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REVIEW

Factors influencing the nutritional composition, quality and safety of dried fishery products

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Abstract

Dried fishery products are popular processed food items throughout the world. Nowadays, the demand for nutritionally rich and safe dried fishery products is increasing. A substantial quality loss in dried fishery products occurs due to the chemical, microbiological and non-enzymatic browning reactions during handling, processing, drying, packaging, storage and distribution lead to influence the safety of the products. However, factors influencing the quality and safety of dried fishery products are poorly understood. Therefore, this review article discussed various quality and safety aspects of dried fishery products, such as raw material quality and pre-treatment, drying methods, additives use, extrinsic factors, irradiation, cold oxygen plasma treatment, corona discharge plasma, high hydrostatic pressure, packaging methods and materials used, storage condition and temperature, and so on, all of which have an impact on the final product. The ultimate aim of this study was to gain a better understanding of the current state of quality in dried fishery products and the techniques for improving it, which will aid processors in ensuring the quality and safety of dried fishery products for consumers in the long run. This review could also be used as a guide for future research and development of dried fishery products as well as ensuring consumer's safety for both domestic and foreign markets.

1. Introduction

Drying is one of the well-known oldest, effective and low-cost fish preservation techniques by lowering the moisture level to inhibit the growth of microorganisms and enzymatic chemical reactions. It also increases the shelf life of food, which facilitate storage, transportation, and consumption of the products (Mansur *et al.*, 2013; Rasul *et al.*, 2018; Qiu *et al.*, 2019). The utilization of global resources for the processing of dried fishery products is considerably high, estimated to be 8% of the total world catch (Paul *et al.*, 2018a; Patterson *et al.*, 2018). The production process of dried fishery products is represented in Figure 1. There are various dried products like the sun/salted dried fish, dried kale, dried herring fillet, dried seaweed, dried squid, dried abalone, dried scallop, dried sea cucumber, dried oyster and dried shark in many countries of the world (Knapp, 1998; Shah, Tokunaga, Kurihara *et al.*, 2009; Ghabshi *et al.*, 2012; Hasan *et al.*, 2016a; Xie *et al.*, 2019). These dried products are widely accepted by the consumers of various countries i.e. China, South Korea, Japan, Vietnam, Thailand, Norway, Portugal, Germany, Bangladesh, India, Sri Lanka, UK, France, Spain, Poland, Italy, Sweden, Denmark, Lithuania and more because of its delicious taste, texture and characteristic flavour (OEC, 2019; IndexBox AI Platform, 2020). These products are also regarded as a good source of protein and amino acids, lipids, polyunsaturated fatty acids and mineral content, which have beneficial effects on human health in reducing the risk of cardiovascular disease, inflammatory, neuro degenerative disease and lowering insulin resistance, triglyceride and obesity (Mohanty *et al.*, 2019; Rasul *et al.*, 2021a). Also, semi-dried fishery products (Tilapia, Silver Pomfret, Pacific herring, semi-dried squid) are not fully dried products (moisture content 25-40%), which have unique flavour and taste as well as recognition as a rich source of protein (Gou *et al.*, 2011; Kim *et al.*, 2014; Kang *et al.*,

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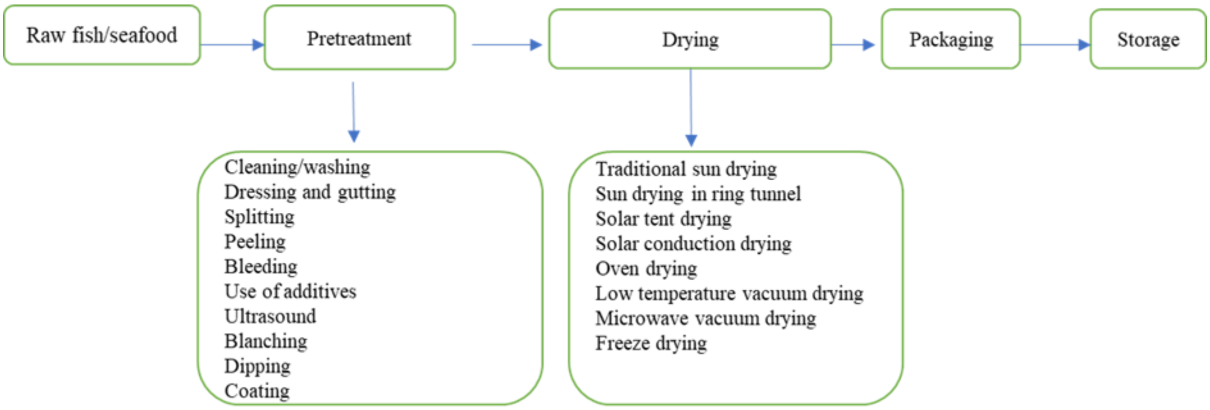

Figure 1. A brief flow diagram for the production of dried fishery products

2016; Chaijan *et al.*, 2017). The demand for these dried products is increasing day by day with the growing fisheries, aquaculture and increasing populations. In recent times, people are more health-conscious about the quality of food having good sensory and nutritional properties (Olatunde and Benjakul, 2018; Rasul *et al.*, 2020).

The quality of fish and fishery products is strictly maintained and monitored for export to foreign countries but unfortunately, such quality control procedure is not maintained for the local market. Many researchers reported that the physicochemical, microbiological and sensory quality of dried fishery products is not satisfactory for human consumption due to various reasons (Paul *et al.*, 2018b; Murthy *et al.*, 2019; Nimrat *et al.*, 2019; Nur *et al.*, 2020; Deng *et al.*, 2020; Gutema *et al.*, 2021; Deng *et al.*, 2021). The responsible factors for quality and nutritional loss of the final product include lack of infrastructure, lack of following appropriate drying methods or negligence and/or lack of awareness about proper handling and transportation of raw material as well as the final product, lack of proper knowledge of drying temperature and time, use of insecticides, unhygienic condition, lack of proper sanitation, the higher moisture content in the final product, low-quality raw materials, improper packaging and storage (Nawsad, 2005; Nurullah *et al.*, 2007; Sam *et al.*, 2015; Gutema *et al.*, 2021). The net effect of all these is compromised quality and safety of dried fish resulting in physical, nutritional quality and economic losses (Namwanje, 2018; Singapurwa *et al.*, 2018). The loss in quality which accounts for 70% of the total loss in fisheries is mainly due to microbial spoilage (Akande and Diei-Ouadi, 2010). However, different types of pre-treatments (such as blanching, ultrasound, high hydrostatic pressure), use of various additives, irradiation can be used in enhancing the drying rate and reducing initial microbial load and improving the quality of dried fish and fishery products (Kim *et al.*, 2014; Yao, 2016; Kang *et al.*, 2016; Odoli *et al.*, 2019; Chaula *et al.*, 2019a; Xie *et al.*, 2019). Despite much research has been done on the quality changes of dried fish and seafood, the factors influencing quality are complicated and there is still an unresolved issue. For this reason, it is necessary to search for the factors that affect the nutritional quality and safety of dried fish. Therefore, this study aimed to review research findings on factors affecting the dried fish and seafood quality parameters and determine how to ensure constant quality and safety which will help to take necessary steps for maintaining the quality and safety of the products.

2. Factors influencing dried products

Drying improves the stability of fish and seafood by reducing moisture content and minimizing physical, chemical and microbial changes during storage (Darvishi *et al.*, 2012). Many factors are responsible for significant physical, chemical, microbial and safety aspects changes in dried fish and seafood such as drying methods, pre-treatment of raw materials, and use of additives. This review makes an attempt to cover the most important aspects of the various effects of each factor on the nutritional composition, quality and safety of the dried fishery products.

2.1 Quality of raw materials

Spoilage of fish occurs rapidly at an ambient temperature. Therefore, different methods of preservation should be applied for maintaining the quality of raw fish or shellfish immediately after harvesting for further processing. A variety of freshwater fish and seafood are being used in sun-drying throughout the world. The quality of fish is influenced by a number of factors that include: temperature, handling practices and initial microbial load (Omoruyi *et al.*, 2018). The freshness of fish before processing is a very important factor in producing good-quality dried fish. It is well known that the final quality of any product largely depends on the quality of raw materials, where once the quality of raw materials deteriorates there is no way of improving the quality by any means of preservation (Reza *et al.*, 2006). The problems associated with the quality loss are probably due to poor water quality, inadequately insulated storage facility and lack of quality consciousness, exposure of harvested fish to high ambient temperature for a long time, unhygienic handling and transportation promote the spoilage of fish (Nowsad, 2005; Odote, 2006; Nur *et al*., 2020). Around 70% of the total catch is dried for sale as human food, and the remaining 15% is 'trash fish', which is dried for use as an ingredient in fish and animal feeds (Belton *et al*., 2018). One of the major reasons for the quality loss in dried products is due to the use of semi-spoiled fishes, and the loss of freshness of raw material before being dried (Reza *et al*., 2006; Samad *et al*., 2009; Dey *et al*., 2016). In artisanal fishing, a huge amount of fish is landed in distant or remote places. The fisheries items may be rotten while it is being taken to market, this unexpected delay of transportation results in a loss of quality (Nowsad, 2007). It has been reported that about 28% of fish were found to lose 60-70% of freshness quality before they reached the consumer in local fish markets (Nowsad, 2007). It was found that gutting by fishermen is not done in most cases. Moreover, the processors did not wash the fish except for large-sized ones and when washing was done, processors used to take the fish to a nearby channel, dipped into the water and wash it several times prior to sun drying (Paul *et al*., 2018a). It has been reported that an increase in temperature from 0 to 10°C at least doubles the rate of spoilage of fishery products, and controlling temperature and time is of prime importance in reducing the deterioration of raw material (Norman *et al*., 2000). Another study reported that when the fresh fish and the 24 hrs stored (at room temperature) fish were dried, there was about a three-log reduction in bacteria and when the 48 hrs iced stored fish was dried there was only a two-log reduction in total bacterial numbers (Ghabshi *et al*., 2012). After drying, coliforms were not detected in all three groups of fish. Proper drying of the product in a hygienic way can prevent the growth of most bacteria and can render the product safe for human consumption (Prakash *et al*., 2011). The content of spoilage bacteria immediately after desalting was slightly lower for fresh raw material than for the others (Barat *et al*., 2006). Excellent quality of dried products having attractive colour, characteristic odour with a firm texture, no infestation and no broken pieces were observed from the raw materials stored up to 3 days in ice. The dried products produced using 10 days' ice stored fish were also found acceptable quality for consumption. However, the products prepared from 13 days of ice-stored fish were poor in quality, dark brown colour, rancid odour, fibrous texture and presence of some broken pieces (Reza *et al*., 2006). Thus, to ensure excellent quality dried fish, fishermen and processors need to maintain the quality of raw materials of fish through proper hygiene, handling practices and keeping the raw materials in chilled and frozen condition.

2.2 Pre-treatment of raw materials

Pre-treatment of fish like cleaning, splitting, blanching, peeling, degutting, bleeding, and ultrasound is important for maintaining the quality of dried fish during processing, storage and distribution. The freshness of fish and better-quality raw material for drying depends on the pre-treatment of fish.

Fish guts are known to be a reservoir of digestive enzymes and bacteria. Bleeding and gutting procedures carried out in fish processing are efficient because removal of enzymatic activity (Olatunde and Benjakul, 2018), which is one of the important factors for the quality deterioration and spoilage of fish. Some fish species' quality and shelf life can be increased much more if they are bled and the viscera removed, as gutting and bleeding practices remove the fish intestine, limiting access to most spoilage bacteria (Omoruyi *et al*., 2018). The gutting process, therefore, destroys the reservoir of these digestive enzymes and bacteria there by reducing the process of autolysis in fish. Moreover, drying time and deteriorative changes could be reduced if the fish were gutted and salted properly prior to artificial drying (Nooralabettu, 2011).

The consequence of blanching prior to drying on fish muscle proteins during drying is less understood (Odoli *et al*., 2019). The blanched (100°C) African catfish (*Clarias gariepinus*) had the highest drying rate for all the temperatures increasing from 1.0 g/hr at 40°C to 2.58 g/hr at 55°C with the increase of temperature than sugaring (15 g/L water) and salting (15 g/L water), though the pre-treatment does not affect the drying rate significantly (Omodara and Olaniyan, 2012). This is due to the effect of heat treatment on the blanched samples which introduced porosity in the fish muscle as a result of cooking thereby enhancing the release of water from the fish muscles. Jason (1980) concluded that the cooking of fish increased 2.7 times the diffusivity of water in the falling rate period, compared with an uncooked sample. The blanched samples have the highest value of protein having a value of 55.94%, blanching is a preferred pre-treatment where the lipid content of dried fish is the most important quality to be preserved (Omodara and Olaniyan 2012). As noted with lipid, the moisture content was reduced significantly following blanching. This occurrence can be ascribed to the reduced water holding capacity of myofibrillar proteins due to denaturation and hydrolysis that may have occurred while blanching (Odoli *et al*., 2019). Capelin (*Mellotus villosus*) blanching pretreatment (in boiling water of 5% NaCl) prior to drying decreased protein solubility and sulfhydryl content due to protein aggregation which may have affected the sensory properties of the dried fish mainly texture (Odoli *et al*., 2019).

Some studies indicated that ultrasound-assisted pre-treatment could effectively improve the drying rate and greatly reduce the processing time (Yao, 2016). With the increase of the ultrasound power, the hardness, the relative content of monounsaturated fatty acid and polyunsaturated fatty acid and the total content of free amino acid decreased while the saturated fatty acid and sensory scores increased, respectively for salt-dried grass carp (Wang *et al*., 2018). Ultrasound-assisted (0–480 W) salting leads to increasing the water removal rate and reduces drying time probably for the "cavitation" produced by ultrasound, which inevitably intensifies the mass transport (Yao, 2016) for the formation of micro channels on surfaces of the meat (Ojha *et al*., 2017). The salt treatment showed significantly lower aerobic bacterial counts in dried *Rastrineobola argentea* compared to the chlorinated and control treatments. It has been reported that chlorinated wash (100 ppm) might be an effective intervention strategy in reducing lipid oxidation of dried fish evident in the lower TBARS and TVBN values (Owaga *et al.,* 2009) possibly as a result of inhibition of the lipolytic bacteria by chlorine. Overall, pre-treatment of fish drying following bleeding, gutting and salting with chlorinated water may be suggested as much more efficient for better quality dried products. Ultrasound pre-treatment was also found as a promising technique that needs to be validated for commercial application.

2.3 Drying methods

Different types of drying methods are traditional sun drying, oven drying, rotary drying, solar tunnel drying, vacuum drying, and freeze-drying is used to prepare various dried fishery products (Figure 2). The major physical changes that occur in fish during drying are changes in texture (becomes hard and firm), changes in colour (the major first judgment detrimental factor) and yields (Nawsad, 2005). The extent of these changes depends on the temperature, time of pre-treatment as well as a drying method. The physicochemical and microbiological changes in dried fish finally affect the quality of fish and fishery products (Abraha *et al*., 2018). There is a significant difference in moisture contents of dried *Oreochromis niloticus* by sun-drying (8.77%) and oven drying (7.17%) (Tarle *et al*., 2016). Likewise, low levels of moisture were achieved for dried products from a solar tent dryer than in the open sun rack dried products (Abraha *et al*., 2017). However, Kumar *et al.* (2017) observed insignificant variation in water activity of dried *Pangasius* in mechanical, kiln and oven drying. They also observed that thiobarbituric acid reactive substances (TBARS) and peroxide value (PV) of *Pangasius* decreased with the increasing drying temperature. Jahan and Akhtar (2019) found that the proximate composition such as moisture, protein, lipid and ash content of traditional sun-dried *Channa punctatus* was 14.83%, 57.50%, 3.10% and 21.0%, respectively, and in oven-dried (105˚C) *Channa punctatus* were 8.50%, 70.15%, 5.85% and 13.0%, respectively. A similar result was observed in the case of some traditional sun and improved dried fish (Hasan *et al.*, 2016). They also noticed that electric oven-dried fish retain higher lipid and protein content than traditional sun-dried fish, and lower ash (with the increasing of drying temperature above 60˚C) and moisture content. Less amount of lipid content in the traditional drying method might be due to comparatively higher oxidation of lipids than the other drying methods (Abraha *et al*., 2018).

Figure 2. Various fish and seafood drying methods: A. Traditional sun drying, B. Sun drying in ring tunnel, C. Oven drying, D. Solar tent drying, E. Solar tunnel drying, F. Low temperature vacuum drying, G. Microwave vacuum drying and H. Freeze drying

The sensory evaluation and rehydration ability of solar-dried *H. molitrix* products showed comparatively better quality than the products produced by traditional sun drying and improved ring tunnel drying methods (Rasul *et al*., 2018). More or less similar findings were summarized by Immaculate *et al.* (2012) and Pradhan *et al.* (2020). It has been reported that comparatively higher amounts of PUFAs were found in solar dried *M. cordyla* followed by improved, improved-TC and traditionally produced dried fish. Significantly ($p < 0.05$) the lowest peroxide value, acid value and carbonyl value were also observed in solar dried products (Rasul *et al*., 2021). The formation of free fatty acid is one of the important factors that increase the acid value in dried fish. The free fatty acid content was comparatively higher in commercially sun-dried fish followed by experimentally sun-dried fish (Patterson and Ranjitha, 2009). A similar trend was reported in the case of dried Indian anchovies (*Stolephorus commersonnii*) (Patterson *et al*., 2018).

The dried fish produced by low-temperature vacuum drying (LVD) had the lowest moisture content and the highest protein content than hot air drying (HAD) and freeze-drying (FD) methods (Kim *et al*., 2020). They suggest that the dried yellow croakers by LVD rather than HAD and FD showed relatively better quality in terms of physicochemical properties (Figure 3) and textural properties. But, there is no difference in TVBN between LVD and FD dried croakers due to low temperature and vacuum drying conditions. The protein content is increased in the dried fish due to the dehydration of water molecules present between the proteins, causing the aggregation of protein (Ninawe and Rathnakumar, 2008). Similarly, freeze-drying (FD) is known to give high-quality products and was inducted into the study as a reference for comparing solar conduction dryer (SCD) and HAD (Nagwekar *et al*., 2017). Freeze drying not being a viable option for processing low-value products, hot air convective dryer can be used on an industrial scale for drying fish. Although the use of hot air drying by the local fishermen is not feasible due to economic challenges, a solar conduction dryer can be a clean and affordable alternative for efficient drying and production of high-quality fish. According to Chukwu *et al.* (2009), electric oven drying is recommended for healthy eating that increased vitamin A content and also longer shelf life of dried fish (*Oreochromis niloticus*). The fatty acid composition of oven-dried products also showed higher lipids loss and slightly higher protein content than smoking kiln-dried products.

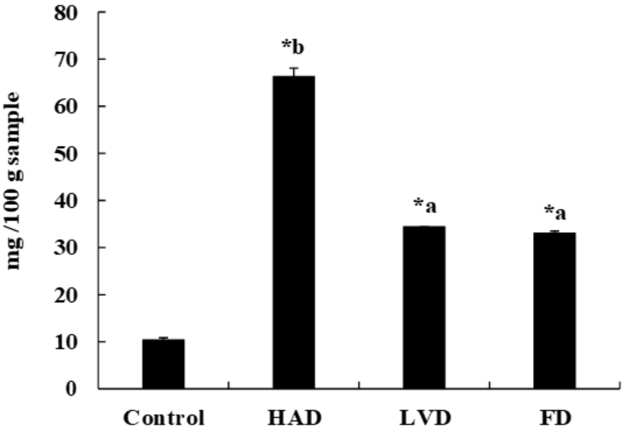

Figure 3. Total volatile basic nitrogen (TVBN) content in the yellow croakers by various drying methods. Bars with asterisk (*) notation are significantly different between groups according to Student's *t*-test. Bars with different alphabet notation are significantly different among groups using one-way ANOVA followed by Duncan's multiple-range test at $p < 0.05$. Control, yellow croakers by cold air drying to remove moisture. HAD, yellow croakers by hot air drying. LVD, yellow croakers by low temperature vacuum drying. FD, yellow croakers by freeze drying (Kim *et al*., 2020).

The microwave vacuum-dried mackerel was superior in rehydration colour, appearance texture and other sensory attributes to hot air oven-dried mackerel. Case hardening was not observed during microwave vacuum drying. This study revealed that the drying period can be significantly reduced by microwave vacuum drying, yielding a better-quality product compared to the conventional drying method (Viji *et al*., 2019). Similarly, semi-dried tilapia (*Oreochromis niloticus*) muscle by microwave oven drying ensured superior quality to the sun-dried samples in terms of lipid deterioration, protein oxidation and discolouration (Chaijan *et al*., 2017). The oven-dried shrimp powder at 70°C was preferred in all parameters (sensory and microbiological) evaluated over the sun-dried powder (Ajifolokun *et al.*, 2019). The total plate count and total fungal count were higher in open sun rack dried anchovy when compared to the solar tent drier dried products (Abraha *et al*., 2017). More or less similar microbiological results were reported in the case of dried *H. molitrix* and *M. cordyla* (Rasul *et al*., 2018; Rasul *et al*., 2021). A solar tent dryer can concentrate solar radiation with the result of elevated temperature, which increases the drying rate, in turn, lower relative humidity makes favourable to lower the activities of microbes and moulds (Abraha *et al*., 2017).

From the above discussions and results found by various researchers, it is clear that every method of mechanical drying, oven drying, solar tent drying, solar tunnel drying, low-temperature vacuum drying, and freeze-drying all resulted in superior quality products for nutritional, chemical and microbial facts than traditional sun drying, open rack drying and improved drying method. However, Chukwu *et al.* (2009) suggested that the electric oven drying method produced a better quality product for healthy eating as well as longer shelf life. Electric oven drying could improve protein quality and prevent lipid oxidation. It was also observed that the selection of drying methods depends on the cost, some commercial purposes, or the quality of the products. In terms of quality, sometimes micro-oven dryers and vacuum dryers are considered better, however, this method is not cost-effective. On the other hand, a solar tunnel dryer is considered a cost-effective method although it depends on sunlight.

2.4 Use of additives

The sun-drying process and subsequent storage promote lipid oxidation and its associated undesired flavours and odours (Slavin *et al*., 2016, Rasul *et al*., 2020). These forces food scientists to investigate the impact of synthetic and natural antioxidants on lipid oxidation and sensory attributes of dried fish. Commercially available synthetic antioxidants like butylated hydroxytoluene (BHT), tert-butylhydroquinone (TBHQ) and butylated hydroxyanisole (BHA) are commonly used to hinder lipid oxidation in food systems (Shahidi, 2000). Conversely, there are studies questioning their application in food due to their potential carcinogenic effects and toxicity (Zheng and Wang, 2001).

2.4.1 Synthetic and chemical preservatives

Chemical preservatives like sodium sorbate, calcium sorbate, and potassium sorbate (200 mg/kg maximum singly or in combination expressed as sorbic acid) are on the list of permitted preservatives/food additives, which can be used in dried and salted fish (EFSA, 2015). It has been reported that a combination of propyl gallate and sodium ascorbate was effective in delaying lipid oxidation in salted dried snakehead during refrigerated temperature (4°C) and showed greater antioxidant activity in terms of lower PV and TBARS values than did not with antioxidants (Nitipong *et al*., 2014). They also observed that lipid oxidation could be controlled by the combined use of propyl gallate and sodium ascorbate and vacuum-packed condition. Another investigation revealed that adding additives (glycerol and sorbitol) leads to a shorter drying process of dried snakehead fish (*Channa striata*). Comparatively higher drying time (29.90 hrs) was required to obtain suitable moisture content in the dried fish when a lower concentration of food additive (1% glycerol or 2% sorbitol) was added, while a higher concentration of food additives (3% glycerol combined with 4% sorbitol) require less time (26.21 hrs) (Tran *et al*., 2020). This might be due to sorbitol and glycerol forming an osmotic pressure that leads to the escape of water in the raw material. The brightness of dried fish is also affected by glycerol addition. In contrast, sorbitol is a colourless compound, which did not involve in the browning reaction (Tran *et al*., 2020). In addition, Park and Xiong (2007) observed that the addition of glycerol to Alaska Pollock (*Theragra chalcogramma*) maintained low water activity (a_w) leading to improving the structure of the dried product. Similarly, Tirtha *et al.* (2016) found that total volatile base nitrogen (TVBN), trimethylamine (TMA) and PV were acceptable when *Harpodon nehereus* was treated with saturated brine with 0.3% sodium benzoate solution, while fish treated with dry salt with 0.25% potassium sorbate, and saturated brine with 0.3% sodium benzoate solution showed better quality and good preservative effects in terms of the microbial load than that of control. It has been reported that fish processors used excessive amounts of insecticides to protect the dried fish from insect infestation. Moreover, many dried fish contains invariably health hazards organochlorine insecticides DDT and heptachlor, eldrin, andrin (Bhuiyan *et al*., 2009; Rahman *et al*., 2019; Rasul *et al*., 2020). It has been observed that DDT and heptachlor cannot be removed completely by any type of washing, even after washing followed by a few minutes of boiling (Bhuiyan *et al*., 2009).

2.4.2 Natural preservatives

Due to safety concerns and increased consumer interest in natural products, efforts are directed to replacing synthetic antioxidants with ones of natural origin (Olatunde and Benjakul, 2018). The polyphenols or phenolic compounds present in the plant are the much important natural antioxidants. Phenolic extracts from vegetables, cereals grains, fruits, and spices had positive effects in preventing lipid oxidation (Mie *et al*., 2019).

Clove (*Syzygium aromaticum*) is a spice with the potential to protect PUFAs against oxidation because they contain anti-oxidative compounds (e.g. polyphenols and flavonoids) that may exert an anti-oxidative effect (Dudonné *et al*., 2009). It has been stated that clove extracts resulted in higher retention of total PUFAs, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and docosapentaenoic (DPA) at the end of 30 days storage period of sun-dried sardines and lower concentrations of secondary lipid oxidation products (Chaula *et al*., 2019). Another study suggests that the use of clove (*Syzygium aromaticum*) and seaweed (*Kappaphycus alvarezii*) water extracts as natural antioxidants to impede lipid oxidation in sun-dried sardines and results revealed that 5, 10, and 20 g/L clove extracts significantly reduced lipid peroxidation in sun-dried sardines by 38.7%, 54.6%, and 56%, respectively (Table 1) (Chaula *et al*., 2019a). Clove extracts resulted in higher retention of omega-3 fatty acids and lower concentrations of secondary lipid oxidation products as opposed to seaweed counterparts. Slavin *et al.* (2016) found that soaking in 10 g/L clove water extract for 1 hr and oven-drying at 150°C for 30 mins significantly reduced TBARS and PV in omena fish by 79%. Thus, it can be concluded that clove water extracts effectively reduced the rate of lipid oxidation as well as improved the quality of fish.

Green tea polyphenol (GTP) as a natural antioxidant has lower toxicity than synthetic antioxidants like BHA and BHT and is more effective than vitamin C, which can be used as an alternative to vitamin C to extend the quality of fish and fishery products during storage (Dembele *et al*., 2011). Results revealed that tea extracts also act as an inhibitor of food pathogens, including *Staphylococcus aureus, Shigella disenteriae, Vibrio cholerae, Campylobacter jejuni, Listeria monocytogenes*. (Taguri *et al*., 2004). Dembele *et al.* (2011) reported that crude green tea polyphenols showed potent antioxidant activity than vitamin C and NaCl (1%) solution. They found that it significantly reduced the rate of lipid

Table 1. Chemical parameters of various dried fishes treated with salt, spices and plant extracts

Fish species	Treatment	pH	TVBN (mg N/100g)	FFA (%)	TBARS (mg MDA/kg)	Acid value (mg KOH/g of Lipid)	PV (meq O_2/kg fat)	References
Pangasius hypophthalmus	Untreated/control	6.86	29.28	1.51	-	-	3.89	Kumar *et al.* (2017)
	Salt (1:1)	5.01	19.58	2.04	-	-	4.53	
Hypophthalmichthys molitrix	Untreated/control	6.65	45.03	-	-	18.87	15.50	Rasul *et al.* (2018)
	Salt (5%)	6.33	37.58	-	-	7.85	9.16	
	Chili and turmeric (0.3%)	6.48	40.05	-	-	12.20	11.68	
Clarias gariepinus	Untreated/Control	6.57	23	0.49	16.9	-	3.5	Dembele *et al.* (2011)
	GTP1 (0.01%)	6.62	23	0.41	13.1	-	3.32	
	GTP1 (0.03%)	6.65	23	0.45	5.9	-	2.91	
	GTP2 (0.01%)	6.64	22.7	0.38	11.1	-	2.98	
	GTP2 (0.03%)	6.68	23.9	0.35	7.8	-	2.5	
	Vitamin C	6.60	25.1	0.45	15.5	-	3.32	
Oreochromis niloticus (Sun dried)	Untreated/Control	-	-	-	13.73	45.43	20.63	Tenyang *et al.* (2020)
	Salt (5%)	-	-	-	10.12	40.89	17.09	
	Moringa oleifeara LE (1%)	-	-	-	9.60	23.83	11.88	
	M. oleifeara LE (1%)	-	-	-	9.19	22.39	6.88	
	M. oleifeara LE (1%)	-	-	-	8.90	19.87	5.63	
	Solanum melongena FE (1%)	-	-	-	12.29	29.29	12.25	
	S. melongena FE (1%)	-	-	-	9.36	28.17	10.63	
	S. melongena FE (1%)	-	-	-	8.46	25.38	7.92	
	Zingiber officinale RE (1%)	-	-	-	14.07	31.80	13.13	
	Z. officinale RE (1%)	-	-	-	13.48	30.32	11.09	
	Z. officinale RE (1%)	-	-	-	12.32	28.17	8.35	

Note: GTP1 = Laboratory-extracted crude green tea polyphenol, GTP2 = Commercial crude green tea polyphenol, RE = Root extract, FE = Fruit extract, WE = Water extract, MOM = *Moringa oleifera* marinade, BHA = Butylated hydroxyanisole

Table 1 (Cont.). Chemical parameters of various dried fishes treated with salt, spices and plant extracts

Fish species	Treatment	pH	TVBN (mg N/100g)	FFA (%)	TBARS (mg MDA/kg)	Acid value (mg KOH/g of Lipid)	PV (meq O_2/kg fat)	References
Oreochromis niloticus (Smoke Dried)	Untreated/Control	-	-	-	12.46	4.06	11.88	Tenyang *et al.* (2020)
	Salt (5%)	-	-	-	8.39	2.70	7.50	
	M. oleifeara LE (1%)	-	-	-	8.52	1.85	3.13	
	M. oleifeara LE (2%)	-	-	-	6.29	1.41	2.50	
	M. oleifeara LE (3%)	-	-	-	5.12	1.04	1.88	
	S. melongena FE (1%)	-	-	-	9.48	2.21	9.38	
	S. melongena FE (2%)	-	-	-	8.17	1.51	5.40	
	S. melongena FE (3%)	-	-	-	7.53	1.41	3.40	
	Z. officinale RE (1%)	-	-	-	10.06	2.39	10.00	
	Z. officinale RE (2%)	-	-	-	9.12	2.17	7.30	
	Z. officinale RE (3%)	-	-	-	7.79	1.93	4.38	
Dosidicus gigas	Untreated/Control	6.58	-	-	0.886	-	-	Dong *et al.* (2013)
	Tea polyphenol (0.15%)	6.57	-	-	0.852	-	-	
Rastrineobola argentea	Untreated/Control	-	-	9.50	-	-	20.32	Chaula *et al.* (2019)
	Clove WE (0.5%)	-	-	12.84	-	-	11.54	
	Clove WE (0.10%)	-	-	11.27	-	-	8.56	
	Clove WE (0.20%)	-	-	12.08	-	-	8.28	
Rastrineobola argentea	Untreated/Control	-	-	-	-	-	18.83	Chaula *et al.* (2019a)
	Seaweed WE (0.5%)	-	-	-	-	-	24.34	
	Seaweed WE (0.10%)	-	-	-	-	-	24.35	
	Seaweed WE (0.20%)	-	-	-	-	-	24.38	
Clarias gariepinus	Untreated/Control	-	-	-	0.94	-	-	Dauda Adeyemi *et al.* (2014)
	MOM (1%)	-	-	-	0.84	-	-	
	MOM (2%)	-	-	-	0.88	-	-	
	MOM (3%)	-	-	-	0.85	-	-	
	Salt (5%)	-	-	-	0.92	-	-	
	BHA (2%)	-	-	-	0.80	-	-	

Note: GTP1 = Laboratory-extracted crude green tea polyphenol, GTP2 = Commercial crude green tea polyphenol, RE = Root extract, FE = Fruit extract, WE = Water extract, MOM = *Moringa oleifera* marinade, BHA = Butylated hydroxyanisole oxidation in dried catfish (*Clarias gariepinus*) and also improved the quality and shelf life of the final products. Dong *et al.* (2013) found that dip treatment of tea polyphenols effectively reduces moisture loss, inhibiting the oxidation of lipids, depressing tri-methylamine oxide (TMAO) breakdown and TVB-N accumulation in dried seasoned squid (*Dosidicus gigas*) during storage at 25°C for 180 days of storage period. Another study reported that pre-treatment of green tea extracts was effective in delaying early-stage peracid inducement and preventing the generation of secondary oxidation compounds, such as carbonyl compound and TBA compound, in the course of the drying and frozen storage of eels (*Anguilla bicolor pacifica*) (Song, 2021). From these results, it is suggested that tea polyphenols can be potentially used as an important food preservative than that of vitamin C and traditional salt treatment. Moreover, no significant difference was observed between tea polyphenols extracted in the laboratory and commercial ones when used in fish preservation. Thus, commercially available tea polyphenols can be used in the processing industry for fish preservation.

Apart from the medicinal uses, *Moringa oleifera* is reported to be a good source of vitamins, amino acids (Olugbemi *et al*., 2010), vitamins C and E, carotenoids and polyphenols and minerals (Ogbe and Affiku, 2012) that are involved in oxidative stability of oils. Thus, it can be used to preserve the quality of fish during processing. It has been reported that the use of an aqueous extract of *M. oleifera* leaves at a concentration of 30g/L provided the best antioxidant activities against lipid oxidation during sun and smoke-dried *Oreochromis niloticus* and *Solanum melongena* fruits *and Zingiber officinalis* roots extract. Smoke dried compared to sun-dried can be recommended for drying *Oreochromis niloticus* because it appears to have a higher lipid quality (Tenyang *et al*., 2020). Adeyemi *et al.* (2013) also reported that 3% *M. oleifera* marinade exhibited the highest antibacterial potency on smoke-dried catfish (*Clarias gariepinus*) stored at ambient temperature (37±2°C) for two months, while 5% brine exhibited the highest antifungal potency. Results suggest that *M. oleifera* extracts act as an antioxidant and antibacterial agent that enhances the nutrient composition and increases the shelf life of fishery products during preservation.

Tejpatta (*Cinnamomum Tamala*) can be an alternative to synthetic additives used in food preservation especially in regards to the growth inhibition of fish spoilage bacteria like *S. putrefaciens, A. veronii,* and *P. jessenii* (Huang et al., 2019). Moreover, the use of tejpata leaves extracts on dried *Corica suborna* significantly reduces total coliform bacteria and total fungal count from >240 MPN/g and 3.8×10^2 CFU/g to 46 MPN/g and 100 CFU/g, respectively (Begum *et al*., 2013). Thus, it may be concluded that tejpata leave extracts might be a feasible treatment option for the preservation of dried fish due to their natural antimicrobials, easy availability in tropical countries and low cost to the consumer.

2.4.3 Salt, turmeric, ginger, garlic, chilli, neem and other plant leaves extracts

Traditionally, raw fish are immersed in concentrated solutions containing salt or other curing agents that can impregnate the muscle (Valencia-Pérez *et al*., 2008) and used as a pre-treatment before drying to achieve a good quality product. A decrease in water activity of salted dried fish was observed may be due to the bounding of water molecules with NaCl and water evaporation (Kumar *et al*., 2017). Salt acts as a seasoning and flavour enhancer and the addition of salt to fish decreases the pH of fish due to an increase in acidic compounds (Farid *et al*., 2014).

The reduction in pH of the salt-washed *Dagaa* fish was due to the leaching of salt soluble proteins (Owaga *et al*., 2009). It has been found that the salt and turmeric treated smoke-drying method has a positive significant role on the chemical and mineral composition of freshwater *G. chapra, X. cancila* and *M. pancalus* fishes and reduces bacterial load as well as make them nutritionally suitable (Begum *et al*., 2017). The pre-treatment combination juice of garlic and ginger improve the nutritional, and sensory quality and reduce the microbial load of dried *Oreochromis niloticus, Pylodictis olivaris* and *Cyprinus carpio* fillets that of control samples (Tarle *et al*., 2016). Blanched samples have increased levels and sugared samples have the least values of protein. Sugaring is not a good pre-treatment method in fish drying because it does not enhance the drying rate but also leads to a reduction in protein content (Omodara and Olaniyan, 2012). Lowest TVB-N and PV were observed in dried fish treated with salt reported by Rasul *et al.* (2018). More or less similar results were reported by Rahman *et al*. (2017) in the case of dried *Channa punctatus*.

It has been reported that PV of thyme oil-treated dried mackerel fishes was significantly lower immediately after drying and during storage followed by clove oil treated and control fishes. Thyme oil-treated samples showed the lowest TBARS values during storage (Viji *et al*., 2019). It has been reported that the antioxidants of tea polyphenols and bamboo leaves effectively extended the shelf life of dried scallop adductor muscle (Xie *et al*., 2019). They also observed that natural phenolics effectively retarded lipid oxidation by reducing primary and secondary lipid oxidation products although they had no effect on moisture contents. Another study reported that the use of lemon leaves extracts produced a better quality of dried chanda (*Chanda nama*) than that of control samples in terms of chemical and microbiological analysis (Begum *et al*., 2014). Sarkardei and Howell (2008) stated that a combination of vitamin E + vitamin C + citric acid (250, 250, 100 mg kg^{-1}) significantly reduced the rate of lipid oxidation in freeze-dried horse mackerel followed by rosemary (250 mg kg^{-1}) and control samples. It has been suggested that 3% turmeric (*Curcuma longa*) and 5% neem (*Azadirachta indica*) powder can be used as suitable field doses for direct application in dried fish to prevent insects (*Dermestes* sp.) infestation during storage (Lithi *et al*., 2019). Similar results were also observed by Baba *et al.* (2014), who found that neem plant products especially neem kernel oil (1 ml/35g dried fish) effectively control the *Dermestes maculatus* infestation of dried *Clariaus* sp. Though these plant extracts exhibit a positive role in the chemical and microbiological quality of dried fish, however, reduce the organoleptic/ sensory quality (Garcia-Diez *et al*., 2016) in terms of appearance and colour as well as negatively affect the taste and aroma of treated fish and seafood even in low concentration (Silva-Angulo *et al*., 2015). From the above findings, it can be concluded that some of the synthetic preservatives have some beneficial effects on dried fish but are not like natural antioxidants (Olatunde and Benjakul, 2018).

2.5 Extrinsic factors

In the case of dried fish products, extrinsic factors play an important role in the quality and microbial contamination of the product (Nawsad, 2005). During the drying process, the removal of moisture depends on the drying conditions and dimensional characteristics (thickness, surface area) as well as the composition of the fish to be dried (Adeyeye, 2019). Drying at higher temperatures increased drying rates and reduced drying time (Lewicki, 2006; Sobukola and Olatunde, 2011). The drying process can be conducted either at high temperature and short time (HTST) or at low temperature and long-time (LTLT) (Piga *et al*., 2003). Usually, fish drying is done on the rack in an open-air/sun or three-stone stove where controlling of heat is difficult and impossible and produces unsatisfactory end products (Komolafe *et al*., 2013; Hasan *et al*., 2016). If acceptable and suitable drying temperature(s) are used, post-harvest losses incurred as a result of under-drying and over-drying would be greatly reduced (Komolafe *et al*., 2013). Increasing of temperature from 30°C to 50°C resulted in a higher decline in moisture content with drying time but further increasing the temperature to 60°C resulted in an initial increase in drying rate because of dramatic decline due to case hardening of the surface layers although it appears well dried (Mujaffar *et al*., 2011).

To prevent this negative effect of drying air temperature, particularly low temperatures should be selected for drying the perishable food products and drying air and drying air temperature should have homogeneous distribution in the dryer (Kilic *et al*., 2009). The higher temperature of the material during drying leads to several irreversible biological or chemical reactions as well as structural, physical and mechanical modifications, including the colouring, crust formation, decrease of sensory quality, inactivation of bacteria and enzymes, loss of nutrients and aroma, and changes of shape and texture (Abid *et al*., 1990). Temperatures above 50°C caused a certain amount of cooking of the seafood muscle resulting in the brittleness of the end product (Balachandran, 1969). Drying rates are shown to increase as the drying temperature increases from 35 to 50°C (Bellagha *et al*., 2002). The low-temperature drying process has a positive influence on the quality of biological materials but requires longer processing times, which has a detrimental effect on the quality and a higher cost of operation (Kilic, 2009). During low-temperature drying, lipid oxidation and antioxidant losses, shrinkage can be reduced and better rehydration properties by low temperatures, and low-pressure operation (Adeyeye, 2019). Low-temperature vacuum drying (LVD) (performed at 30-35°C) could be better for the longer storage of dried fish by preventing microbial contamination than HAD (at 60°C) and FD (at -40°C) yellow croakers (Kim *et al*., 2020).

The relative humidity is one of the important factors that are responsible for the consumable quality of dried fish. In any drying process, the temperature and speed of vaporization depend on the water vapour concentration in the atmosphere (Lewicki, 2006). The higher the relative humidity (RH), the longer the drying time (Adeyeye, 2019). RH particularly at 65% and above significantly increased the amount of crystals on the surface of dried scallop (*Chlamys farreri*). RH of 43% and below was recommended to prevent the formation of amino acid-rich crystals on dried scallops during storage (Hu *et al*., 2016). Temperature and relative humidity were within the recommended range of values for fish drying should not exceed 60°C for temperature and 10-40% for relative humidity (Sidhi *et al*., 2018). Relative humidity below this certain level resulted in case hardening (Sigge *et al*., 1998). Shah, Tokunaga, Kurihara *et al.* (2009) reported that the rate of lipid oxidation was comparatively lower in dried herring fillets when drying temperature and RH were maintained at 15°C and 45%, respectively. They also suggested that during the drying period, proteolysis, as well as Maillard reaction products, increased markedly in dried herring fillet, which might contribute to the characteristic taste and flavour of the final product (Shah, Tokunaga, Ogasawara *et al*., 2009). Therefore, drying of fish samples should be done carefully maintaining proper temperature and relative humidity to prevent loss in nutrients, quality and consumer acceptability, and to improve the shelf life and keep the quality of dried fish products (Adeyeye, 2019).

2.6 Irradiation

Irradiation, one of the emerging and hygienic technologies ensures a potential to improve microbiological safety and quality of fish and fishery products through shelf-life extension (Prakash *et al*., 2015). The irradiation of food products is a physical treatment involving direct exposure to electron or electromagnetic rays, for their long-time preservation and improvement of quality and safety (Akuamoa *et al*., 2018). The major problem of the distribution of seafood or fishery products is their susceptibility to spoilage, mainly due to contamination of spoilage and pathogenic microorganisms (Özden and Erkan, 2010). The quality of sun-dried fishes is adversely affected by microorganisms. Gamma irradiation combined with air-tight packaging can be applied in preserving and improving the quality of sun-dried fish (Kwon and Byun, 1995). The quality parameters like FFA, TMA-N and TVB-N values of irradiated (5 kGy) dried Sharp fin barracuda (*Sphyraena acutipinnis*) were significantly reduced than the untreated control samples (Prakash *et al*., 2015). The organoleptic qualities of the irradiated fish products were good. The total bacterial count was reduced, whereas *Salmonella*, *Vibrio* and fungi were totally eliminated after irradiation. It also destroys many of the spoilage agents like bacteria, insects, parasites, moulds and yeasts from food that are known to be the main cause of food losses in developing countries (Prakash *et al*., 2015). It has been reported that the total bacterial count, and the total fungal count was acceptable at the end of the six months of storage of dried *C. malabaricus*, *S. lysan*, *S. acutipinnis*, *L. dussumieri*, *L. platypterus*, *L. rubrioperculatus* and *A. thazard* treated with gamma irradiation (5 kGy). Growth of *Salmonella* and *Vibrio* were observed in the non-irradiated samples, whereas it was not observed in the gamma-irradiated dried fishes stored at ambient temperature for six months (Sinduja *et al*., 2014). Similar results were also reported by Prakash *et al.* (2014) in some dried products. The global colour difference of irradiated muscles and by-product powders from dried *Sardinella aurita* showed little variations during storage at room temperature. After irradiation, the microbial changes in by-product powder decreased to a steady state during the storage period (Tarhouni *et al*., 2015). The irradiation of both products at 5 and 10 kGy doses provided products with acceptable colour and microbial quality. However, irradiation at doses of 6 and 7.5 kGy reduced significantly the poly-unsaturated fatty acid fraction of bonito (*Sarda sarda*) (Mbarki *et al*., 2008). The extent of lipid oxidation in dried file fish (*Stephanolepis cirrhifer*) drastically increased in doses above 10 kGy (Cha, 2009). For semi-dried shrimp, irradiation at 2 and 4 kGy could extend the shelf life to 35 and 49 days of storage compared to 10 days of control (Noomhorm *et al*., 2003). The effects of the radiation treatment and frozen storage on the survival of total bacterial count, total coliforms, *E. coli* and *S. aureus* in shrimp were more effective (Hocaoğlu et al., 2012). It has been reported that gamma irradiation using a dose > = 7 kGy could be effective in reducing murine norovirus-1 (MNV-1) titers by more than 1 log (10) CFU/mL (>90%) in half-dried Pacific herring and semi-dried squid without any concomitant changes in colour and sensory evaluation (Kang *et al*., 2016).

Combination of irradiation with any one of the preservation methods like icing, salting, drying, smoking and irradiation resulted in greater reductions of microbial loads, extending the shelf life of meat for commercial application and critical conditions (Prakash *et al*., 2014). Yeast and moulds are sensitive to the irradiation process because of their large genomic structure (Fallah *et al*., 2008). The irradiation process improves the taste and texture of dried fish through the amino acid composition increases. *Aspergillus niger*, *Penicillium citrinum*, and *Cladosporium cladosporioides* strains counts were significantly ($p < 0.05$) reduced by the 600 mWs/cm^2 of ultra-violet (UV) at 260 nm dosage on the surface of dried filefish fillets without any concomitant changes in the colour or sensory qualities of the fillets (Park *et al*., 2014). The overall reduction of the spoilage moulds by UV treatment ranged from 1 to 2 log$_{10}$CFU/g. Similar effects of UV radiation of food on *Aspergillus flavus*, *Penicillium corylophilum* and *Eurotium rubrum* were reported by Begum *et al.* (2009). Gamma irradiation method develops the best quality dried fish product in combination with safety and extended shelf life. The process of irradiation uses a low dose rate which reduces product degradation and even kills pathogenic viruses present in that fish product. During applying gamma irradiation, the dose should be maintained at very low because gamma-ray may destroy living cells, produce gene mutation and cause cancer in humans through consumption of the treated dried fish product. Moreover, UV processing alone may not be adequate to ensure the safety of fish products. Therefore, UV radiation's impact on nutrients and mainly lipid oxidation of fishery products need to be monitored in future studies.

2.7 Cold oxygen plasma

Cold oxygen plasma (COP) is an effective tool for food decontamination, reduction of the microbial growth of meat and fish food and shelf life extension (Misra *et al*., 2011; Pankaj *et al*., 2018). Park and Ha (2014) investigated the effects of COP on the reductions of *Penicillium citrinum* and *Cladosporium cladosporioides* on the surface of dried file fish fillets (*Stephanolepis cirrhifer*). The counts significantly ($p < 0.05$) were reduced with the increase in the treatment time (3–20 mins) of COP on the fillets (Figure 4). Results showed that a 10 mins COP could be effective in reducing >90% and inactivating these moulds without causing any deleterious changes to the physicochemical and sensory qualities of the fillet. A 10-min COP treatment could achieve an approximately 1-log10 reduction in the mould population without inducing lipid peroxidation or negatively affecting the flavour. However, COP increases the lipid oxidation in food (Pankaj *et al*., 2018) and they suggested that COP processing alone may not be adequate to ensure microbial safety of dried fish products. Therefore, further studies need to be optimized to avoid the negative impacts on quality, such as accelerated lipid oxidation, loss of vitamins and sensory characteristics. Another study investigated the antibacterial effects of Bio Zone atmospheric plasma (AP) against *Bacillus cereus* (F4810/72) and *Staphylococcus aureus* (ATCC 6538) as the major foodborne bacteria on the surface of dried file fish fillets. The fillets were experimentally contaminated with 7-8 log CFU/mL of *B. cereus* or *S. aureus* using a spot inoculation method. The reductions of the pathogens by AP treatment ranged from 0.9 to 2.93 log CFU/g for *B. cereus* and from 1.04 to 2.55 log CFU/g for *S. aureus*. A reduction of >1-logCFU/g for *B. cereus* and *S. aureus* was observed on the fillets treated with AP for >3 mins. They suggested that 3 mins of AP could be effective in reducing >90% of the bacteria without causing any concomitant changes in the colour of the fillets (Park, 2019).

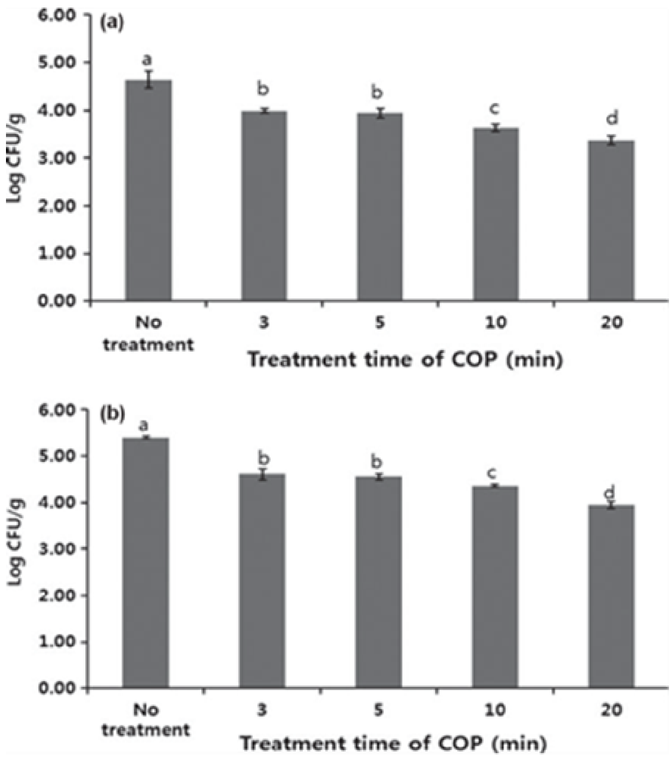

Figure 4. Counts of *Cladosporium cladosporioides* ($\log_{10}$ CFU/g) (a) and *Penicillium citrinum* ($\log_{10}$ CFU/g) (b) colonies on the surface of dried filefish fillets treated by cold oxygen plasma (Park and Ha, 2014). Bars with different alphabet notation are significantly different ($p < 0.05$) by Duncan's multiple-range test at the 5% level of probability.

2.8 Corona discharge plasma

Non-thermal techniques for microbial decontamination in food are becoming more promising. Choi *et al.* (2017b) worked on the suitability and effectiveness of corona discharge plasma jet (CDPJ) for the inactivation of microbial contaminants of dried squid shreds. CDPJ was generated using 20 kV pulsed DC voltage and at a 58 kHz frequency. Upon the CDPJ treatment (0-3 mins) of dried shreds, contaminants namely aerobic bacteria, marine bacteria and *S. aureus* were inactivated by 2.0, 1.6, and 0.9 log units, respectively. In contrast, the moisture and TBARS levels of shreds were significantly ($p < 0.05$) altered by the plasma exposure. However, the treatment exerted no significant ($p > 0.05$) impact on the sensory characteristics of dried squid shreds. The CDPJ was found to be effective for microbial decontamination of real-world samples of dried squid. Upon the CDPJ treatment (current strength of 1.5 A for 0 to 3 mins) of dried Alaska pollock shreds, microbial contaminants namely aerobic and marine bacteria, and *S. aureus* were inactivated by 2.5, 1.5, and >1.0 log units, respectively (Figure 5) (Choi *et al*., 2016). Similarly, The CDPJ treatment for 10 min did not exert significant changes in TVB-N and TMA content of semi-dried squid as compared to untreated controls. Also, CDPJ-treated

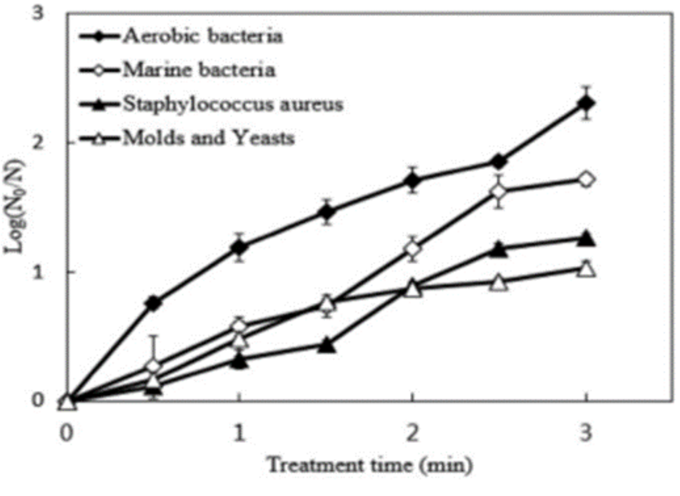

Figure 5. Log reduction of microorganisms on dried Alaska pollock shreds by corona discharge plasma jet treatment (Choi *et al*., 2016)

samples displayed slightly better sensory properties than the controls in terms of appearance, visual colour, and flavour (Choi *et al*., 2017a). This technology can readily be applied to commercial dried squid and other dried seafood processing.

2.9 High hydrostatic pressure

High hydrostatic pressure **(**HHP) is a non-thermal processing technology used in various food processing (Yordanov and Angelova, 2010). It has been reported that HHP treatment and brining significantly increased the total colour difference, and the HHP and the brine-treated group scored significantly higher than the others in terms of sensory evaluation. The HHP treatment combined with brining could have a significant effect on the quality characteristics of the semi-dried Silver Pomfret (*Pampus argenteus*) (Kim *et al*., 2014). A similar result reported that the HPP of semi-dried squid was lower microbial growth, dimethylamine (DMA), TMA and biogenic amines than the control group for 28 days at 4°C (Gou *et al*., 2011). Thus, HPP could be a good approach to extending shelf life and improve the microbiological safety of semi-dried seafood.

2.10 Packaging methods and materials

Proper packaging protects the fish from contact with air and thus it prevents lipid oxidation and other cross-contamination and extends the shelf life as well (Remya *et al*., 2018). Technological advancements are directly reflecting the consumer's ever-increasing demand for healthy, safe and quality food products. There are many packaging methods for dried fish such as traditional packaging, modified atmosphere packaging, vacuum packaging etc. Major active packaging systems include oxygen (O_2) scavengers, carbon dioxide (CO_2) emitter/absorbers, moisture regulators, antimicrobial packaging, antioxidant packaging, ethylene absorbers and flavour releasing and absorbing systems (Solanki *et al*., 2019). Debbarma *et al.* (2019) investigated the shelf life of dried *H. toli* in transparent (TP), opaque (OP) and vacuum packaging (VP) was found to be 120, 150 and more than 210 days, respectively under ambient temperature. A relatively high TMA-N value was found in the air-packed sardine sample as compared to vacuum-packed and oxygen scavengers (Solanki *et al*., 2019). Oxygen scavenger-packed dried marine fish is comparatively better than air-packed and vacuum-packed samples. It was observed that the active packaging using oxygen scavenger in the packaging of dried fish, may assure an effective packaging for dried fish, quality for long-term storage (Corzo *et al*., 2006). A gradual increase in TVB-N value was observed in air and vacuum-packed samples during storage, however, the values were comparatively lower than that of the control sample (Chowdhury *et al*., 2020). The APC value gradually increased in all packaging types throughout the study period but comparatively lower APC was observed in vacuum and nitrogen-packed samples than in control samples throughout the storage period (Chowdhury *et al*., 2020). Similar results were also found by Nitipong *et al.* (2014). Various packing materials such as cardboard boxes, gunny bags, polythene bags, bamboo baskets, waxed corrugated cartons, dead wood and ply wood boxes and plastics can be used during the storage of dried fish (Sam *et al*., 2015). Multilayer plastics such as a combination of polythene (gas barrier) and polyamide, can be used to protect products from moisture and oxygen and thus may increase the shelf life (Dixon, 2011). Dried fish remained in good condition for a long time when stored in films of high gauge (Chowdhury *et al*., 2020). This is mainly because of the low water vapour transmission rate and oxygen transmission rate, which decrease with an increase in thickness. Dried fish having a pH range of 6.0-6.9 are considered to be of very good quality. The pH value of dried fish increased with the increase of storage time due to the increase of basic compounds, indicating the loss of quality of the product. The highest value of pH at the end of storage days observed in air pouch-packed sun-dried samples was 7.70 for sardine (Mannar and Farag, 2013). However, if packaging and storage techniques are combined and applied in an innovative way, fishery products with high-quality, good sensory properties and a beneficial nutritional value might be achieved (Sampels, 2015). In another study, a packaging system of green tea extract (GTE)-incorporated poly vinyl alcohol (PVA) films were applied to package dried eel and the quality of dried eel was evaluated during storage. The result showed that dried eel packed with GTE-incorporated PVA films showed lower weight change, PV and TBARS values during storage than that packed without PVA films or with PVA films but no GTE (Figure 6). Moreover, PVA film containing 2% GTE showed the best quality

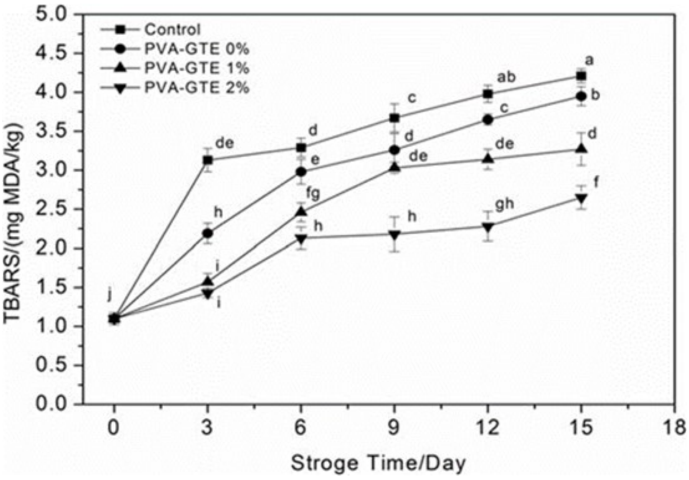

Figure 6. Effects of different packaging systems on the TBARS value of dried eel. PVA means polyvinyl alcohol incorporated with green tea extract (GTE) (Chen *et al*., 2017)

protective effectiveness to prevent the dried eel from absorbing moisture and oxidizing lipid (Chen *et al*., 2017). Therefore, it is clear that the moisture-absorbing agents and antioxidants can be incorporated into the packaging structures to develop an active multifunctional food packaging material that potentially removes or reduce moisture inside the food packaging system instead of desiccants and preservatives added to the food. A disadvantage of vacuum packaging is that some dried fish have sharp, hard points and edges, which puncture and rip the plastic or polythene bags, thus allowing air moisture, dust, and insects to spoil the fish. Packaging of cured fish poses a problem because of the irregular shape and sharp protrusions.

To overcome this problem, dried fish can be packed in multi-layered, white-coloured (non-transparent) pouches (polythene/polyamide) having low moisture and oxygen permeability. Thus, proper packaging could be an alternative to reduce the quality deterioration of these dried products.

2.11 Storage condition and storage temperature

Dried fish can be stored for months in a proper way of storage. Otherwise, physical, chemical, biological and nutritional quality will deteriorate, and the product will lose its acceptability for consumption. Open storage of dried fish encourages attack by mycotoxin-producing fungi insect infestation, sensory properties and nutrient degradation which translate into post-harvest fish losses (Sam *et al*., 2015; Getu *et al*., 2015). The nutritional value and quality of dried products decrease with the increase in storage period (Siddique and Aktar, 2011; Majumdar *et al*., 2018). In dried shoal, protein content was found at 41.48%, and 41.0%, in fresh process conditions and after completing the duration of the storage period and the value was decreased to 38.62% (165 days) (Farid *et al*., 2014).

The modified frozen storage (-20°C) of dried herring gave the highest storage yields and higher sensory scores than the other (polyethylene bags at ambient temperature with and without desiccant, the traditional and a modified oven storage technique) storage methods (Plahar *et al.*, 1991). Storage in polyethylene bags at ambient temperature was ineffective, while the inclusion of desiccant only delayed total decomposition beyond one month (Plahar *et al*., 1991). pH and TVB-N values indicated that oven-dried blue stripe herring were still good in fresh condition even after 6 months of storage at -20°C. Frozen storage is still considered the best method for mitigating quality changes of blue stripe herring (Sung and Haryono, 2017). Dried mackerel showed an increase in biochemical values as a result of the decomposition of lipid and nitrogenous substances and a decrease in sensory scores when stored at ambient temperature for 120 days (Chavan *et al*., 2011). Similarly, PV, acid value, and conjugated dienes of the lipids and microbial load increased significantly during 90 days of storage at an ambient temperature of dried *M. vitatus* and *T. faciata* and these products could be consumable for up to two months (Majumdar *et al*., 2018; Rasul *et al*., 2019). The water reconstitution capacity of the dried fish decreased slowly during the storage period due to a slow increase in moisture content in the fish (Jahan *et al*., 2018; Majumdar *et al*., 2018). Moisture uptakes during the storage period are significant in the dried *Labeo gonius* stored in gunny bags as moisture absorption in such products is obvious during monsoon due to high RH difference, which makes the product susceptible to insect infestation and reduces the sensory and microbiological load with the increase of storage period (Kumar *et al*., 2013). Quality deteriorations such as lipid hydrolysis that influence the formation of oxidation products to occur during storage of dried fish cause brown discolouration, unpleasant flavour and odour in the product, reduction in the nutritive value and affecting consumer acceptance (Zhu *et al*., 2016; Majumdar *et al*., 2017; Remya *et al*., 2018). Proper storage conditions and storage temperature can reduce the loss of nutritional, microbial and physical quality loss. Otherwise, the products might be harmful to human health. Insect and mould attack was monitored during the storage period (Mohamed *et al*., 2011). The recommended storage conditions are < 60% RH and temperature from 0-10°C; low oxygen levels of 0.5% (Nowsad, 2007). Dried fish should be stored in a well-ventilated separate room from other food products. Viji *et al.* (2021) found that the microbial and fungal growth was lower in 1% carboxymethyl chitosan (CMCH) treated dried anchovy than in 0.5% CMCH treated and control samples. The CMCH also reduced lipid oxidation during the storage of dried anchovy. Therefore, the edible coating of 1% CMCH has effectively controlled the spoilage changes in dried anchovy during storage.

3. Conclusion

The results of this review revealed the quality of raw materials, pre-treatment of raw materials, drying methods, use of additives, extrinsic factors, irradiation, cold oxygen plasma, corona discharge plasma, high hydrostatic pressure treatment, packaging methods and materials, storage condition and temperature of dried products have a great influence on the quality, safety and shelf life of dried fishery products. To reduce quality loss of dried fishery products, excellent quality raw materials with vacuum drying, oven drying, solar tunnel drying with different pre-treatments of chlorinated wash, bleeding, gutting, blanching, ultrasound and treatment with various plant extracts such as clove, *M. oleifera,* tea polyphenol and salt along with clove extract have a broad potential application for the improvement of quality and safety of the dried products. Moreover, various chemical preservatives have also been found to be effective in increasing better organoleptic scores of the products although they have potential carcinogenic and toxic effects on human health. Drying temperature and relative humidity should be below 60°C and 10–40%, respectively to prevent loss of nutrients, quality and consumer acceptability. Multilayer plastics, polyethylene films of high gauge, poly vinyl alcohol film containing 2% green tea extract along with vacuum packaging and oxygen scavenger packaging ensure the best quality protective effectiveness to prevent the dried fishery products from absorbing moisture and oxidizing lipid. Recommended storage conditions for dried products are <60% relative humidity and temperature from 0-10°C; low oxygen levels of 0.5%. Low-dose gamma irradiation (<5 kGy) reduces microbial loads, extends the shelf life and improves the taste and texture of dried fish. Ultraviolet light treatment, 10 mins cold oxygen plasma treatment, 3 mins atmospheric plasma treatment, corona discharge plasma (0-3 mins) and high hydrostatic pressure effectively inactivate the microbial contaminants from dried fishery products with better sensory properties. Therefore, the factors discussed in this review should be considered during the production of dried fishery products at the industrial level to ensure the best quality for consumers' safety.

Conflict of interest

The authors declare no conflict of interest.

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