muscles are also affected the percentage of triacylglycerol content (Moradi *et al.*, 2011; Kaçar *et al.*, 2016). Fatty fish usually has higher PUFA compared to lean fish. Lean fish contain a higher percentage of phospholipids than triacylglycerol compared to fatty fish (Moradi *et al.*, 2011). Saturated, monounsaturated and polyunsaturated are the main groups of fatty acid composition in the fish lipids (Zhang, Ning, He *et al.*, 2020). These three types of fatty acid groups are classified based on their position and number of double bonds as each parameter determines the physical and functional properties of fatty acid (Taşbozan and Gökçe, 2017). The proportion of each fatty acid group is commonly depending on the total lipid content of the fish (Moradi *et al.*, 2011). An omega-3 polyunsaturated fatty acid consists of EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid) are highly found in marine fatty fish compared to the fatty acid composition of fish caught in fresh waters (Huynh and Kitts, 2009; Muhamad and Mohamad, 2012; Gladyshev *et al.*, 2018).

Meanwhile, for the protein content, fish have a high nutritive value, similar to meat proteins and slightly lower than egg protein (Ariño *et al.,* 2013). The fish muscle proteins contain a great amount of essential amino acids, such as 9.3% lysine, 1.0% tryptophan, 2.1% histidine, 4.2% phenylalanine, 8.9% leucine, 6.4% isoleucine, 4.9% threonine, and 4.2% methionine–cystine (Sikorski *et al*., 2020). Fish protein has a stable composition of essential amino acids with higher content of lysine and lower content of methionine and threonine (Lozano and Hardisson, 2003). The protein content of fish is also depending on different factors such as biological and environmental factors. For example, Ariño *et al.* (2013) reported that fatty fish are slightly higher between 18% to 21% in terms of protein concentration than lean fish. Fish protein also contains non-protein nitrogen compounds besides the essential amino acid (Lozano and Hardisson, 2003; Limsuwanmanee *et al*., 2014). The non-protein nitrogen substance is located in the sarcoplasm fibre of the fish muscles and consists of free amino acids, peptides, amines, amine oxides, guanidine compounds, quaternary ammonium molecules, nucleotides, and urea (Ariño *et al.,* 2013). Lozano and Hardisson (2003) claimed that the non-protein nitrogenous compound is also responsible for the fish's taste and odour. Fish also contains water-soluble proteins such as sarcoplasmic protein which could leach out during washing or frying.

2.2 Frying mechanism

Frying is classified as a dry heat cooking method that is widely used at both domestic or industrial levels. The mechanism of frying can be described in four-stage which are the heat up stage, surface boiling stage, falling rate stage and bubble end point stage (Pankaj and Keener, 2017). The heat-up stage occurs when the food is immersed in the oil until the temperature of the surfaces reaches the boiling point of water. When the food containing water and air is immersed in the oil, the free water at the surface of the food will evaporate rapidly causing an explosion of bubble, drying the surface of the food and forming the crust (Gertz, 2014). At this stage, water present at the surface of the fish and products are exuded and heat is transferred only at the surface. The bubbling detected during initial frying is caused by the enlargement of surface contact between air and oil. This condition is categorized as the surface boiling stage where the heat transfer coefficient increases by conductive (heat transfer within food) heating and free convective (heat transfer from the oil to the food surface) (Pankaj and Keener, 2017). The increasing heat transfer rate between oil and air leads to an increase in the oxidative degradation of oil (Gertz, 2014). At this point, the outer layer of the fish will experience oxidation such as protein and fat at the subcutaneous layer.

Next, the falling rate stage is the longest frying stage that involved the transfer of heat to the core. At this stage, several processes occur such as thickening of crust at the outer layer of food, rapid loss of moisture in food, protein denaturation and starch gelatinization (Oke *et al.,* 2018). Protein denaturation is caused by the shrinkage of both collagen and filament lattice of proteins during frying leads to a loss in water holding capacity and changes the texture of the food (Abraha *et al.,* 2018). Besides that, the protein denaturation during frying is also caused by the accumulation of sarcoplasmic protein and the destruction of the cell membrane of the food protein (Alipour *et al.,* 2010). The food enters the bubble end point stage, where the water vaporization is closed to the end. The condition during the last stage of the frying mechanism is caused by several factors such as the reduction in heat transfer to the crust or core interface or the complete removal of water inside the food (Pankaj and Keener, 2017).

The frying mechanism combines several processes that occur simultaneously. Sequences of heat-induced chemical reactions such as protein denaturation, Maillard reaction and starch gelatinization are processes that were involved during frying (Zhang, Zhang and Adhikari, 2020). The breakdown of molecules in the starch granule causes the particle to expand and reduce its solubility during the starch gelatinization process (Yusop *et al.*, 2011). Hence, the crust layer will be formed on the surface of fried foods, and this promotes a lower oil absorption rate. Maillard reaction takes place when foods containing reducing sugar and proteins such as fish products were subjected to frying at a higher temperature, the heat and mass transfer by both convection and conduction during this process causes the browning effect (Zhang, Zhang and Adhikari, 2020). Therefore, the chances of acrylamide formation may increase due to the Maillard reaction. Thus, the possibility of potential hazards in fried food may increase as acrylamide is considered a carcinogen (Aiswarya and Baskar, 2018). Next, the dehydration process causes removals of water and changes the phase of water from liquid to vapour and evaporates out from the pores of frying foods (Dueik and Bouchon, 2011; Zhang, Zhang and Adhikari, 2020). Small amounts of oil will permeate into the pores of the fried food as the oil uptakes were heavily dependent on the water content of fried food (Marquez *et al.,* 2014).

Frying causes degradation and some undesirable changes especially on frying medium or frying oil. Hydrolysis, oxidation and polymerization is the type of chemical reaction that occurs in oils during frying. Oke *et al.* (2018) reported that the hydrolysis reaction occurs when the water inside the food reacts with the ester linkage of triacylglycerols of frying oils producing di- and monoacylglycerols, glycerol, and free fatty acids. Oxidation of oil occurs when the oxygen interacts with oil specifically fatty acid or acylglycerol molecules with the presence of heat causing the oil to oxidize (Choe and Min, 2006). The oxidation reaction also can occur based on several factors such as the stability of oil quality, the fatty acid composition of oil and the temperature during frying besides the oxygen factor (Choe and Min, 2006). The increasing of time and temperature of frying can lead to an increase in the oxidation process leading to the presence of hydroperoxides. At the highest temperatures, when the oxygen supply is limited, the main reactions can lead to polymerization rather than oxidation (Gertz *et al.,* 2000). The major decomposition products of frying oil during polymerization are non-volatile polar compounds, triacylglycerol dimers and polymers. A higher amount of polymer compounds and hydroperoxides in food can lead to potential health hazards to consumers (Jurid *et al.,* 2020). Therefore, the parameter of frying such as frying cycle, frying time, frying temperature, frying oil and frying technique must be controlled as those parameters can affect the fish and oil quality.

2.3 Effect of frying cycle

Generally, the frying cycle is commonly used in two ways either the fish and the fish product were repeatedly fried using the same oil or the fish and fish product was reheated again after frying with a different oil. The first method is adopted by food industries to fry large amounts of products whereas the latter is commonly adopted by the consumer when foods are reheated at home using oil. For the first method, many researchers have reported the effects of increased frying cycle using the same oil and its effect. Most products undergo repetitive frying to a maximum of six cycles using the same oil before it is discarded (Ngozi *et al.,* 2019). The changes of fatty acid in fish and frying are the major concern in the increased frying cycle as oxidation will produce hydroperoxides and other compounds which is hazardous to health. It was reported that repetitive frying using the same oil will also produce certain toxic compounds such as peroxide and trans-fatty acids compound that is carcinogenic and hazardous if consumed excessively (Bansal *et al.,* 2010; Ganbi, 2011). Fat in fish and fish products was reported to increase with an increasing number of frying cycles. Jane and Grace (2020) report that an increased amount of frying cycle will increase the amount of fatty acid due to the breakdown of the primary oxidation product such as hydroperoxides. The increased amount of fat is also related to the duration of immersion which allows the fatty acid in the oil to seep into the fish to replace the loss of moisture during frying (Ghidurus *et al.,* 2010; Tadesse *et al.*, 2020). Frying cycles up to 50 times were found to significantly increase the amount of trans fatty acid in fish and fish products by up to 60% and decrease the amount of polyunsaturated (Wang *et al.,* 2015; Tadesse *et al.,* 2021). This is not a good indicator as fatty fish is consumed due to its high PUFA and after frying, the amount of PUFA could not be maintained due to oxidation. Other than that, this will cause the product to be less healthy as the development of trans fatty acid could contribute to health risks. The migration of fish lipids to oil repeatedly with each frying cycle will also reduce the amount of fatty acids present in fish and accelerate lipid oxidation due to thermal degradation to produce acyl groups. This has been reported by Nieva-Echevarría *et al.* (2016) when the amount of acyl group was found to increase in the frying oil. Besides that, repetitive frying affects the odour and flavour of the fish and fish products. The formation of free fatty acids and polycyclic aromatic hydrocarbons which are considered carcinogenic compounds contributes to the off flavour and rancidity of the fried products (Maduelosi and Worlu, 2015; Iwegbue *et al.,* 2020).

Repetitive frying also affects the physicochemical composition, sensory attributes and textural properties of fried fish and fish products especially moisture content, protein content, colour and fat content (Manral *et al.,* 2008; Tadesse *et al.,* 2020). As the frying cycle increases, a decrease in interfacial tension and increase in oil polarity could be observed that causes the fried products to absorb more oil (Ghidurus *et al.,* 2010). As oil is absorbed, the water will exude out causing a decrease in moisture content due to moisture evaporation and dispersion of water from the core of the fish to the crust (Gertz, 2014; Tadesse *et al.*, 2020). Moisture is important and it is associated with the gelation of fish protein to provide a good quality texture. Coating batter and functional ingredients play an important role in repeated frying of fish products as some coating tends to reduce oil absorption, thus, reducing moisture loss (Kilincceker, 2011; Zarulakmam *et al.,* 2021). Protein changes during repetitive frying are also considered as the main concern as fish and fish products are composed of proteins. The amount of protein present in fish and fish products was reported to decrease with an increasing amount of the frying cycle. The protein decrease could be explained by the deamination process, pyrolysis, and formation of aldehydes and other polar compounds due to heat which produces pyrazines and amine derivatives (Ghidurus *et al.,* 2010). Protein is susceptible to heat that will denature, aggregate and form gelation. However, usually, gelation is already formed in the first cycle of frying due to high heat. Repeated frying will only further break down the gelation network, releasing more water and producing various proteins by-products.

The sensory acceptability of fried fish was also affected by the number of frying cycles. Colour, flavour, odour, juiciness, appearance and overall acceptability decrease as the frying cycle increases (Tadesse *et al.,* 2020; Pawar *et al.,* 2013). The decrease in flavour acceptability was caused by the formation of a free fatty acid compound from the lipid and protein oxidation process whereas the decline in odour acceptability was caused by the formation of peroxides and free radical compounds (Ketaona *et al.,* 2013). The decreasing appearance acceptability is contributed by the degradation of the frying oil colour as the oil experience continuous thermal degradation with an increased frying cycle (Tadesse *et al.,* 2020). Other than that, the Maillard reaction also contributes to the lower appearance acceptability. The texture is an important characteristic sought by the consumer as it is related to the mastication process and satiety. Repetitive frying causes changes in protein gelation and also the crust formation for fried products. As the frying cycle increases, the texture of the inner part of the fish nuggets becomes rougher, however, the crust part of fish nuggets becomes smoother (Del Carmen Flores-Álvarez *et al.,* 2012). This is also related to the amount of protein, protein gelation and moisture content of the fried products which experience decrease and changes during repetitive frying.

The frequency of frying using the same oil also influences the physicochemical properties of the frying oils. The colour of the frying oils was found to degrade and turn darker with each frying cycle (Del Carmen Flores-Álvarez *et al.,* 2012). The degradation of the colour may be caused by polymerization reactions at high temperatures (Manral *et al.,* 2008; Idun-Acquah *et al.*, 2016). Repeated frying makes this process more imminent. Moreover, the free fatty acids values that act as a rancidity parameter for the quality of frying oil were also reported to increase due to the thermal degradation of unsaturated fatty acids present in the frying oils (Manral *et al.,* 2008; Del Carmen Flores-Álvarez *et al.,* 2012; Ngozi *et al.,* 2019). At the end of the frying cycle, most oils will be composed of unsaturated fatty acids, trans fatty acids and experience oxidation. Most finding recommends frying up to 2 or 3 cycles depending on factors such as the type of fish and fish products, frying oils, frying time and frying temperature. A higher amount of frying cycle will have a hazardous effect on the product and oil such as the presence of trans fatty acids, acrylamide, ketones, aldehydes and acyl group (Ghidurus *et al.,* 2010; Nieva-Echevarría *et al.,* 2016; Ngozi *et al.,* 2019; Iwegbue *et al.,* 2020). The findings of all previous studies were shown in Table 1.

2.4 Effect of frying time and temperature

Frying time and temperature are considered important factors during frying. Different times and temperatures affect the fish and fish product physically, chemically and also its sensory quality aspects (Fofandi, Bhola, Chudasama *et al.,* 2020). As for the increase in frying temperature, the rate of heat transfer to the core increases and this causes many effects such as thermal degradation and changes in the properties of the fried products. Longer immersion time in frying oil also contributes to the oil uptake and changes in the fatty acid composition. A prominent effect that could be observed with different times and temperature is the loss of moisture content in fish and fish products. Moisture content decreases with the increase in time and temperature of frying (Tavares *et al.,* 2018; Fofandi, Bhola, Chudasama *et al.,* 2020). The loss of moisture content is due to the oil and water exchange during frying and evaporation at high temperatures. Oil absorption and oil uptake become greater as temperature and time increase up to 180°C and 15 mins (Delgado-Andrade *et al.,* 2010; Fofandi, Bhola, Chudasama *et al.,* 2020). This is because, as temperature increases, the rate of moisture evaporation increases causing multiple voids in the fried product that will be filled by oil through absorption (Gertz, 2014). Protein gelation networks were also compromised by this effect as water is usually trapped within the network to provide texture and juiciness. As the water evaporates, the gelation network becomes weaker, and the water inside the network might be substituted with the oil that seeps into the product. This also contributes to the increase of fat content in fried foods. Other than that, a change in the protein and lipid composition was also observed with increased time and temperature. The increasing amount of protein and lipid content were caused by the nutrient absorbed from the frying oil such as phospholipids, tocopherol and other compounds (Delgado-Andrade *et al.,* 2010; Tavares *et al.,* 2018; Fofandi, Bhola, Chudasama *et al.,* 2020). However, the composition of ash and fat reported no significant results. The crust and core of breaded and battered fish nuggets initially recorded a decrease in moisture content and an increase in fat content with an increase in frying temperature. However, the fat content gradually decreases, and the crust pore size increases as frying continues up to 180 s (Zhang, Chen, Yue *et al.* 2020). The study from Fofandi, Tanna, Ghandiya *et al.* (2020) reported that there were discrepancies in the percentage of oil absorption for fried fish cutlets. As the frying time increases, the percentage of oil absorption also increases until it achieves a specific value before it starts to decline. This could be due to the rate of heat transfer gradually increasing and the decline of absorption caused by saturation of oil absorbed into the fish and fish products.

The composition of fish also plays an important role in the presence of polyunsaturated and monounsaturated fatty acids. Stephen *et al.* (2010) reported about a 70% loss of saturated fatty acid and a 45% loss of monounsaturated fatty acid as tuna skipjack was fried at 180°C using sunflower oil for 10 mins. However, polyunsaturated fatty acid was found to increase 1.5 times higher due to the migration of the fatty acid from sunflower oil to the fried tuna (Stephen *et al.,* 2010). Fatty fish such as tuna, salmon and mackerel which initially are high in polyunsaturated fatty acid will experience a loss with higher temperature and longer frying time. These PUFA will be converted to unsaturated fatty acid and some trans-fatty acid with prolonged immersion and a higher temperature of frying.

The most acceptable and preferable heat treatment for fish products was frying at 170 - 180°C for 3 mins as it resulted in a good value of physical and sensory properties. The final product also appears to be more outstanding in whiteness, good in organoleptic aspect and low oil absorption rather than other treatments (Ojagh *et al*., 2018; Fofandi, Tanna, Ghandiya *et al.* 2020). At this temperature and time range, the product will experience sufficient heat treatment to induce gelation for texture whilst reducing the colour changes and oil absorption to an acceptable level. Thus, the composition of the products such as moisture, protein and fats should be considered before selecting the best frying temperature and time. Fatty fish and lean fish has different composition of fatty acids. Double bond fatty acids are more susceptible to oxidation with higher temperatures and prolonged frying time. The findings of all previous studies were compiled in Table 1.

2.5 Effect of different frying oil

Frying oil is a medium used in heat processing, especially in frying. Vegetable oils are commonly used for frying due to their nutritional benefit and stability (Bansal *et al.,* 2010). Palm oil or its fraction is commonly used as a frying medium, followed by soybean oil and canola oil due to its heat stability (Park and Kim, 2016). Different type of frying oils has different effect on the final composition and quality of fried products (Peng *et al.,* 2017). The properties of oils themselves such as the fatty acid composition, oxidative stability and cloud point will affect the properties of the

Table 1. Effect of frying parameters on fish, fish products and frying oils.

Reference	Frying parameter	Fried product	Condition	Results
Tadesse *et al.* (2021)	Frying cycle	Fried Nile tilapia Fish	Deep frying in palm oil at 170°C for 10 mins for each frying cycle (6 frying cycles).	• Polyunsaturated fatty acids decrease in fried fish with the increase in the frying cycle. • Saturated and trans fatty acids increase in fried fish with the increase in the frying cycle.
Tadesse *et al.* (2020)	Frying cycle	Fried Nile tilapia fish	Deep frying in palm oil at 170°C for 10 mins for each frying cycle (6 frying cycles).	• Decrease in moisture and protein content of fried fish as the frying cycle increase. • Increase in ash and fat content of fried fish with increasing of the frying cycle. • Decrease in colour, flavour, odour, appearance and overall acceptability value of fried fish with increasing of the frying cycle.
Iwegbue *et al.* (2020)	Frying cycle	Atlantic horse mackerel (*Trachurus trachurus*)	3 cycles of frying in sunflower, mustard seed, olive seed, soybean and almond seed, palm oil for 3-7 mins at 150-180°C	• Composition and concentration of polycyclic aromatic hydrocarbon in frying oil increase with the increase of the frying cycle.
Fofandi, Bhola, Chudasama *et al.* (2020)	Frying time and temperature	Fried batter and breaded Unicorn file (*Aluterus monoceros*) fish fillet	Frying at 150°C, 160°C and 170°C for 8 mins, 10 mins and 12 mins.	• Decrease in moisture content in fried fish with increasing time and temperature. • Increase in protein content in fried fish with increasing in time and temperature. • No significant difference in ash and fat content in fried fish with increasing time and temperature. • The oil absorption of fried fish decreases with the increase of temperature (almost 0.082%) during frying at 8 mins while the increase of frying time shows a non-significant value as not many differences in the value of oil absorption at each frying time.
Fofandi, Tanna, Ghandiya *et al.* (2020)	Frying time and temperature	Fried mackerel cutlet	Frying for 2 mins, 3 mins and 4 mins at 180°C.	• Increase in percentage of oil absorption in fried fish until achieves specific value with increasing of time and temperature. • The preferable fried fish cutlet was fried at 180°C for 3 mins (good physical, sensory and organoleptic properties) • The oil absorption of fried fish decreases with the increase of temperature (almost 0.04%) during frying at 2 mins while the increase of frying time shows non-significant value as not much difference of the value of oil absorption at each frying time.
Zhang, Chen, Yue *et al.* (2020)	Frying time and temperature	Battered and breaded fish nuggets	Frying at 160°C, 170°C and 180°C for 0, 30, 60, 90, 120, 150, and 180 s.	• Moisture content of crust and core decreases in fried fish products with increasing of time and temperature • Fat content of crust in fried fish products increases up to 120s and the decrease of fat content after frying time is increased. • Pore size of crust in fried fish product increase with increasing frying time.

Table 1 (Cont.). Effect of frying parameters on fish, fish products and frying oils.

Reference	Frying parameter	Fried product	Condition	Results
Tavares *et al.* (2018)	Frying time and temperature	Fried hairtail fish fillet	Frying at 160°C for 5 mins, 10 mins and 15 mins.	• Decrease in moisture content on fried fish with increasing frying time. • Increase in protein and lipid content on fried fish as the frying time is increased. • The cooking yield of fried fish show decreasing with increasing of time up to 0.18% after 15 mins of frying.
Ojagh *et al.* (2018)	Frying time and temperature	Nugget of silver carp (*Hypophthalmichthys molitrix*)	Frying at 150°C, 170°C and 190°C for 30 seconds.	• Frying the fried fish product at 150°C showed lower absorption rate than frying at 170°C and 190°C. • Frying the fried fish product at 170°C and 190°C showed better sensory attributes and no significant difference. • Frying the fried fish product at 170°C showed the best overall attributes including sensory, yield, colour, oil absorption and moisture.
Ojagh *et al.* (2018)	Frying oils	Nugget of silver carp (*Hypophthalmichthys molitrix*)	Frying using sunflower oil, olive oil, canola oil, and sesame oil.	• The yellowness index in fried fish nuggets was higher in olive and canola oil. • Lower oil absorption rate, moisture content, yield and high red colour index when frying the fish nugget with sunflower and sesame oil.
Jayasena *et al.* (2018)	Frying oils	Fried Nile tilapia fillets	Deep frying at 160°C for 4 mins using soybean oil, sunflower oil and coconut oils separately.	• Increase fat content in fried fish when using these three types of oil. • Higher amount of fat content in fried fish when using soybean oil. • Higher saturated fatty acid and lower polyunsaturated fatty acid in fried fish when using coconut oil.
Idun-Acquah *et al.* (2016)	Frying cycle	Fried redfish	30 batches of frying in palm oil for 5 mins each batch at 180 °C.	• Increase in peroxide value in frying oils as the frying cycle is increased.
Wang *et al.* (2015)	Frying cycle	Fried grass carp fish patties	50 cycles of frying in refined soybean oil at 170 °C for 10 mins in each frying cycle.	• The total of trans-fatty acid in fried fish increase with the increasing of frying cycles.
Del Carmen Flores-Álvarez *et al.* (2012)	Frying cycle	Fried fish nuggets	30 batches of frying for 12 days in blended oil at 180 °C for 2.5 mins for each batch.	• The texture of the inner part becomes rougher but smoother at the crust part of fried fish as the frying cycle is increased. • Increasing of free fatty acid content in frying oils with the increasing of the frying cycle. • Colour of the oil becomes dark from light yellow to brown as the frying cycle is increased
Oluwaniyi *et al.* (2010)	Frying oils	Fried Herring fish fillet, fried Atlantic mackerel fillet, fried horse mackerel fillet and fired white hake fish fillet	Frying using palm oil, soybean oil, vegetables oil and groundnut oil between 170 to 200 °C.	• Decrease amount of total amino acids in fried fish • Higher loss of total amino acid in palm oil.

Table 1 (Cont.). Effect of frying parameters on fish, fish products and frying oils.

Reference	Frying parameter	Fried product	Condition	Results
Stephen *et al.* (2010)	Frying time and temperature	Skipjack tuna (*Katsuwonus pelamis*)	Frying at 180°C for 5, 7.5 and 10 mins in sunflower oil.	• 70% saturated fatty acid loss in fried fish as frying time is increased. • 45% monounsaturated fatty acid loss in fried fish as frying time is increased. • Polyunsaturated fatty acid in fried fish is increased 1.5 times due to absorption of sunflower oil with the increase of frying time.
Ansorena *et al.* (2010)	Frying oils	Fried salmon and fried cod	Frying using sunflower oil and extra virgin olive oil at 180°C.	• High moisture, ash and protein content in fried salmon using sunflower oil • Lower moisture, ash and protein content in fried salmon using extra virgin olive oil • The lower moisture content of fried cod in sunflower oil, higher moisture content of fried cod in extra virgin olive oil • Higher protein and ash content of fried cod in sunflower oil, both content of fried cod lower using extra virgin olive oil. • The higher fat content of fried cod and salmon using extra virgin olive oil • High cholesterol content of fried salmon and fried cod using extra virgin olive oil, lower cholesterol content when frying the fish nugget using sunflower oil.
Manral *et al.* (2008)	Frying cycle	Fried fish (*Catla catla*)	14 hrs of frying in sunflower oil at 180 °C.	• Colour of oil becomes dark as the frying cycle is increased. • Increase value of free fatty acid of frying oil with the increasing of the frying cycle.
Weber *et al.* (2008)	Frying oils	Fried silver catfish fillet	Frying using soybean oil, canola oil and partially hydrogenated vegetable oil for 3.5 mins at 215-220 °C.	• Lower total polyunsaturated fatty acids (PUFA) content for fried fish in canola oil. • Lower omega-3 fatty acid content for fried fish fillet in hydrogenated vegetable oil. • Higher in omega-6 fatty acid content for fried fish fillet in soybean oil.

fried products. Some fatty acids in fried food may decrease or increase depending on the changes in fatty acid profiles as they are dependent on the composition of frying oils (Ekiz and Oz, 2019). Furthermore, during frying, oil seeps into the product to replace the loss of moisture, thus, carrying its nutrition with them. These changes the final composition of the fried fish and fish products.

Frying fatty fish such as tuna and salmon will cause an increase in the fat content and the composition of the fish. Frying these fishes with a high polyunsaturated fatty acid such as sunflower oil and olive oil was found to have an adverse effect on the fish composition. Moisture content was affected greatly by the use of different oil for fatty fish. Extra virgin olive oil was found to increase the fat content and moisture content of fish when compared to the usage of sunflower oil (Ansorena *et al.,* 2010). Olive oil has higher fatty acid content than sunflower oil, this could explain the higher fat content in fish when olive oil is used for frying due to oil absorption (O'Brien, 2008; Aşkın and Kaya, 2020). The difference between sunflower oil and olive oil is notable, especially in the fatty acid composition and oxidative stability. Oxidative stability and cloud point for sunflower are 1.5 to 2.2 and 9.5°C whereas for olive oil is 5.2 and 5.6°C (O'Brien, 2008). Higher stability could contribute to a better heat transfer rate as the oil would not be easily oxidized and evaporated. These could affect the moisture content and thermal degradation of other components in fish and fish products. However, when palm oil is used to fry mackerel, the fried fish recorded a great reduction in the amino acid content compared to the usage of soybean oil and groundnut oil (Oluwaniyi *et al.,* 2010). The possible explanation is due to the stability of the oil and the ability of the oil to conduct heat. As palm oil is highly stable at higher temperatures, heat is transferred more efficiently and the rate of heat transfer is higher (O'Brien, 2008). This causes a significant change in protein as protein is susceptible to heat. However, the protein and ash content were higher when sunflower oil is used compared to extra virgin olive oil (Ansorena *et al.,* 2010).

Frying of lean fish such as tilapia also displays a similar trend in fat content. Different types of oil may influence the nutritional quality of lean fish more compared to fatty fish (Ansorena *et al.,* 2010). A study done by Jayasena *et al.* (2018) using soybean oils, sunflower oil and coconut oils on fried Nile tilapia fillets show an increase in the fat content of raw tilapia fillets and a decrease in the amino acid content. The finding shows that frying in coconut oil will cause the product to contain higher saturated fatty acid and lower polyunsaturated fatty acid due to the higher saturated fatty acid content present in coconut oil (Orsavova *et al.,* 2015; Jayasena *et al.,* 2018). The decrease in an amino acid is due to the occurrence of the Maillard reaction during frying, amino groups such as lysine react with the aldehyde groups of reducing sugars or carbonyls from the oxidised fat, thus, making those amino acids metabolically unavailable, especially in cross-linkage reactions (Oluwaniyi *et al.,* 2010). Weber *et al.* (2008) reported that the fried fish fillet in hydrogenated vegetable oil has lower omega-3 fatty acid content (2.48%) but is high in omega-6 fatty acid content (18.9%) compared to canola oil (1.08%) due to the composition of the oil itself. Therefore, frying in enriched-polyunsaturated fatty acid frying oils can increase the polyunsaturated fatty acid proportion in fish and fish products (Jayasena *et al.* 2018).

Different types of oils were also found to produce different concentrations of aldehydes which contribute to flavour and aroma depending on the fatty acids profile and oxidation rate (Peng *et al.,* 2017). Peng *et al.* (2017) state that soybean oil and sunflower oil that is high in linoleic acid are more susceptible to oxidation because of their double bond. Aldehydes, furans, ketones, alcohols and acid formation during frying contributes to the aroma of oil and products (Zarulakmam *et al.,* 2021). Colours are also affected by the type of oil used for frying. The presence of pigment such as tocopherol in oil could also contribute to the colour of the product other than the Maillard reaction. The yellowness index in fried nugget's sliver carp was higher in olive oil and canola while sunflower oil and sesame oil shows a high red colour index (Ojagh *et al.*, 2018). The presence of tocopherol in sunflower oil is higher than in olive oil and in canola oil, thus, contributing to a higher red colour index (O'Brien, 2008). Therefore, to produce healthier and better-quality fried fish and fish products, the composition of the fish and the composition of the frying medium need to be studied before frying. These findings are reported in Table 1.

2.6 Effect of the different frying methods

Various frying techniques are currently being applied in the food industry. New frying techniques nowadays are more focused on producing fried products with low oil or fat quantities whilst maintaining the sensory profile and texture similar to traditional deep-fat frying (Fang *et al.,* 2021). Furthermore, there are some emerging technologies that are more focused on sustaining the nutrient and palatability of products after frying rather than the amount of fat present.

Vacuum drying is currently slowly gaining popularity due to its efficiency in maintaining the nutritional quality of foods, lowering oil absorption and also lowering the rate of oxidation (Zhang, Zhang and Adhikari, 2020). This method utilizes low pressure below 6.65kPa and low temperature for frying. Vacuum frying has been found to decrease the amount of moisture loss during the frying of fish and fish products (Albertos *et al.,* 2016). The higher moisture content in fish and fish products using this method may be related to the microstructural changes during the depressurization process and the changes in porosity of the fried product (Moreira, 2014). Higher moisture content contributes to the juiciness, texture and availability of water-soluble compounds in the product. Vacuum frying was reported to reduce the oil uptake, and oxidation rate and provide better colour for fried products (Albertos *et al.,* 2016; Fang *et al.,* 2021). The lower value in oil uptake was due to the pressurization process as the process plays an important role in the reduction of oil absorption that is affected by the amount of free water rate of pressurization process and surface oil present in the fried product (Pandey and Moreira, 2012; Moreira, 2014). Vacuum frying could also retain the original colour as the method reduced colour degradation by preventing oxidation and Maillard reaction (Andrés-Bello *et al.,* 2010). When comparing vacuum frying with atmospheric frying, vacuum frying was found to reduce moisture loss, shrinkage, oil uptake and colour changes in fish and fish products (Andrés-Bello *et al.,* 2010; Ophithakorn and Yaeed, 2016). This indicates that vacuum frying could produce a better-fried product with low-fat content and high moisture.

Deep frying is the most common method adopted by the food industries and consumers. Deep frying is preferable due to its contribution to the sensory properties of fried products. However, deep-frying causes lipid oxidation and severe changes to the colour of fried fish (Viera *et al.*, 2018). The colour change is mainly caused by the Maillard reaction. This reaction causes the food to become darker, thus decreasing the reflection of light (Vieira *et al.,* 2018). Deep frying was also reported to have an effect on the fats, minerals and vitamins composition of the fish product. A study conducted by Larsen *et al.* (2010) reported that king salmon fried using the deep frying method causes a significant increase in total PUFA due to the uptake of linoleic acid content from the oil compared to pan-frying. Thus, it increases the omega–6 fatty acids content in the fried king salmon. Comparing deep frying with pan-frying, the surface area that interacts with the frying oil is much larger in deep frying, thus, allowing maximum absorption and interaction between oil and the fried products compared to pan-frying. This allows the fatty acid from the frying oil to seep better in deep frying compared to pan-frying. Zarulakmam *et al.* (2021) also reported a significant increase in the fat content of fish sausage after being deep-fried at 165°C for 4 mins. The study by Marimuthu *et al.* (2012) reported that pan-frying can cause loss of mineral content such as Ca, Fe, Zn, Mn and P content but can gain mineral content such as Na, K, Mg and Cu content. The statement of increasing K and Cu content and decreasing Zn and Fe content was also supported by Hosseini *et al.* (2014). Moreover, Hosseini *et al.* (2014) also reported that the loss of vitamin content in fried fish fillets such as vitamin B1 (13%), vitamin B3 (10.6%), and vitamin A (49.6%) and vitamin D (32%).

The opposite of deep fat frying is air frying. Air frying has become a common way of frying, especially in the household due to its low usage of frying oil to fry foods and its convenience. Heat is transferred using fine oil droplet mist directly to the food under hot air conditions during frying and this reduces the amount of oil uptake in the fried foods (Dehghannya and Ngadi, 2021). This is because, during air frying, the fried product experiences slower temperature increases and a lower moisture loss rate (Dehghannya and Ngadi, 2021). Comparing air frying and deep frying, air frying is much more superior in reducing lipid oxidation for fried fish compared to deep frying (Viera *et al.*, 2018). This resulted in healthier fried food compared to deep frying. However, parameters such as temperature and time will affect the properties of the fried products. Hydrolysis, polymerization and oxidation in surimi increase with the increase of time and temperature of air frying (Yu *et al.*, 2020). The texture of surimi also experienced changes with different times and temperatures of air frying (Yu *et al*., 2020). The change in texture is closely related to the loss of moisture, protein gelation and heat transfer. Air frying produces a more compact and honeycomb-like microstructure which contributes to the texture of the product due to slower temperature penetration and loss of moisture (Dehghannya and Ngadi, 2021; Tian *et al.*, 2017). When hot air is applied, the outer layer of the food will experience immediate change due to protein denaturation, starch gelatinization and moisture evaporation (Abd Rahman *et al.*, 2017). The hot air causes the outer layer of the food to become dry and form a crust that will help reduce moisture loss in the inner layer initially (Isik *et al.*, 2016). The formation of crust on the outer layer also is much more homogenous due to the slow evaporation rate (Dehghannya and Ngadi, 2021). However, as temperature and time increase, the rate of heat transfer also increases and eventually the moisture in the inner layer of the fried product will also evaporate and experience loss. Other than that, air frying also reduces the yellowness of the fried product compared to deep frying. The high yellowness in deep-frying is contributed by the absorbance of oil during prolonged immersion, however, in air frying, the such process does not occur. Despite that, with higher temperature and prolonged time of air frying, the colour will also change and become darker due to Maillard reaction rather than contributed by the colour of oil (Yu *et al.*, 2020). Air frying also has been reported to preserve soluble vitamins (Dehghannya and Ngadi, 2021).

Therefore, the effect of different frying methods on fish and fish products varies depending on several factors such as the mechanism of the frying method used, the composition of fish and the frying parameter. Moreover, vacuum frying and air frying methods are recommended for consumers who preferred healthier choices of fried food. The findings cited are compiled in Table 2.

3. Conclusion and recommendation

Frying is a common method utilized by the food industry and households to increase the palatability and shelf life of the fish. It gives a unique sensory property and improves the quality of the food product. For a product with a high amount of protein and fat such as fish and fish products, the composition of the product and the frying medium should be studied to produce decreased health risks upon consumption such as the formation of trans fatty acids, free fatty acids and polycyclic aromatic hydrocarbons. Parameter identification such as frying cycle, frying time, frying temperature, frying oil and frying techniques are important in ensuring the production of low-health risk fried foods. Furthermore, the moisture content is one of the major compositions in fish that is affected by frying other than a fatty acid. Changes in moisture will affect the physicochemical properties and sensory properties of the fried products. Air frying and vacuum frying were

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Table 2. Effect of different frying methods on fish and fish products

Reference	Frying method	Fried product	Condition	Results
Zarulakmam *et al.* (2021)	Deep Frying	Fish sausage	• Deep frying using sunflower oil at 165°C for 5 mins	• Increase protein content, fat, water holding capacity, hardness, gumminess and chewiness of fried fish sausage when deep frying. • Reduce moisture content of fried fish sausage when deep frying.
Fang *et al.* (2021)	Deep frying, electrostatic frying, air frying and vacuum frying	Fried tilapia fish skin	• Deep frying using refined palm oil at 180°C for 2, 4, 6 and 8 mins. • Electrostatic frying using refined palm oil at 180°C for 2, 4, 6 and 8 mins with discharge plate in the bottom of fryer. • Air frying at 180 °C for 6, 8, 10, 12 or 14 mins. • Vacuum frying using refined palm oil at 120°C for 4, 8, 12, 16, 20 or 24 min and under 0.058 Mpa in vacuum.	• Decrease rapidly moisture content on fried fish skin in both deep frying and electrostatic frying than air and vacuum frying method. • Decrease faster water activity on fried fish skin in an early stage when using deep frying, electrostatic frying and vacuum frying. • Lower oil content on fried fish skin using the air frying method. • Best appearance of fried fish skin when using vacuum frying followed by air frying method. • Best puff texture of fried fish skin when using air frying followed by vacuum frying method.
Yu *et al.* (2020)	Air frying	Surimi	• Air frying at 120 °C, 160 °C and 200 °C for 10 and 15 mins.	• Increase in colour value with the increase temperature and time in air frying. • Increase in TBARS value with the increase temperature and time in air frying. • Increase hardness, springiness, chewiness and gumminess with the increase in
Vieira *et al.* (2018)	Deep frying and air frying	Fried arapaima fish fillets	• Deep frying using soybean refined virgin oil. • Both air frying and deep-frying fry at temperatures (150°C, 170°C and 190°C) until the center of fish reached 70°C.	• Less lipid oxidation in fried fish using the air frying method. • Lower yellowness value of fried fish using air frying. • Reduces in lightness value of fried fish for both methods, deep frying and air frying. •
Albertos *et al.* (2016)	Vacuum frying and conventional frying	Fried Atlantic mackerel patties	• Vacuum frying at 107°C with 80 mmHg pressure and 42°C boiling point while conventional frying at 165°C using high oleic sunflower oil. • Frying times of 2, 4, 6, 8 and 10 mins for both frying methods.	• Increase moisture content of fried fish patties using vacuum frying. • No differences in oil content on fried fish patties in both frying methods, vacuum frying and conventional frying. • Decrease protein and ash content of fried fish patties in both frying methods, vacuum frying and conventional frying. • Lower lipid oxidation of fried fish patties using vacuum frying. • Lower peroxides value of fried fish in
Ophithakorn and Yaeed (2016)	Vacuum frying and atmospheric frying	Fried fish tofu	• Atmospheric frying at 165°C and 150 s while vacuum frying at 120°C and 21 kPa using soybean oil.	• Lower oil uptake on fried fish using vacuum frying.

Table 2 (Cont.). Effect of different frying methods on fish and fish products

Reference	Frying method	Fried product	Condition	Results
Hosseini *et al.* (2014)	Pan-frying	Fried kutum roach fish fillets	• Pan frying at 150°C for 15 mins.	• Increasing of K and Cu content of fried fish fillets from raw fish fillets. • Decreasing of Zn and Fe content of fried fish fillets from raw fish fillets. • Loss content of vitamin A, D, B1 and B3
Marimuthu *et al.* (2012)	Pan-frying	Fried stripped snakehead fish fillets	• Pan frying at 180°C for 15 mins using sunflower oil.	• Loss of mineral content on fried fish fillets such as Ca, Fe, Zn, Mn and P content during frying. • Gain of mineral content on fried fish fillets such as Na, K, Mg and Cu content during frying. • Higher loss of mineral content on fried fish fillets especially Mn and P content during frying • Higher gain of mineral content on fried fish fillets especially K and Na content during frying.
Andrés-Bello *et al.* (2010)	Vacuum frying and atmospheric frying	Fried gilthead sea bream fillets	• Vacuum frying at 90, 100 and 110°C for 1, 2, 3, 4, 5, 6, 8 and 10 mins using sunflower oil. • Vacuum pressure used for vacuum frying for each temperature is 15 kPa for 90°C, 20 kPa for 100°C and 25 kPa for 110°C. • Atmospheric frying at 165°C using sunflower oil. The condition of atmospheric frying is the same as the condition of vacuum frying but the vacuum pump was switched off.	• Lower moisture loss on fried fish fillets when using vacuum frying. • Lower shrinkage value on fried fish fillets when using vacuum frying. • Higher oil uptake on fried fish fillets using atmospheric frying. • Better retained original colour of fried fillet when using vacuum frying.
Larsen *et al.* (2010)	Deep frying and pan frying	Fried king salmon	• Pan frying at 180°C for 8 min. • Deep frying using sunflower oil for 5 mins at 180°C.	• Increase total polyunsaturated fatty acid on fried fish in the deep frying method. • Increase omega-6 fatty acid on fried fish in deep frying. • Higher DHA and EPA content on fried fish using pan-frying. • Less value of the ratio of omega-3/omega-6 fatty acid on fried fish using deep frying.

found to possess great potential in producing healthier fried fish and fish products. However, research data on the effect of these methods on fish and fish products are still limited. Therefore, analyzing the effect of air frying and vacuum frying on fish and fish products should be explored as research providing scientific information on this area is still scarce.

Conflict of interest

The authors declare no conflict of interest.

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