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A review on the physicochemical and nutritional changes influenced by the drying techniques and the processing of dried fish

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Abstract
Fish processing occurs internationally through both traditional and non-traditional methods. In the Philippines, traditional techniques are rooted in a long nutritional culture, while modern methods are gaining popularity. Fish and fishery products are vital for nutrition and food security, but overfishing and post-harvest loss pose challenges. Drying is a common method, transitioning from sun drying to cabinet-style dehydrators. Quality relies on proper drying conditions and raw material quality. Factors like pesticide use, drying temperature, cleanliness, and storage affect quality. The texture, color, and microbiological aspects of a product are influenced by gutting, salting, and diverse drying methods. Additionally, the use of both natural and synthetic additives, along with antioxidants, plays a crucial role in preserving the quality of the product. Nutritional and sensory characteristics are influenced by fish species, environment, and drying methods. Understanding these dynamics is essential for maintaining fish quality and nutrition during processing.

Keywords: Additives, drying, fish, physicochemical

1. Introduction
Fish is one of the most traded commodities, and this commercial activity takes place on a variety of scales [1]. Most fish processing is done by individuals who work in the artisanal sector. Fish that has been dried, salted, fermented, and smoked are the primary exports [2]. The term "fish processing" refers to the series of procedures that take place with fish and fish products in the period between when the fish are caught or harvested and when the final products are sold to consumers [3]. The goal of processing and preserving fish is to deliver fish in usable condition to the final consumer. The necessary stages commence prior to the fishing exploration and continue until the fish is consumed or processed into oil, meal, or animal feed. Many fish and fishery products are consumed locally, and are typically eaten fresh, chilled, or in some other kind of preparation [4]. The purpose of fish processing and preservation is to deliver fish that is consumable to the final consumer [5].
There are two types of fish processing techniques distinguished: traditional and non-traditional. Traditional methods of fish processing are limited to smoking, curing, and salting, whereas nontraditional methods include chilling, freezing, and canning. Within the value chains of small-scale fisheries, conventional processing techniques are typically utilized with minimal facilities and services and low-cost technology [6]. Non-traditional processing techniques, such as canning, freezing, and chilling, are typically employed in factories with high capital expenditures and in international trade. Traditional fish processing techniques (TFPTs) are extensively used throughout the globe, particularly in Asia, and include curing, salting, pickling/marinating, and smoking, which differ only in terms of the final product and a few variations [6].

Fishery products are the primary source of protein in the Philippines, with each Filipino consuming approximately 37 kg of protein per year [7]. About 78% of these are fresh fish, while 22% are processed fish such as smoked/canned, dried, and preserved fish [8].Traditional fish processing is prevalent in the country particularly in impoverished families [6]. Philippines' fish processing industry adopted modern processing techniques to supply a tremendous quantity of preserved products across the country and for export.

1.1. Different Drying Conditions and Effect on Fish Quality

Drying is one of the ancient methods of preserving fishery products [9]. Drying generally means removing water from the fishery products either by means of evaporation or other techniques [10]. Traditional drying is often conducted in rural locations in unsanitary conditions, which frequently results in microbial contamination. Aside from a lack of sanitation, pollutants such as air, dust, polluted water, and dirt are the biggest drawbacks of this old process on the quality of dried fish [11]. Species of major halotolerant bacteria such as *Staphylococcus*, *Vibrio*, and *Pseudomonas* have been identified in dried fishes. Halotolerant bacteria are those that can survive and grow in conditions with both low and high salt concentrations [12]. Previously mentioned bacteria are both gram-negative and gram-positive bacteria that are identified in dried fish.

Typically, when it comes to bacteria found in food, Gram-positive strains tend to have a higher tolerance to salt compared to Gram-negative ones [13]. The resistance of Gram-negative bacteria to various salt solutions and antibiotics is largely attributed to their outer membrane [14]. Gram-positive bacteria, on the other hand, do not possess this crucial barrier, making Gram-negative bacteria more resistant than Gram-positive counterparts [15]. Drying fishery products at below 15% moisture content (MC) hinders spoilage from numerous microorganisms while drying products at 10% MC can entirely suppress the growth of molds, thereby extending the shelf-life. In the Philippines, the drying of fishery products is the most famous traditional fish processing techniques among coastal villagers, especially when caught fish landed does not fall into the category of fresh fish due to a lack of sufficient cold storage facilities [10]. The traditional drying technique in the Philippines is either contact or air drying (sun drying) or drying with the use of salts as an additional flavor and preservative agent. Whole or round fish and split-salted fish are the two types of dried fish widely done in the Philippines [17].

Dried fishery products are not only consumed locally by Filipinos but are also exported to other nations including the United States of America and Canada [6]. Small fish with scales, such as anchovies and other tiny scaly fish, are one of the most common types of fish that are dried and sold [18]. To increase the shelf life of dried fish in the Philippines, a more modern drying technology was evaluated versus conventional sun-drying and revealed that cabinet-type dehydrators generated the highest quality dried product [6].

2. Factors Influencing Dried Products

Product quality and nutritional value are affected by several factors. Inadequate infrastructure, inappropriate drying methods, negligence, and/or unawareness of proper handling and transportation of raw materials and final products are these issues. Quality and nutritional value are lost due to pesticide usage, wrong drying temperature and length, unclean circumstances, inadequate sanitation, excessive moisture content in the final product, low-quality raw materials, and improper packing and storage [11].

2.1. Quality of raw materials

Spoilage on fish happens quickly at room temperature. As a result, various preservation procedures should be used to protect the quality of raw fish immediately after harvesting for subsequent processing. Sun-drying is used to preserve a wide range of freshwater fish and seafood across the globe. Temperature, handling habits, and the initial microbial load all have an impact on the quality of fish [19]. The freshness of the fish before processing is a critical aspect in creating high-quality dried fish. It is generally recognized that the ultimate quality of any product is heavily dependent on the quality of raw materials, and if the quality of raw materials deteriorates, there is no way to improve the quality by any sort of preservation [20].

The issues related to the degradation of quality are likely attributed to substandard water quality, insufficiently insulated storage facilities, and a lack of attention to quality awareness. Additionally, prolonged exposure of harvested fish to higher ambient temperatures, as well as unhygienic handling and transportation practices, contribute to the spoilage of fish [21]. The use of partially spoiled fish and the loss of freshness of raw materials prior to drying are two primary causes of the quality loss in dried goods [20]. Therefore, to make dried fish of an exceptional quality, fishermen and processors need to preserve the quality of the raw materials of fish by maintaining adequate cleanliness, handling procedures, and keeping the raw materials in a cold and frozen state [22].

2.1. Pre-treatment of raw materials

Bleeding and gutting procedures carried out in fish processing are efficient because removal of enzymatic activity, which is one of the important factors for the quality deterioration and spoilage of fish [23]. Moreover, drying time and deteriorative changes could be reduced if the fish were gutted and salted properly prior to artificial drying [24]. 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 [25]. 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 [19]. The gutting process, therefore, destroys the reservoir of these digestive enzymes and bacteria there by reducing the process of autolysis in fish [22].

2.1. Other drying processes

For nutritional, chemical, and microbiological data, mechanical drying, oven drying, solar tent drying, solar tunnel drying, low-temperature vacuum drying, and freeze-drying all produce goods of higher quality than conventional sun drying, open rack drying, and enhanced drying methods [22]. However, [24] emphasized that the product quality and shelf life were both improved by the electric oven drying procedure. Protein quality may be enhanced and lipid oxidation may be prevented by electric oven drying [26]. Additionally, it was shown that the choice of drying techniques is influenced by factors such as price, specific business requirements, or product quality [23]. Micro-oven dryers and vacuum dryers are occasionally thought to provide dryers of higher quality; however, they are not economical [27]. However, even though it depends on sunshine, a solar tunnel dryer is seen to be a cost-effective technique [22].

2.1. Use of additives

To prevent lipid oxidation in food systems, synthetic antioxidants that are readily accessible on the market are frequently utilized. Examples include butylated hydroxytoluene (BHT), tert-butylhydroquinone (TBHQ), and butylated hydroxy anisole (BHA) [28]. In contrast, studies have questioned their use in food due to their probable toxicity and carcinogenic consequences [29].

2.1. Synthetic and chemical preservatives

Fish that has been dried and salted may include chemical preservatives such sodium sorbate, calcium sorbate, and potassium sorbate (200 mg/kg maximum alone or in combination expressed as sorbic acid) [30].

2.1. Natural preservatives

The polyphenols or phenolic compounds present in the plant are the much important natural antioxidants and phenolic extracts from vegetables, cereals grains, fruits, and spices had positive effects in preventing lipid oxidation. Natural preservatives should, ideally, have wide bactericidal and fungicidal properties, be non-toxic, be active at low concentrations, not impart any taste or color to food, not have any pharmaceutical uses and inexpensive.

To create a high-quality product, raw fish is traditionally soaked in concentrated solutions containing salt or other curing chemicals that might saturate the muscle [31]. The study conducted by [32] revealed that the utilization of the salt and turmeric treated drying method has a notable impact on the chemical and mineral composition of freshwater fishes. Additionally, this method was found to effectively decrease the bacterial load present in the fishes, thereby rendering them nutritionally appropriate for consumption. In addition, the combination of the juices of garlic and ginger used as a pretreatment helps to enhance the nutritional and sensory quality of dried foods while also lowering the number of microorganisms present [33]. According to the researches conducted, it has been observed that various plant extracts, including tea extracts, exhibit positive effects on dried products. Specifically, tea extracts have been found to possess the capability to inhibit the development of food-borne pathogens such as *Staphylococcus aureus, Shigella disenteriae*, *Vibrio cholerae*, *Campylobacter jejuni*, and *Listeria monocytogenes*. Although one may draw the conclusion that some artificial preservatives have beneficial effects on dried fish, even though these effects cannot be compared to the effects of natural antioxidants [23].

3. Physicochemical changes

3.1. pH

The pH level serves as a measure of the degree of microbial spoilage in fish. Certain proteolytic microorganisms generate acid because of carbohydrate decomposition, consequently elevating the acidity of the surroundings [34]. The assessment of the pH of dried fish products can serve as an indication for a number of factors throughout the drying process. The pH level of freshwater fish flesh in its natural state is approximately neutral [35]. After the fish has died, the breakdown of nitrogenous substances causes an elevation in pH in the flesh of the fish. This happens throughout the post-mortem period [36]. The addition of salt to fish results in a decrease in pH value because of an increase in acidic compounds. Subsequently, during the shelf-life study, the pH value increases over time due to an increase in basic compounds [37]. The fish products are regarded acceptable up to a pH of 6.8, but deteriorated above pH 7.0 [38]. Moreover, 6.8 to 7.0 is typically the acceptable range [39].

However, dried fish with a near neutral pH are thought to be more appetizing than dried fish that is extremely acidic or quite basic [34]. Different dried fish species often have varying associations between flavor and pH. The methods used for salting and drying the fish might modify its pH, which in turn can impact how many microorganisms are present in the dried fish. It is therefore a reliable predictor of the level of spoiling [40]. So, while the various drying techniques do affect the pH of the fish, the pH of dried fish is more influenced by the salting process. Salted sun-dried fish products exhibit the combined effects of the salting and drying techniques.

3.2. Water activity, a_w

During processing and storage, a_w determines the product's microbiological and chemical stability. Although it is not always the case, the moisture level of a dried fish product can be correlated with its water activity [41]. According to study, even though drying lost more water than salting did, the a_w at the conclusion of the procedure was comparable to flourish on the dried

fish, each microbe needs a certain a_w [42]. Controlling this parameter is therefore a key step in assuring the safety of dried fish. Most bacteria require a_w greater than 0.85 to multiply, whereas yeast and fungus may proliferate at a_w as low as 0.61. At a_w less than 0.60, almost little microbial growth may occur. As a result, a_w in the range of 0.85-0.60 is ideal for dried fish [43].

3.3. Lipid oxidation

The lipid oxidation of dried fish products is influenced such as drying temperature, whereas with higher temperatures ranging from 50 to 70 °C, it could lead to reduced lipid oxidation. In addition, the duration of storage also exerts a substantial influence on the process of lipid oxidation in dried fish products [43]. The study conducted [17] places emphasis on the impact of storage duration on lipid oxidation, regardless of any treatments applied to the dried fish. This effect might be explained by the fact that the longer dried fish is exposed to ambient oxygen, the higher the contribution to the rise in lipid oxidation during processing and storage.

3.4. Color

One of the first elements that influences product acceptability is the color of the dried fish, which is a significant visual indicator of quality [43]. The most browning was seen in conventionally sun-dried fish, followed by hot air drying, solar conduction drying, and finally freeze-drying, in a comparison between these methods and sun-drying, freeze-drying, and solar conduction drying. The hypothesized factor is the non-enzymatic browning processes, which are aided by high temperatures, such as the Maillard reaction and protein-lipid oxidation reactions [43]. Enzymatic and nonenzymatic oxidation develop browning. Food spoils during storage and processing due to amino compound reactions with reducing sugars, vitamin C, and quinones (nonenzymatic browning, also known as Maillard reaction). Enzymatic browning of fish that has been dried depends on phenolic chemical concentrations, temperature, pH, and tissue oxygen availability [44]. Provided below is the summary of the physicochemical changes and recommended ranges for dried fish (Table 1).

Table 1: Summary on the ecommended cal changes and ecommended ranges for dried fish

PHYSICOCHEMICAL CHANGES	IDEAL RANGE	ACCEPTABLE
pH	6.8-7 pH	6.8 pH
Water activity (a_w)	0.85-0.60	<0.60
Liquid oxidation	-	-
Color	-	Yellow-brownish

4. Proximate composition and nutritional changes

4.1. Moisture

The procedure of drying fish, which typically entails drying and salting, has a significant effect on the fish's moisture content [43]. This suggests that pure water is more readily lost during evaporation as fish dries, thus contributing to the decrease in moisture content [45]. Various drying techniques are used to reduce the fresh fish's moisture content in order to accomplish the appearance and qualities of desiccated fish [24]. Number of studies have been conducted to compare these drying techniques and identify methods that can reduce moisture content more effectively and efficiently. After drying, the moisture content of each dried fish decreased significantly. The ideal amount of moisture for dried fish, regardless of the species, is between 7.0 and 50.0% [43]. In general, a quicker drying time for dried fish needs a greater drying temperature. Sun drying is the traditional technique for drying fish, and it has been proved to reduce the level of moisture [40]. Despite this, the contamination of open-air drying by flies and insects has become a safety concern as some individuals have used organochlorine insecticides [46]. While the fish are drying in the sun, one solution involves covering them with a nylon mesh or a mosquito net to prevent contamination from the outside, bird attack, and fly infestation [37]. A smoking oven, which is also commonly used for fish drying. This technique can reduce the moisture content of dried tilapia to as low as 15.30% at a lower temperature than conventional furnaces [43]. The other species are presented in Table 2, which presents the various species in accordance with the various drying processes. However, the drying time is typically between 10 and 24 hours, which is longer than higher-temperature drying methods [47].

When fat is oxidized, it undergoes both physical and chemical changes. From the research done by [24], the most noticeable changes in tilapia fish after drying were a decrease in moisture and an increase in protein, lipids, vitamin A, potassium and phosphorus content. The amount of moisture, protein, lipids and vitamin A in treated samples rose considerably. In the study of [48], salted dried fish has a substantially greater average moisture content than unsalted dried fish. This is because the salting process involves the expenditure of fluid from within to outside the body of the fish as a result of the introduction of salt crystals into the flesh of the fish [22]. The liquid in the fish flesh will then dilute the salt solution. The salt solution will seep into the fish flesh until the osmotic pressure equilibrium between the fluid outside and within the fish flesh is reached [43].

Table 2: Proximate composition of various fish species and its respective drying technique [43].

Type of Fish	Drying Technique	Moisture (%)	Lipids (%)	Protein (%)	Ash (%)	Carbohydrates (%)
Catfish (*Clarias gariepinus*)	Electric oven	15.62	29.60	67.21	3.62	3.84
	Smoking kiln	28.92	21.20	53.10	3.92	2.78
	Smoking kiln (developed by NSPRI)	7.30	12.50	68.4	6.40	1.80
Indian mackerel *Rastrelliger kanagurta*	Hot air	31.11	5.28	43.38	17.0	N/A
	Microwave vacuum	32.45	4.02	44.53	21.61	N/A
Shoal/shol (*Chana striatus*)	Sun dry, salting as pre-treatment	29.77	5.10	41.48	22.80	N/A
	Dry salting	48.84	3.99	28.21	18.89	N/A
Yellow croaker (*Larimichthys polyactis*)	Hot air	47.08	14.67	31.32	3.74	N/A
	Low temperature vacuum	38.56	12.56	41.48	6.26	N/A
	Freeze dry	47.38	13.43	33.54	4.02	N/A
Iridescent shark catfish (*Pangasius hypophthalmus*)	Mechanical (kiln) at 60 ºC	13.50	15.31	65.16	4.38	N/A
	Sun dry (unsalted)	14.59	15.17	63.39	5.22	N/A
	Sun dry (salted)	15.36	9.32	55.53	18.72	N/A
Nile tilapia (*Oreochromis niloticus*)	Smoke dry at 60 ºC (15 h)	15.30	12.35	49.40	21.61	N/A
	Smoke dry at 70 ºC (10 h)	17.95	7.85	56.70	18.52	N/A

The Table 2 shows how different ways of drying fish affect their nutritional content. For example, catfish can have more or less water, fat, and protein depending on whether it's dried in an electric oven or a smoking kiln. The same goes for other fish like Indian mackerel, shoal, yellow croaker, iridescent shark catfish, and Nile tilapia. These differences in drying methods influence not just moisture, fat, and protein but also other parameters like ash (minerals) and carbohydrates [43].

4.2. Lipid

Due to a various factor, the nutritional composition and, consequently, the lipid content of fish varies widely. Variations in fish species, ecological conditions, fishing season, size, status, and aquaculture nutrients are among these factors [37]. In addition, fish can be classified according to their lipid content; fish with less than 5% lipid are considered slender, while fish with more than 5% lipid are considered fatty or oily [47]. Still, fish is considered a healthy source of fat, as it provides essential dietary fatty acids such as eicosatetraenoic acid (EPA) and docosahexaenoic acid (DHA), which are n-3 polyunsaturated fatty acids (PUFA) [49]. Therefore, it is necessary to analyze the crude lipid content of the fish in order to recommend an appropriate intake of nutrients, in this case lipid, within the range of the daily requirement and to determine the most effective packaging method for an extended shelf life [50]. As part of the proximate composition analysis, the measurement of crude or total lipid in fish is represented as a percentage. In general, the drying procedure used to prepare dried fish causes a significant increase in lipid content [43].

4.3. Protein

The process of salting dried fish has a significant impact on the protein content of the fish as a result, salted sun-dried fish has a lower protein level than unsalted sun-dried fish [24]. This is because salting removes some of the moisture from the fish [40]. This effect is due to the addition of salt to the dried fish, which caused the proteins in the fish muscles to enlarge and deteriorate [43]. Compared to freeze-drying and heated air-drying, low temperature vacuum drying resulted in the highest fish protein content after drying [51]. Several research articles suggest that this is due to the retention of protein and nitrogen during drying [50]. Normally, the sun-dried fishes contain 60% to 80% protein [52]. This may also be caused by the dehydration of water molecules present between protein molecules, which led to the aggregation of protein molecules. Several variables can affect the fish protein content during and after drying and storage [24]. Temperature, the addition of salt, storage conditions, and packaging methods are a few of the causes of the fluctuations in protein content observed during drying and storage [43].

4.4. Ash

Ash is the inorganic residue remaining after complete oxidation or combustion of the organic components of a food sample [53]. Ash content is a proximate composition that is typically analyzed in food quality evaluations [40]. To analyze the ash content, the fish is burned, the organic matter is removed, and the inorganic matter that remains is white ash, ash analysis is essential because it measures the mineral content of food [54]. As such, it is the first stage in preparing a food sample for a specific elemental analysis, such as one for highly toxic heavy metals for essential nutrients [43]. In general, after drying, the ash content of fish increased, and the inclusion of salt enhanced this increase. Comparing salted dried fish to unsalted dried fish, salted dried fish has a higher ash content [37]. The ash content of specific dried fish may be elevated due to variations in drying conditions [43]. According to [51], when comparing different drying methods such as freeze drying, kiln drying, and electric oven drying, it can be observed that fish dried outdoors, particularly through sun-drying, exhibits a higher ash content following the drying process.

Also, fish that was sun-dried in an open area contained more ash than fish that was dried in a closed system

[40]. Therefore, the increased quantity of ash in dried fish can be attributed to salinity and air exposure. Several studies have suggested that the increased ash content was the result of substantial water loss due to the presence of salt, which increased the quantity of water extracted by the drying process [43]. Furthermore, the higher ash level of certain dried fish may be due to the drying conditions [47]. When several research' drying approaches were compared, fish dried in the open, predominantly sun-dried fish, had greater ash levels after drying than methods utilizing closed systems, such as freeze drying, kiln drying, and electric oven drying [24].

4.5. Carbohydrates

Aside from the percentage of carbohydrates in dried fish, there are surprisingly few studies focusing on the carbohydrate content (Table 1) [55]. Carbohydrates are typically present in fish in small quantities, as proteins are typically the most prominent nutrient in dried fish. However, carbohydrate still required as a nutritional food source [43].

4.6. Vitamins

According to [56], the dried products from small fish exhibit a low cholesterol content, while notably being abundant in essential vitamins and minerals such as iron, calcium, and phosphorus. Dried fish contains numerous minerals that give health benefits on the product. Additionally, the drying process is crucial for preserving the mineral content of fish. Vitamins, for instance, can be easily degraded by high temperatures and sunlight, particularly vitamin A in sun-dried small fish. Vitamin A degrades more rapidly in direct sunlight than at high temperatures. In addition, vitamin C was present in dried tilapia fish and exhibited no significant changes between fresh and dried states [43].

Provided below (Table 3) is a more comprehensive table for physicochemical and nutritional changes in dried fish during the drying process along with the influence of different drying techniques.

Table 3: Summary of the physicochemical and nutritional changes in dried fish

Parameter	Changes during drying	Influence of drying techniques
Moisture content	Decreases as water is removed	Varied rates depending on method (sun drying air drying, freeze-drying)
Nutrient retention	Loss of water-soluble vitamins	Vacuum drying may better preserve some nutrients
Lipid oxidation	Increased risk due to exposure to air and heat	Freeze-drying and vacuum drying may reduce lipid oxidation
Protein denaturation	May occur, impacting texture and digestibility	Gentle drying methods like freeze-drying may minimize protein denaturation
Color changes	Browning due to Maillard reactions	Sun drying can lead to pronounced color changes
Texture	May become harder or brittle	Freeze-drying tends to better preserve the original texture
Nutrient concentrations	Increase due to moisture loss	Vacuum drying may help retain higher nutrient concentrations
Shelf life	Generally extended due to reduced moisture	Freeze-drying provides longer shelf life due to minimal moisture content

It's critical to understand that the efficacy of drying procedures varies and the method used is determined by criteria such as desired product quality, available resources, and the species of fish being processed. Technological and processing advancements may continue to improve the nutritional quality of dried fish [26].

5. Sensory Characteristics of Dried Fish

The sensory characteristics of a product can be assessed using a testing technique based on the sensing process, physio-phycological process, or recognition of the human senses as the main appliance for determining its acceptability [43]. Sensory characteristics can be measured via color, odor, texture, flavor, appearance, palatability, insect invasion, and overall acceptability on the products [57]. Measuring sensory characteristics in fish drying are crucial to determine and maintain the quality of the products. Preferable parameters of a dried fish have been suggested to indicate the better quality of the products.

Fish dried using solar tunnel drying method showed the most desirable overall acceptability score. Fish dried using traditional sun drying method obtained the least desirable sensory score, and exhibited a poor color, texture, and odor quality compared to solar tunnel drying [58]. Meanwhile, the fish dried using improved drying method obtained a more desirable overall acceptability sensory score.

5.1. Appearance

Appearance is the first characteristics perceived by the human senses and play an important role in the identification and final selection of food [59]. This is the visual perception of food comprised of color, shape, size, gloss, dullness and transparency [60]. The appearance of a food has shown impact on appetite stimulation or depression resulting in pleasure or total depression. The look of a food or beverage impacts crave ability and acceptance, before the product touches the lips. This is because people eat with their eyes before they ever smell or taste [60]. [48] claimed that during the drying process, the air transmits heat into the food, causing the water to evaporate and the food to be released into the environment. Heating causes protein denaturation and reduces meat's water retaining

ability. The texture of fish muscle fluctuates depending on the raw ingredients, drying procedures and drying factors such as temperature, air velocity, and relative humidity of the air in the drying chamber [61].

Drying modifies the surface properties of food, resulting in changes in reflectivity and color induced by heat and oxidation during the drying [62]. The hardness, color, and general quality of salted dried tilapia were discovered to be influenced by process factors such as salting time, drying time and temperature [12]. Textural alterations are caused by the loss of water and changes in the proteins and lipids of the fish muscle throughout the drying process [24]. Moreover, according to [63], salting and drying caused lipid oxidation in fish by concentrating unsaturated fatty acids and acting as a pro-oxidant.

5.2. Texture

Texture is perceived by a combination of senses touch, mouthfeel, sight and hearing [59]. Texture is one of the most important characteristics of a food product and a condition for the acceptance of many different goods [43]. When fish is dried, one of the most noticeable changes that takes place in its physical appearance is that its texture transforms, becoming firmer and harder [26]. The degree to which these changes take place is influenced not only by the temperature but also the length of time spent in the pre-treatment stage and the drying technique [22]. The elevated temperature experienced by the material during the drying process results in a range of irreversible biological or chemical reactions, as well as structural, physical, and mechanical alterations. These modifications encompass phenomena such as coloration, crust formation, diminished sensory quality, deactivation of bacteria and enzymes, nutrient and aroma loss, and alterations in shape and texture [1].

6. Conclusion

Drying techniques significantly impact dried fish by altering its texture, color, and chemical composition. Physicochemical changes include moisture reduction affecting proteins and lipids, leading to variations in flavor and aroma. Nutritional changes involve concentration of nutrients and potential loss of essential vitamins and minerals. Optimizing drying processes is essential for preserving both the sensory and nutritional quality of dried fish. The findings of this article demonstrated that the quality of raw materials, pre-treatment of raw materials, drying processes, and additive use all have a significant impact on the quality, safety, and shelf life of dried fisheries products. Fish processing processes are critical for a country's food security and economic growth.

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