



Faculty of Resource Science and Technology

Hybrid Solar-Sun Drying and Canning: Sustainable Solutions for
Marine Fish Preservation and Community Development

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Hybrid Solar-Sun Drying and Canning: Sustainable Solutions for Marine Fish Preservation and Community Development

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



.....

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ABSTRACT

Fish is an important source of protein and nutrients, but due to its perishable nature, significant postharvest losses occur. Preservation techniques like drying and canning help extend its shelf life. Traditional drying methods are widely used but are often inefficient because of inadequate facilities, leading to spoilage. Additionally, to protect dried fish from pests, processors use harmful chemicals, making the product unsafe for consumption. The conventional drying process is also time-consuming, taking 6-7 days. The Hybrid Solar Dryer (HSD) presents a more sustainable and efficient alternative. It encloses the drying space, which reduces contamination and improves hygiene. With the integration of Internet of Things (IoT) technology, HSD allows real-time monitoring and enhances energy efficiency. This system ensures better product quality, supports continuous drying, and increases the potential for export, offering a safer and more consistent drying process for the fish industry. The marine fish churi (*Trichiurus lepturus*) and loitta (*Harpodon nehereus*) were dried using HSD and stored for nutritional, biochemical and microbiological quality analysis throughout the study period (365 days). The findings revealed that fish dried with HSD had higher sensory ratings (8.8 for churi and 8.6 for loitta) and kept the maximum protein content (62.8%) throughout storage. Furthermore, the approach greatly decreased microbial contamination, decreasing the Total Viable Count (TVC) with *E. coli*. Although canning is a commonly used method for preserving marine fish, no canning industry has been established in Bangladesh so far. In light of this, the present study developed a low-cost, household-level canning procedure along with suitable recipes. Hilsa (*Tenualosa ilisha*), the national fish of Bangladesh was chosen for canning, and its quality was evaluated throughout a year's storage. The canned hilsa (CH)

remained sensory acceptable for 365 days. The analysis of fatty acid (FA) groups showed that canned and raw hilsa differed significantly ($p < 0.05$), with a tendency for the sequence of MUFA > PUFA > SFA to decline. Furthermore, the fish were successfully sterilized using the Small-Scale Canning (SSC) technique, which stopped *Clostridium botulinum*-a frequent bacterial issue in canned fish from growing throughout the storage period. The comparative analysis of livelihood conditions highlights a complex link between socio-economic status and fish production practices. Fishermen with higher education and improved living standards are more inclined to adopt modern preservation methods and access a wider range of marketing options, suggesting a connection between socio-economic factors and production effectiveness. Despite this, many are dissatisfied with their current livelihood and are seeking ways to improve it. This study demonstrates that the nutritional, biochemical, and microbiological integrity of specific marine fish products may be effectively preserved using both the HSD and SSC approaches. Adoption of these techniques might transform Bangladesh's fishing industry, increasing exports and enhancing product quality as well as plays a significant role in coastal community development.

Keywords: Hybrid solar dryer, small-scale canning, fish preservation, sensory evaluation, proximate composition, microbial quality, fatty acid profile

Cara meningkatkan pendapatan komuniti pesisir pantai melalui pengeringan hibrid cahaya matahari dan pengetinan ikan laut berskala kecil

ABSTRAK

*Ikan adalah sumber protein dan nutrien yang penting, tetapi disebabkan sifatnya yang mudah rosak, menyebabkan berlaku kerugian selepas tangkapan dengan ketara. Teknik pemeliharaan seperti pengeringan dan pengetinan boleh membantu memanjangkan jangka hayat ikan. Kaedah pengeringan tradisional digunakan secara meluas tetapi selalunya tidak cekap kerana kemudahan yang tidak mencukupi, yang membawa kepada kerosakan. Selain itu, untuk melindungi ikan kering daripada perosak, pemproses menggunakan bahan kimia berbahaya, menjadikan produk tidak selamat untuk dimakan. Proses pengeringan konvensional juga memakan masa, mengambil masa 6-7 hari. Pengering Suria Hibrid (HSD) memberikan alternatif yang lebih mampan dan cekap. Ia menutup ruang pengeringan, yang mengurangkan pencemaran dan meningkatkan kebersihan. Dengan penyepaduan teknologi Internet of Things (IoT), HSD membenarkan pemantauan masa yang sebenar dan meningkatkan kecekapan tenaga. Sistem ini memastikan kualiti produk yang lebih baik, membantu pengeringan yang berterusan, dan meningkatkan potensi eksport, menawarkan proses pengeringan yang lebih selamat dan konsisten untuk industri ikan. Churi ikan laut (*Trichiurus lepturus*) dan loitta (*Harpodon nehereus*) telah dikeringkan menggunakan HSD dan disimpan untuk analisis kualiti pemakanan, biokimia dan mikrobiologi sepanjang tempoh kajian (365 hari). Penemuan mendedahkan bahawa ikan yang dikeringkan dengan HSD mempunyai penarafan deria yang lebih tinggi (8.8 untuk churi dan 8.6 untuk loitta) dan mengekalkan kandungan protein maksimum (62.8%) sepanjang penyimpanan. Tambahan pula, pendekatan ini telah mengurangkan pencemaran mikrob, mengurangkan Jumlah Kiraan Berdaya maju (TVC) dengan *E. coli*. Walaupun pengetinan adalah kaedah yang biasa digunakan untuk*

memelihara ikan laut, tiada industri pengetinan telah ditubuhkan di Bangladesh setakat ini. Sehubungan dengan ini, kajian ini telah membangunkan prosedur pengetinan peringkat isi rumah dengan kos rendah bersama-sama dengan resipi yang sesuai. Hilsa (*Tenualosa ilisha*), ikan kebangsaan Bangladesh dipilih untuk pengetinan, dan kualitinya dinilai sepanjang penyimpanan selama setahun. Hilsa dalam tin (CH) kekal diterima oleh deria selama 365 hari. Analisis kumpulan asid lemak (FA) menunjukkan bahawa hilsa dalam tin dan mentah berbeza dengan ketara ($p < 0.05$), dengan kecenderungan untuk urutan MUFA > PUFA > SFA menurun. Tambahan pula, ikan itu berjaya disterilkan menggunakan teknik Pengetinan Skala Kecil (SSC), yang menghalang *Clostridium botulinum*-isu bakteria yang kerap dalam ikan dalam tin daripada membesar sepanjang tempoh penyimpanan. Analisis perbandingan keadaan mata pencarian menonjolkan hubungan yang kompleks antara status sosio-ekonomi dan amalan pengeluaran ikan. Nelayan yang mempunyai pendidikan tinggi dan taraf hidup yang lebih baik lebih cenderung untuk menggunakan kaedah pemeliharaan moden dan mengakses pilihan pemasaran yang lebih luas, mencadangkan hubungan antara faktor sosio-ekonomi dan keberkesanan pengeluaran. Walaupun begitu, ramai yang tidak berpuas hati dengan kehidupan semasa mereka dan mencari jalan untuk memperbaikinya. Kajian ini menunjukkan bahawa integriti pemakanan, biokimia dan mikrobiologi produk ikan marin tertentu boleh dipelihara dengan berkesan menggunakan kedua-dua pendekatan HSD dan SSC. Penggunaan teknik ini mungkin mengubah industri perikanan Bangladesh, meningkatkan eksport dan meningkatkan kualiti produk serta memainkan peranan penting dalam pembangunan komuniti pantai.

Kata kunci: Pengering suria hibrid, pengetinan berskala kecil, pengawetan ikan, penilaian deria, komposisi proksimat, kualiti mikrob, profil asid lemak

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LIST OF ABBREVIATIONS

AC	Alternate Current
ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemist
APC	Aerobic Plate Count
BPM	Behavioral Perspective Model
BSTI	Bangladesh Standardization Testing Institute
CAP	Control Atmosphere Packaging
CD	Control Dried
CFU	Colony Forming Unit
DC	Direct Current
DGA	Dietary Guidelines for Americans
DHA	docosahexaenoic acid
EAA	Essential Amino Acid
EMB	Eosin-Methylene-Blue
FA	Fatty Acid
FAO	Food and Agricultural Organization
FFA	Free Fatty Acid
FIQC	Fish Inspection and Quality Control
GC-MS	Gas Chromatography-Mass Spectrometry
GDP	Gross Domestic Product
GO	Government Organization

HAD	Hot Air Dryer
HDPE	High-density polyethylene
HIS	hyperspectral imaging method
HPP	high-pressure processing
HSD	Hybrid Solar Dried
HUFA	Highly Unsaturated Fatty Acid
ICMSF	International Commission on Microbiological Specifications
IoT	Internet of Things
IPS	Instant Power Supply
LCPUFA	Long Chain Polyunsaturated Fatty Acid
LPG	Liquified Petroleum Gas
LSTM	Long Short-Term Memory
MAP	Modified Atmosphere Packaging
MC	MacConkey
MS	Mannitol Salt
MSA	Mannitol Salt Agar
MSE	Mean Squared Error
MUFA	Monounsaturated Fatty Acid
NB	Nutrient Broth
NCD	Non-communicable diseases
NEAA	Non-Essential Amino Acid
NGO	Non-Government Organization

OSD	Open Sun Drying
PCA	Plate Count Agar
PEF	Pulsed electric field
PUFA	Poly Unsaturated Fatty Acid
PV	Peroxide Value
RBP	Raising Bamboo Platform
RCM	Reinforced Clostridium Medium
RH	Relative Humidity
RMSE	Root Mean Squared Error
RTC	Ready to Cook
SARIMA	Seasonal Autoregressive Integrated Moving Average
SBHCD	solar biomass hybrid cabinet dryer
SD	Smart Dried
SDC	Smart Dried Churi
SDG	Sustainable Development Goals
SDL	Smart Dried Loitta
SEAA	Semi Essential Amino Acid
SMS	Short Message Service
SS	<i>Salmonella-Shigella</i>
SSD	Salt-Smoke-Dried
STD	Solar Tent Dryer
STFA	Saturated Fatty Acid

TD	Traditional Dried
TDC	Traditional Dried Churi
TDL	Traditional Dried Loitta
TVAC	Total Viable Aerobic Count
TVB-N	Total Volatile Base Nitrogen
TVC	Total Viable Count
VP	Vacuum Packaging
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Fisheries and aquaculture play a crucial role in food security, supplying around 20% of animal protein to over 3 billion people globally (FAO, 2020). This contribution holds significant importance in people with low incomes in food-deficit countries, where fish serves as a key and affordable source of necessary nutrients (Kawarazuka and Bene, 2010). Nonetheless, the extremely perishable characteristics of fish lead to significant postharvest losses, potentially reaching as high as 35% in tropical and subtropical areas (Akintola et al., 2022). Post-harvest can be minimized by preserving the fishes using different processing techniques viz. drying, canning, smoking, fermenting, salting etc. In Bangladesh, fish drying is traditionally carried out through various methods, including spreading the fish on mats made from split bamboo, using concrete floors, utilizing elevated platforms, and use of bamboo poles and bars (Reza and Hossain, 2023). A number of significant losses occur from the extended drying process.

A significant quantity of dried fish undergo spoilage every year due to insufficient drying, preservation, and storage facilities, especially under unfavorable weather conditions (Reza et al., 2005). Sun drying has been widely used in practical applications. Although the drying process has a number of drawbacks. For instance, these are vulnerable to product

contamination due to the dust, dirt or other alien materials (Panchal et al., 2013) as well as product loss from animal interference and insect infection (Prakash and Satyanayarana, 2014).

Additionally, many drying techniques are very labor and space intensive, particularly during the rainy season. To cope with these differences, a variety of sun dryers have already been developed. To reduce spoilage and improve the quality of fish products there is an increasing tendency to adopt innovative methods of preservation including vacuum drying, freeze drying, and advanced solar assisted drying technologies (Fitri et al., 2022). Three types of solar dryers have been created in the area solar energy (El-Shiatry et al., 1991; Dronachari and Shriramulu, 2019). The hybrid solar dryers, direct solar dryers (Bolaji and Olalusi, 2008), indirect solar dryers (Zoukit et al., 2019) and mixed solar dryers (Bolaji and Olalusi, 2008; Forson et al., 2007, César et al., 2020) are amongst these. A solar energy dryer is constrained by one key factor being dependent on daylight hours to convert solar radiation to generate heat.

1.2 Preservation of Fish by Drying

The growing demand for sustainable and efficient preservation methods for fish products has sparked a revival in the development and enhancement of solar dryers (Hao et al., 2021). These structures significantly aid in minimizing post-harvest losses and are essential for enhancing food security, particularly in rural areas of developing nations (Fernandes et al., 2022). There are two main types of drying: thermal drying and non-thermal drying (Zhao et al., 2019). Thermal drying uses heat to remove air. It can be done naturally in the sun or with a

variety of high-tech thermal tools and ways (Kamfa et al., 2020). Some non-thermal technologies are ultrasounds, high-pressure processing, pulsed electric fields, and others (Zhang et al., 2019). These can kill microorganisms at temperatures close to room temperature, keep food components from breaking down during heating, and keep the nutritional and sensory value of foods (Pereira and Vicente, 2010). Non-thermal drying is still not widely used in the industrial processing of fish (Wang et al., 2011). Traditional sun-drying comes with several challenges, including a slow process, reliance on weather conditions, risks of insect infestations, threats from rodents and birds, as well as issues related to storage and marketing (Kumar and Kalita, 2017; Suresh et al., 2023; Baidhe et al., 2024; Saklani et al., 2024). To address these limitations, especially in reducing drying time and enhancing product quality, numerous energy-efficient and environmentally friendly thermal drying technologies have been developed and implemented in various countries today (Wang et al., 2011; Chojnacka et al., 2021; Acar et al., 2022). Several advanced technologies include controlled mechanical heating, hot air oven drying, heat pump drying, freeze drying, microwave drying, radio frequency drying, infrared drying, electro-hydrodynamic drying, and hybrid drying methods that combine two or more techniques (Cheng et al., 2021; Acar et al., 2022; Fathi et al., 2022; Yoha et al., 2024; Fernandes et al., 2024). Salts are often added to both traditional and modern ways of drying fish to help remove water quickly, which gives the fish more texture and flavor (Wu et al., 2022). The addition of salt to fish may keep it from going rotten and stop insects from consuming it during traditional food preparation (Adeyeye and Oyewole, 2016).

Solar dryers exemplify an optimal solution, harnessing the plentiful and cost-free solar energy, especially in areas with ample sunshine, to effectively and economically

dehydrate agricultural products (Kumar et al., 2021). Solar dryers are very important for drying fish products in a way that keeps their quality and safety (Villagran et al., 2024). These structures keep the food product from coming into contact with dust, insects, and germs that could make the end product less safe and less clean by creating an enclosed or partially enclosed environment (Tiwari et al., 2016). These advancements not only make solar dryers more efficient and effective, but they also encourage the manufacture of fish products in a way that is less harmful to the environment.

1.3 Preservation of Fish by Canning

The canning process is comprised of precooking the food, packaging it with filling material, and sealing and sterilizing the cans. The filling medium distributes heat from the retort to the fish muscle, acts as a preservative, and raises acidity (Rabiepour et al., 2024). Nonetheless, the filling medium has the potential to dilute and extract certain components, thereby modifying their concentrations in the final product (Aubourg, 2001; Naseri et al., 2011). Interactions with the fish lipids affect the fatty acid profile of the filling medium. The fish canning industry uses vegetable oils (olive, sunflower etc.) as filling media. However, during storage, many substances pass between the fish and oil until a dynamic equilibrium is established between the fish, oil, and processing and storage methods used (Gómez-Limia et al., 2020). The amount (natural protection) and the degree various foods have against spoiling differ (Sahu et al., 2017). The pressure canner, also called a retort, is used for the majority of food products to sterilize before they are bottled or canned. Its purpose is to kill microbes generally inclined to survive heat, including *Clostridium botulinum*.

Pathogenic bacteria are eliminated through sterilization at a temperature of 121°C for a particular time, in order to attain a maximum loss in nutritional and organoleptic qualities. Heating food in jars or containers kills spoilage-causing microorganisms. Canned fish is regarded as appropriate for individuals with busy lifestyles while upholding health standards. Canning aims to extend shelf life and enhance the market value of fish relative to fresh fish prior to processing.

1.4 Challenges and Opportunities in Fish Processing

Value-added products development from captured marine fishes is an area where Bangladesh is far behind from many other maritime countries. However, there are enough opportunities to develop this sector, particularly, invention of low-cost and house hold level technologies for value added product development which can increase income and socio-economic conditions of marginal fishers and small-scale fish processors. Sun drying is one of the most extensive low-cost preservation methods for captured marine fishes in Bangladesh. Traditional sun-drying is absolutely dependent on the climate. Drying needs more time when the air is more humid. Due to the influence of monsoon, the relative humidity of the air is higher in 4-5 months of the year. It is the biggest constraint of absolutely climate-dependent process of sun-drying. Peak fishing starts from mid-August but peak drying cannot be achieved until October. Bulk of the harvest of peak fishing season cannot be sun-dried properly. The drying process in the sun takes about a week depending on the weather conditions.

The physical and organoleptic qualities of most of the traditional sun-dried products deteriorate remarkably due to unfavourable weather (e.g., rainy, cloudy or foggy weather). The longer duration of drying causes considerable spoilage, blowfly infestation, broken pieces and contamination with filth and soil particles. Therefore, the quality standard of the products cannot be sustained. Based on these facts, it is needed to develop a suitable and efficient fish dryer which will resolve these problems. Canning is another process of preserving food (e.g., fish, meat etc.) in sterile, airtight containers without the use of artificial preservatives. It typically involves heating the containers to at least the boiling point of water, adding fresh or processed food, and heating them again to sterilize the contents. When properly prepared, tightly sealed, and stored in a cool, dry place, unopened canned food remains safe to eat for at least a year without refrigeration. If it is possible to develop simple house-hold level fish canning methods for small-scale fishers or fish processors especially for women members, they can generate income for better leading of their life.

The developed integrated solar-sun dryer and canning techniques are two new technologies in the fisheries field of Bangladesh. The dryer will be able to produce safe and quality dried fish products round the year, at both day and night, even, it will produce dried fish in the bad weather condition e.g. (cloudy and foggy weather) using the solar energy backup. There are no native canned fish products in Bangladesh. All of the canned fish products found in the market are imported from foreign countries. So, optimized household canning technologies in the field level will popularize the value-added canned fish especially hilsa will help to popularize and disseminate the native canned fish production. Thus, these

two technologies will contribute to add extra value in the market chain. To address the issues encountered in conventional fish drying systems, hybrid solar dryer has the potential to improve the drying process, leading to shorter drying periods and possibly higher-quality products.

The uses of Internet of Things (IoT) and can be monitored in real-time using a smartphone to track how well the fish is integrating, keeping it from turning spoiled. Canning is a process of preserving food (e.g., fish, meat etc.) in sterile, airtight containers without the use of artificial preservatives. It typically involves heating the containers to at least the boiling point of water, adding fresh or processed food, and heating them again to sterilize the contents. When properly prepared, tightly sealed, and stored in a cool, dry place, unopened canned food remains safe to eat for at least a year without refrigeration.

Products processed through hybrid solar drying and small-scale canning method leading to get higher prices and increased income for producers as well as, this innovation supports UN Sustainable Development Goals SDG 1-3, SDG 8-9, and SDG 13, thereby enhancing the economic growth of coastal communities. Consequently, this study was conducted to assess the likelihood of consumer acceptance of canned fish by examining its qualitative attributes from microbiological, physical, and chemical perspectives, in addition to its shelf life, which plays a role in contributing to the national GDP.

1.5 Research Objectives

Based on the conditions outlined, the present study was conducted with the aim of achieving the following objectives:

- i. To develop an efficient IoT enabled Hybrid Solar Dryer (HSD) for optimal dried fish products
- ii. To establish a small-scale canning protocol for Hilsa (*Tenualosa ilisha*) at community industry level
- iii. To assess the nutritional and microbiological quality of the products over the storage in order to determine the shelf-life
- iv. To evaluate the livelihood conditions of marine fish processors and explore ways to enhance them

CHAPTER 2

LITERATURE REVIEW

2.1 Marine Fish Products and Its Potentiality

Reza (2024) studied different types of dried fish products considering a country's perspective, good amount of protein, omega-3 polyunsaturated fatty acids, vitamins, and minerals is obtained from dried fish. Dried fish offers the same nutrients as fresh fish but less moisture. The product is a mainstay in many low-income developing nations diets due to its inexpensive price. Fishing, processing, distributing, transporting, and selling dried fish employs millions of Bangladeshi people. This industry offers jobs, money, and a constant supply of nutritious food to many people worldwide.

Tacon (2023) conducted a review of contribution of fish and seafood to global food and feed supply of the FAO food balance sheet for 2019. Fish and seafood are a healthier alternative to meat and processed meat products because they are typically higher in protein on an edible fresh weight basis, leaner, and lower in saturated fat. They are also unique in the animal kingdom because they are naturally rich in heart-healthy long-chain omega-3 polyunsaturated fatty acids and docosahexaenoic acid, higher in essential minerals and trace elements, and higher in several important vitamins than most meats.

Farmery et al. (2022) investigated designing sustainable and secure future seafood systems. By improving production, distribution, and equitable access to wild harvest and

mariculture resources and products, seafood may contribute more to sustainable and healthful diets and the fight against hunger and malnutrition. Various "drivers" impact the production and consumption of seafood, such as ocean management and ecological change, changing consumer demand, and the increased recognition of the nutritional value of seafood. To gain comprehensive knowledge, possible effects, and solutions that match seafood production and consumption with pertinent 2030 Sustainable Development Goals (SDGs), these factors must be investigated holistically.

Khalili Tilami and Sampels (2018) carried out an evaluation entitled nutritional value of fishlike lipids, proteins, vitamins, and minerals. The long-chain polyunsaturated n-3 fatty acids found in fish are largely responsible for its reputation as a nutrient-dense food item that humans should eat at least twice weekly. Because of their involvement in several metabolic processes, these fatty acids are nutritionally essential to humans. They are crucial components of cell membranes, the circulatory system, the brain, and the neurological system; they also reduce platelet aggregation and have anti-inflammatory functions.

Hixson et al. (2014) observed the current issues in aquaculture to provide safe and nutritious seafood, in an environmentally sustainable manner. Aquaculture is expected to be the most dependable source of seafood in the future, and production has grown globally in recent years. The research on fish nutrition has been updated, offering insights into how the area has developed to suit industrial demands and strike a balance between sustainable environmental practices and seafood production. The review's findings support the use of

biotechnology as a tool to accomplish environmental sustainability and seafood production goals to enhance resource utilization and guarantee future global food security.

Oehlenschlager (2012) examined nutritional benefits and risk aspects of seafood. The edible portions of seafood contain numerous nutrients that are good for human's diets. This encompasses n-3 polyunsaturated long-chain fatty acids (PUFAs), specifically eicosapentaenoic acid (EPA) as well as docosahexaenoic acid (DHA), essential trace elements such as selenium and iodine, elevated potassium levels coupled with reduced sodium levels, vitamins D, A, E, and B₁₂, as well as taurine, among various other components. The fat percentage of lean fish species is incredibly low, at less than 1%, but the PUFA level of fatty fish species is extraordinarily high.

Rustad et al. (2011) searched the possibilities for utilization of marine by-products. Because fish stocks are finite, maximizing the catch's use is necessary. Increased scientific knowledge of the characteristics of fish oil and proteins might turn the remaining raw resources into extremely valuable commodities. This would enable the sustainable use of fish resources, have positive economic and environmental benefits, and boost the availability of vital marine proteins and lipids for a world population that is continuously increasing. About 14-15% of the world's animal protein demands and 4-5% of the minimum protein requirements are met by fish.

McManus and Newton (2011) investigated the nutritional benefits of consuming seafood. Seafood is a very nutrient-dense whole food. In comparison to other protein sources,

seafood provides a wide range of highly accessible vitamins, as well as superior macronutrients in the optimal form of lean proteins together with beneficial omega-3 long chain polyunsaturated fatty acids (n-3 LCPUFAs). The impact of important nutrients found in seafood on human health. Protein, vitamins A, B₁₂, D, and E, iodine, selenium, calcium, zinc, iron, and omega-3 fatty acids derived from marine sources are given special attention.

2.2 Preservation of Fish Using Different Techniques

The nutritional value, preservation, and processing of fish were the subjects of research conducted by Ali et al. (2022). Fish helps to provide a balanced diet for the growing demand of food because of the high nutritious content; it contains and the low cost it carries. To further increase the shelf life of the product, several methods such as cooling, freezing, super-chilling, as well as chemical preservatives are being investigated. In the marine food industry, non-thermal technologies such as pulsed electric field (PEF), fluorescence spectroscopy, hyperspectral imaging method (HSI), and high-pressure processing (HPP) are utilized to process the most cost-effective fish products in order to satisfy the needs of consumers while causing the least amount of damage to the fish's quality.

Rumape et al. (2022) studied the quality of fish products based on different preservation techniques. Due to its susceptibility to spoiling, oxidation, and the production of off-flavors from incorrect handling, fish is often perceived as a difficult culinary commodity. By mixing and employing preservation procedures creatively, however, it is possible to get things with exceptional quality, good sensory features, and a favorable nutritional value.

Speranza et al. (2021) provided a description of novel preservation techniques that enhance the quality of fish products while also ensuring their safety. Fish products, which are very perishable, are required to go through a meticulous processing process in order to guarantee their quality and safety during the storage phase. In contrast to the traditional methods of preserving these products for longer periods of time (such as smoking, salting, marinating, icing, chilling, cooling, drying, boiling, steaming, and so on), new methods of processing have emerged that can ensure the extension of their shelf life.

At the year 2021, Al-Ismaili was successful at drying fish using solar energy in Oman. Because fish is so perishable, it can be preserved using a variety of methods, including smoking, being dried, chilling, brining, and chilling. Solar drying is a process that is widely used since it is both easy and economical to use. The methods of solar drying and the quality of fish were investigated in this study. It is possible to dry solar materials using open-sun, direct, and indirect approaches.

In their study, Abraha et al. (2018) witnessed the impact that various processing techniques had on the nutritional and physicochemical composition of fish. A number of different fish processing techniques, including drying, smoking, freezing, boiling, and canning, were investigated in this study to determine how they affected the chemical, physical, and nutritional content of the fish. It is possible for processing processes to have an effect on the composition of fish, which can include proteins, lipids, vitamins, minerals, in addition sensory attributes such as color, flavor, texture, and appearance. Processing can result in a

number of changes to the chemical makeup of the product, including denaturation, coagulation, decreased protein digestibility, oxidation, along with vitamin loss.

Mahmud et al. (2018) studied multi-dimensional fish preservation approach and several preservation methods have been and will be developed to address the issues of fish and fisheries products quality and safety. There isn't a magic bullet that can guarantee safety and stop spoiling in its tracks, even though all of the methods can work. Physical, chemical, and bio-preservation methods are the three main categories into which the fish and fishing industry's numerous preservation techniques fall. To make fish and fisheries products last longer, people use these methods, which all work in their own unique ways.

Aravindh and Sreekumar (2015) examined solar drying as a sustainable way of food processing. Over time, food preservation methods including cold storage, drying, and others have evolved to reduce losses. Therefore, sustainable food preservation technologies are essential. Different sun dryer types have been created, and most nations are researching to promote solar drying for farm product value addition. Solar drying is a famous illustration of how the sun's free energy can assist humanity.

Sampels (2015) reviewed the effects of processing technologies and preparation on the final quality of fish products. Traditional methods include marinating, smoking, salting, drying, and their mixtures. Modern technologies include sous-vide cooking, canning, and the production of ready-to-eat foods including surimi. It is emphasized that every step taken during processing and preparation will have an impact on the quality of fish products.

Processes must be modified to meet the unique needs of items that deteriorate easily, like fish. Innovative use of processing processes will result in high-quality, nutritionally valuable goods.

Ghaly et al. (2010) monitored fish spoilage mechanisms and preservation techniques. Fish and fish products can be preserved and handled with care to extend their shelf life and improve their quality. Traditional methods for preserving fish and extending its shelf life include salting, drying, smoking, fermenting, and canning. New techniques, such as chemical preservation, cooling, and freezing, were developed in response to customer demand for texture, look, and flavor.

Kose (2010) evaluated seafood safety health hazards for traditional fish products. Salting, fermenting, drying, and smoking are some of the traditional preservation techniques used to make traditional fish products. These items also varied substantially across nations and even within the same nation due to the wide variety of uses for which they are produced. Food safety concerns have also led to documented adjustments to these methods. Due to their distinctive flavor and scent, these preservation methods continue to enjoy widespread popularity, despite their long-standing reputation as antiquated practices.

Aubourg (2001) monitored quality loss during the manufacture of canned fish products. Raw fish undergoes many industrial processes before being canned. Thus, chilling or freezing is needed to hold the raw material to be canned; cooking is used to reduce moisture and inactivate endogenous enzyme activity; sterilization is used to inactivate microorganisms; and proper canned storage ensures product palatability. Thus, labile and important elements of

proteins, vitamins, lipids, and minerals in raw fish are processed under diverse circumstances, reducing their nutritional and sensory value. To extend the shelf life of stored material and preserve sensory and nutritional quality in canned goods, new technology is proposed.

2.3 Performance of Solar Drying Techniques

Deef et al. (2023) carried out a study on a hybrid solar dryer for efficient fish waste processing. Fish waste samples were dried at 45, 50, and 55 °C. After drying for 10, 7, and 5 hours at the given temperatures, moisture content decreased from 75.2% to 24.8%. At temperatures of 45, 50, and 55°C, maximum drying rates of 1.10, 1.22, and 1.41 kgH₂O/kg dry material/h were reported. HSD energy efficiency was 79.2%, 75.8%, and 62.2% at each temperature. Microbial load, crude lipid, and moisture decreased as drying temperature increased, whereas crude protein and ash increased. This sustainable, renewable energy-based method protects the environment and reduces industrial fossil fuel use.

Murali et al. (2023) appraised solar hybrid drying systems for marine applications. The globe currently benefits greatly from the fishing industry as a source of cash and nutrition. Due to the lack of cold chain facilities, a large portion of marine products like fish, prawns, and squid often spoil. Although various solar hybrid dryer designs have been applied for drying these items, comprehensive studies on their design, application, and impact on product quality remain limited. This research focused on evaluating different solar dryer designs and their effectiveness in processing marine products.

Natarajan et al. (2022) considered solar dryers for drying fish. Preserving food items from the point of harvest all the way to the consumer level is the primary focus of this study. This problem accounts for 60% of food product losses caused by the lack of available preservative technologies. The traditional approaches to enhanced solar drying technologies for persevering fish were the primary subject of this article. When everything is said and done, this study will aid fish drying researchers in selecting optimal drying methods for certain fish, which in turn will allow any business to choose the most cost- and time-efficient way.

Murali et al. (2020) designed and evaluated performance of solar-LPG hybrid dryer for drying of shrimps. The goal of the project was to design and build an energy-efficient solar dryer that could be used continuously for drying. After 6 hours of drying, the fresh shrimp's moisture content dropped from 76.71% (w.b) to 15.38% (w.b). Shrimp dried over a falling-rate drying phase, according to the drying rate curve. During drying, a maximum collector outlet temperature of 73.5 °C was achieved. In all, 73.93% of the heat energy came from the solar system. For the drying of shrimp, the highest drying and collector efficiencies were 37.09% and 42.37%, respectively.

Mehta et al. (2018) analyzed the design and performance of a mixed-mode tent-type solar dryer for fish drying in coastal areas. While it took 38 hours to dry the fish in the open, as is typically done in the field, the fish maintained in the solar drier saw their moisture content drop from around 89% to 10% in just 18 hours of sunshine. The Lewis model of drying was well suited to the drying model that was created. $1.53 \times 10^{-7} \text{ m}^2/\text{s}$ was the calculated diffusivity

value based on the moisture ratio. In coastal villages that dry fish, this type of solar dryer would be important since it would increase productivity and provide a sanitary method.

Rizal and Muhammad (2018) accomplished fabrication and testing of hybrid solar-biomass dryer for drying fish. Post-harvest processing is one way to raise the added value of the plentiful fish products. A solar energy drying equipment with air heating powered by biomass is being manufactured and tested as part of this investigation. The dryer is made up of a glass-covered drying chamber that is 260 cm long and 80 cm wide. The dryer also has a crossflow heat exchanger installed for a biomass-fueled air heater. 25 kg of fish were utilized as raw material, and they were dried using a variety of techniques and specialized equipment.

An investigation of the drying process of salted silver jewfish was carried out by Fudholi et al. (2016) using a hybrid solar drying technology that included the sun. Experiments regarding the drying of salted silver jewfish were compared to ten different drying models. The results of this study investigated the sun drying energy and exergy of salted silver jewfish. During the process of solar drying, the first and second principles of thermodynamics were utilized to conduct a study of energy and exergy, respectively. When the solar radiation was 540 W/m² and the mass flow was 0.0778 kg/sec, the efficiency of the collector system was 41%, while the efficiency of the drying system was 23%. A specific energy of 2.92 kWh/kg was measured. The solar drying process has an exergy efficiency that ranges from 17% to 44%, with an average of 31%.

In their 2014 study, Hubackova and colleagues evaluated the creation of a solar drying system for a selection of Cambodian fish species. It was compared to drying in an electric oven to drying in the sun. They selected five species of fish that are commonly found in Cambodia. The air humidity was 19.9%, while the average temperature for sun drying was 55.6 degrees Celsius. Generally speaking, solar dryers that use natural convection have an efficiency of 12.37%. It was found that solar dryers had an average evaporation capacity of 0.049 kilograms per hour.

An evaluation of a combined solar and biomass dryer for use by small and medium-sized businesses in poor countries was carried out by Okoroigwe et al. (2013). Solar and biomass heating sources allowed the tray to attain a maximum temperature of 53 degrees Celsius, despite the fact that the temperature of the surrounding environment ranged from 24 to 30 degrees Celsius during the course of the test. An optimal drying rate of 0.0142 kg/hr was achieved by the combined solar and biomass dryer, which was higher than the lower rates of 0.00732 kg/h for sun drying as well as 0.0032 kg/h for biomass drying.

Şevik (2013) conducted an evaluation of a sun drying system from the perspective of its design, experimental study, and analysis. The drying system made use of a double-pass solar air collector, which was responsible for supplying the thermal energy that was required for the drying process. The moisture content dropped from 7.76 g water/g dry matter to 0.1 g water/g dry matter. There was accomplished by drying the air at a temperature of 50 degrees Celsius and using variable air volume. A change in the air velocity has occurred as a result of

the drying cabinet's air input temperature. During the whole drying process, the air velocity was measured to be between 0.4 and 0.9 meters per second.

Reza et al. (2009) executed an experiment on the optimization of marine fish drying using solar tunnel dryer. Research was carried out to find the best way to dry fish in a Hohenheim-type solar tunnel drier so that the finished goods would be both safe and of good quality. The fish samples were dried for 36 hours at 45 to 50 °C and for 32 hours at 50 to 55 °C, respectively, until their moisture content reached 16%. Flavor, color, and texture were all positively impacted by products made between 45 and 50 °C. From big-eye tuna, which had the lowest rehydration ability, to silver jew fish, which had the highest, the range was 65 to 80%. All of the finished dry goods met the required standards for total volatile base, peroxide, and aerobic plate count.

Sengar et al. (2009) worked on a low-cost solar dryer for fish. Open sun drying and sunlight drying were compared in terms of the time it took to reduce the moisture content from 75% to 16%. It took 8 hours for salted fish to dry shrimp to a moisture content of 16.15% in the drier, but unsalted fish needed 15 hours to achieve the same level in open conditions. We discovered an overall collecting efficiency of 70.97%. While unsalted fish had an average drying efficiency of 11% and salted fish of 14%, the pickup efficiencies of the two types of fish were determined to be 9% and 10%, respectively.

Sablani et al. (2003) assessed drying rates and quality parameters of fish sardines processed using solar dryers. By comparing the efficiency of three distinct solar dryers with

sardines, they aimed to find a solution to the problems associated with conventional sun drying methods. Open rack, convection cabinet, and multi-rack dryers were the types of dryers utilized. The proximate composition, yeast, mold, and bacterial counts, peroxide value, and color were used to evaluate the quality features of dried sardines. They found a wide range of drying rates and quality features.

2.4 Marketing Strategy of Dried Fish Products

Purkait et al. (2024) analyzed the process of fish drying and marketing in coastal West Bengal. An integral part of the Indian cuisine is dry fish, which is rich in micronutrients. The cultural importance of dried fish, called "shutki" in Bengali, guarantees a consistent demand in the local market. Nevertheless, the business faces a multitude of complex obstacles in addition to these encouraging possibilities. Government agencies, business groups, academic institutions, and local communities must work together to overcome these obstacles. The fish drying and marketing sector in coastal West Bengal may improve economic growth and community well-being by carefully addressing these difficulties. It has the ability to fulfill local demands and carve out a position in the global seafood market.

Belton et al. (2022) studied dried fish at the intersection of food science, economy, and culture. Dried fish products continue to play an essential role in production, commerce, diets, and cuisines in the Southern Hemisphere. Millions of people rely on the dried fish industry for their livelihood, with a disproportionate number of women working in this field in various parts of the world. Concerns about food safety and exploitative work conditions are two of the major problems that the industry faces and causes.

2.5 Processing of Marine Fishes Through Canning

Karaca and Capanoglu (2022) experimented on canned fish products. Because of rich nutritional makeup and positive health impacts, canned fish products are valued by consumers and have significant commercial value in many nations. Depending on the species being processed and the intended final product, several procedures are involved in the canning process and formulation. Furthermore, the demand for canned fish products is rising globally as a result of consumers shifting consumption patterns and adoption of healthier eating practices following the epidemic.

According to Prego et al. (2022), the composition of fatty acids of canned mackerel was examined to see how the freezing process, the canning process, and the packing media affected the mixture. The purpose of this experiment was to determine the number of fatty acids (FA) that are present in canned Atlantic mackerel (*Scomber scombores*). The effects of various packing mediums, canning techniques, and previous freezer storage (6 months at 18 °C). Consequently, the canning process resulted in greater PUFA/STFA and ratio values, a reduction ($p < 0.05$) in saturated FA (STFA) levels, and an increase ($p < 0.05$) in polyunsaturated FA (PUFA) and total FA values.

Bell et al. (2019) assessed the food security benefits of canned fish for Pacific Island countries. Poor-quality, imported, processed meals in Pacific Island countries are unhealthy compared to canned fish. Increased canned fish consumption will also assist bridge the gap between sustainable coastal fish production and nutritional fish intake. Promoting health

benefits and local canning are key to maintaining/increasing per capita canned fish consumption in Pacific Island nations. Increasing the market share of locally-canned tuna to achieve economies of scale might help compete in domestic and intra-regional canned fish commerce, generate jobs, and indirectly improve local food security.

Lucci et al. (2016) represented impacts of canning on food products, food preservation often entails avoiding the growth of germs. These microorganisms can be found on the food, in the water of fresh food, in the air, on equipment. Sufficient heat for a specific amount of time destroys germs and ensures a safe product. *Clostridium botulinum*, is an obligate anaerobe that generates an acute toxin known as botulin. *C. botulinum* spores are unaffected by boiling water at 212°F or 100°C. This creature generates no gas or apparent flavor and is undetectable by taste or smell. Canning involves heating food in hermetic vessels for a set period and temperature to kill harmful microorganisms and enzymes that degrade food quality during storage.

2.6 Sensory Quality of Marine Fish Products

Al Banna et al. (2022) aimed to assess the sensory quality of five dried fish species from five drying centers in Bangladesh, as well as customers perceptions of quality and health concerns associated with dried fish consumption. Data on individuals' perceptions of the quality attributes of dried fish were gathered via a standardized questionnaire. Sensory research indicated that Cox's Bazar samples exhibited greater acceptability than those from other places. Among 500 responses, the predominant majority (94.8%) indicated the absence

of difficulties following the consumption of dried fish. Notable quality discrepancies among the dried fish samples indicated the necessity for enhanced hygiene and sanitation practices to ensure the production of high-quality and safe dried fish for consumers both domestically and internationally.

Rasul et al. (2021) analyzed effects of drying methods on physico-chemical and sensory properties of torpedo scad. Researchers looked at how drying techniques affected the sensory and physico-chemical characteristics of *Megalaspis cordyla*. They used four different drying procedures on the fish: traditional (no pre-treatment), enhanced (5% salt solution), improved-TC and sun tunnel (5% salt solution). According to sensory evaluations, solar-dried items are of higher quality compared to those made using conventional drying processes. Solar dried goods have a better rehydration capacity than regular-dried goods. According to the study's findings, solar tunnel drying produces safer, higher-quality dried fish compared to conventional drying processes.

Olokor and Ngwu (2009) monitored the solar dried and traditional sun-dried fish products. Organoleptic testing revealed that dehydrated fish from the Kainji Solar Tent Dryer had a pale, whitish-yellow hue, in contrast to the deep orange hue of sun-dried fish. On the appearance scale, solar-dried fish scored 8.2, while those from other sources scored 5.2; on the texture scale, solar-dried fish scored 6.6, while those from other sources scored 7.8. After being sun-dried, fish had an average score of 8.2 for odor and 8.4 for flavor, compared to 4.6 and 0 for sun-dried, respectively. When compared to conventional sun-dried fish, the

organoleptic evaluation of the finished dried product revealed that the sun-dried fish had superior fish quality.

2.7 Nutritional Properties of Marine Fish Products

Sultana et al. (2024) analyzed the nutritional quality of dried fish from three different countries. The purpose of this study was to examine nutritional profiles of; *Otolithoides pama*, *Trichiurus haumela*, and *Harpodon nehereus* imported from India, Myanmar and Bangladeshi fish. Among the species, the dried *H. nehereus* from Myanmar had the greatest protein content at $62.81 \pm 2.83\%$ and the highest lipid content at $11.03 \pm 0.39\%$. The dried *H. nehereus* from Bangladesh exhibited greater moisture and fiber content, whereas the ash concentration was $10.18 \pm 0.72\%$ in Indian *H. nehereus*. Among the *T. haumela* samples tested, the one from Bangladesh had the highest concentrations of lipids and proteins, while the one from Myanmar had the highest concentrations of ash. The protein, ash, moisture, and fiber levels of *O. pama* varied between nations, with the maximum moisture content found in India.

Ullah et al. (2022) executed nutritional profiling of some selected commercially important marine water fishes of Bangladesh. *Lates calcarifer* had the most protein (18.673%), lipid content ranged from 0.316% to 13.396%, with *Mugil cephalus* having the most. Its moisture content is 68.343%-81.160%. Ash levels range from 0.850% to 4.350% in all fish. Energy is also higher in marine fish. Mineral concentration varied greatly. There were significant variances amongst the twelve samples, although all fish species had reduced

sodium, potassium, and sulfur. The PCA biplot for proximate composition analyses showed positive affinity only for *Lates calcarifer* and *Mugil cephalus* for ash, lipid, and carbohydrate.

Jaman et al. (2021) compared dried fish quality collected from market and drying center at Kuakata in Patuakhali, Bangladesh. Bombay duck had the greatest moisture content (29.78%) from the market, while Chinese pomfret had the lowest (20.06%) from the drying facility. Highest protein content was found in Chinese pomfret (60.73%) and lowest in Bombay duck (47.9%) from drying center and market, respectively. Lipid and ash content ranged from 2.85% to 7.20% and 13.98% to 19.57% for all dried fish species from both locations.

Bahurmiz et al. (2018) examined nutritional and sensory characteristics of locally produced canned tuna from Hadhramout, Yemen. Wet weight basis values for moisture ranged from 59.77 to 63.11%, protein from 23.33 to 24.56%, fat from 8.05 to 8.97%, and ash from 2.01 to 2.25%. In terms of overall rating and the majority of individual features, sensory evaluation revealed significant differences ($P < 0.05$).

Jamil et al. (2017) studied the proximate composition of sun-dried Bombay duck and Ribbon fish of Cox's Bazar district of Bangladesh. According to their organoleptic quality, the majority of these sun-dried fish were in good condition, with an SDP of 2.33 and 2.35, respectively. The sun-dried Bombay Duck has the following components: $32.21 \pm 1.05\%$ crude protein, 3.51% lipid, $37.26 \pm 0.70\%$ moisture, $16.22 \pm 0.56\%$ TVB-N, 115.45 ± 1.73 mg/100g

moisture, and 9.37 ± 0.13 mg/100g TMA-N. While the percentages of crude protein, lipid, moisture, ash, TVB-N, and TMA-N were $31.64\% \pm 1.28\%$, $5.06\% \pm 0.10\%$, $35.78\% \pm 0.97\%$, $12.33\% \pm 0.27\%$, 107.69 ± 1.37 mg/100g, and 9.91 ± 0.23 mg/100g, respectively, in sun-dried ribbon fish.

Siddiky et al. (2017) conducted a study on the proximate composition analysis of five significant species of sundried marine fish taken from Cox's Bazar. These species were *Stromateus chinensis*, *Harpodon nehereus*, *Trichiurus haumela*, *Strongylura leiura*, and *Engraulis tellara*. Sun-dried *S. chinensis* had a crude protein content of 60.61 ± 0.25 , a lipid content of 7.35 ± 0.09 , a moisture content of 22.62 ± 0.81 , and an ash content of 8.56 ± 0.32 percent, respectively. Sun-dried *H. nehereus* had a crude protein content of 61.53 ± 1.01 , a lipid content of 7.44 ± 0.48 , a moisture content of 17.93 ± 1.04 , and an ash content of 12.78 ± 0.75 correspondingly. *T. Haumela* that had been sun-dried had crude protein, lipid, moisture, and ash levels (in percentages) of 58.36 ± 0.46 , 11.24 ± 0.36 , 18.66 ± 0.42 , and 11.22 ± 0.34 , respectively. The crude protein, lipid, moisture, as well as ash content (percentage) of sun-dried *S. leiura* were obtained to be 50.16 ± 0.44 , 9.17 ± 0.55 , 22.09 ± 0.90 , and 17.57 ± 0.38 respectively. A total of 52.82 ± 0.18 percent of crude protein, 10.40 ± 0.73 percent of fat, 22.13 ± 0.60 percent of moisture, and 15.17 ± 0.66 percent of ash were found in the sundried *E. tellara*.

Begum et al. (2016) detected the nutritional profile of hilsa fish in six selected regions of Bangladesh. Moisture, protein, fat, carbohydrate, and energy values ranged from 66.94 ± 7.34 to $72.04 \pm 5.77\%$, 18.95 ± 3.97 to $20.56 \pm 4.57\%$, 4.97 ± 0.89 to $8.21 \pm 1.87\%$, $3.08 \pm$

0.68 to $4.84 \pm 1.22\%$, 0.35 ± 0.09 to $0.72 \pm 0.05\%$, and 128.38 ± 11.43 to 161.68 ± 13 . These values help consumers pick fish and shellfish depending on their nutritious content.

Kundu et al. (2016) observed the nutritional quality of major sun-dried fishes from Government regulated dry fish market, West Bengal. This study examined the nutritive value and food quality of four major sun-dried fish species: Bombay duck, Ribbon fish, Tapra and Ruli after one year of storage. As dry fish absorb moisture from the environment, their nutritional content and quality degrade. This study found mean protein, fat, carbohydrate, moisture, and ash levels of 49.45 to 69.5, 3.5 to 7.8, 1.15 to 4.2, 35 to 14.4, and 2.2 to 8.2. Protein, fat, carbohydrate, and ash levels decreased while moisture increased during storage. The investigation also found major gaps in dried fish drying, packing, and storage.

Olokor and Ngwu (2009) kept an eye on both conventional and solar-dried fish products. To make this process even better, the Kainji Solar Tent Dryer was invented. In just two or three days, the fish were dried using the open sun and the Kainji Solar Tent Dryer. The moisture content of sun-dried fish was 10.6%, whereas that of air-dried fish was 22.26 percent. The sun-dried fish had a crude protein and fat content of 62.3 and 16.25, respectively, whereas the fresh fish had 82.14 and 8.46. When tested for microbiological load, sun-dried fish had 43.3 CFU/g whereas fresh fish had 132 CFU/g.

2.8 Biochemical Properties of Marine Fish Products

Majumdar et al. (2023) assessed the biochemical quality of sun-dried marine fish sourced from the Bay of Bengal in Bangladesh for five different sun-dried marine fish species- White sardine (WS), Longjaw thryssa (LT), Double spotted queenfish (DQ), Chinese pomfret (CP), and Indian threadfin (IT). In comparison to LT, DQ, CP, and IT, WS exhibited superior quality in terms of biochemical properties. Total volatile basic nitrogen was highest in CP (54.22 mg/100g) and lowest in WS (29.77 mg/100g) when measured on a fresh matter basis. Sun-dried WS was highly accepted because of its low peroxide value, acid value, and conjugated diene. To satisfy the high standards set by consumers for these dried fish products, it is essential to pay close attention to processing, handling, hygiene, and storage.

Al-Ismaili (2021) accomplished solar drying of fish in Oman. Fish must fulfill pH, water activity, microbial load, TVB-N, TMA-N, and enzymatic autolysis requirements for longer shelf life. The pH should be 6.0-6.9 and the water activity below 0.6 for optimal quality. TVB-N and TMA-N are spoiling markers with maximum limits of 10-15 mg/100g and 35-40 mg/100g, respectively.

In their 2018 study, Paul and colleagues conducted an evaluation of the quality of Bangladeshi sea fish that had been traditionally dried. These items had a range of proximate compositions, which included their moisture content, crude protein content, lipid content, and ash content, which ranged from 18.56% to 24.20%, 33.56% to 58.22%, 2.74% to 15.44%, as well as 15.87% to 32.22%, by their respective percentages. The concentrations of total volatile

base nitrogen and peroxide were also found to be greater than the levels that were recommended for dried fish.

In 2017, Siddiky and colleagues conducted a study in which they analyzed the proximate composition of five significant dried sea fish and evaluated the nutritional value of these fish. The fish that was available in the local market in Cox's Bazar, as well as the specific species of dried sea fish, were of a high quality from an organoleptic standpoint. The TVB-N concentration (percentage) of sundried *Stromateus chinensis*, *Harpodon nehereus*, *Trichiurus haumela*, *Strongylura leiura*, as well as *Engraulis tellara* was 16.81 ± 0.82 , 9.92 ± 0.80 , 20.26 ± 0.70 , 13.89 ± 0.47 , and 19.62 ± 0.30 , respectively. The organoleptic qualities of the traditional dried sea fishes that were examined in the experiment were found to be satisfactory and good.

The purpose of the study conducted by Pradhan et al. (2016) was to determine the proximate composition and biochemical properties of fish samples that were taken from a variety of marketplaces in Nepal. The moisture content, protein content, and fat content of the sun-dried fish were found to range from $11.8 \pm 0.3\%$ to $19.9 \pm 0.7\%$, $55.1 \pm 0.9\%$ to $69.5 \pm 0.3\%$, as well as $3.7 \pm 0.0\%$ to $15.4 \pm 0.3\%$, accordingly.

A study conducted by Begum et al. (2016) aims to evaluate the biochemical characteristics of hilsa fish in six different localities in Bangladesh. In terms of pH, TVB-N, and salt values, the ranges that were observed were as follows: 6.52 ± 0.07 to 6.84 ± 0.10 , 2.01 ± 0.71 to 3.50 ± 0.33 mg/100 g, and 2.05 ± 0.03 to 6.48 percent. For vitamin A, the values

varied between 33.50 ± 14.28 to 95.54 ± 11.69 $\mu\text{g}/100$ g, while for vitamin C, the values ranged from 11.20 ± 0.47 to 14.28 ± 1.93 $\mu\text{g}/100$ g.

2.9 Microbiological Quality of Marine Fish Products

Majumdar et al. (2023) tested the microbial properties of five different marine fish species from Bangladesh's Bay of Bengal-White sardine (WS), Longjaw thryssa (LT), Doublespotted queenfish (DQ), Chinese pomfret (CP), and Indian threadfin (IT). In comparison to LT, DQ, CP, and IT, WS exhibited superior quality in terms of microbiological properties. In terms of total plate count and total *Vibrio* sp. count, only WS was determined to be safer and more appropriate for human consumption. Except for CP and IT, which had total *E. coli* count values of 2.84 log CFU/g and 3.06 log CFU/g, respectively, no sun-dried fish was determined to be devoid of harmful bacteria such *Salmonella* sp. and *E. coli*.

In their study, Al Banna et al. (2022) looked into the microbiological quality of various dried fish that were purchased from commercial fish drying centers in Bangladesh. The approach of total plate count was utilized in order to determine the bacterial load measurement. The mean total plate count of dried Bombay duck was 7.1 ± 0.217 , 9.8 ± 0.117 , along with $7.8 \pm 0.52 \times 10^7$ CFU/g. On the other hand, the total count of *Vibrio* spp. was found to be 1.1 ± 0.113 , 3.7 ± 0.215 , and $1.8 \pm 0.1 \times 10^5$ CFU/g for Chittagong, Cox's Bazar, and Bhola, respectively. There was no evidence of the pathogenic bacterial species *E. coli* or *Salmonella* sp. in any of the dried Bombay duck samples that were collected from any region.

In the year 2022, Mukilan et al., conducted an evaluation of the microbiological quality of several dried fishes that were gathered from the fish market in Tamil Nadu. During the course of this research, each and every one of the dried fish specimens tested positive for contamination. Among the bacteria that were found, the following were identified: *Staphylococcus* species (8.9%), *E. coli* species (22.9%), *Bacillus* species (12.7%), *Pseudomonas* species (7.0%), *Salmonella* species (12.7%), *Lactobacillus* species (5.7%), *Vibrio* species (10.8%), and unidentified bacteria (9.3%). The diversity of microbes found in various dried fish The 10 distinct dried fish items tested here were all found to have harmful microorganisms.

Dhinesh et al. (2021) examined microbial pathogens in canned fish collected from Tamil Nadu. Using various selective medium, they tested three distinct canned fish items for microbial contamination, results demonstrated the presence of many harmful bacteria, including *E. coli*, *Staphylococcus aureus*, *Salmonella* spp., *Vibrio* spp., and *Listeria* spp. *Vibrio* spp. total viable count (TVC) ranged from 1.2×10^2 to 2.5×10^3 , 1.8×10^2 to 2.3×10^3 , and 2.0×10^2 to 2.8×10^3 CFU/g in canned products A, B, and C, respectively. Product A contained 1.1×10^2 to 2.3×10^2 , Band C contained 1 to 1.0×10^2 , and Band D contained 1.0×10^1 to 2.8×10^2 CFU/g of *Salmonella* spp. In terms of CFU/g, *E. coli* was 1.8×10^2 , 2.5×10^3 , and 1 to 1.0×10^3 in products A, B, and C, respectively.

Hassan et al. (2021) studied bacterial flora isolated from dried fishes sold at retail markets within Dhaka city corporation of Bangladesh. Bacterial contamination in dried fishes, along with other pollutants, significantly impacts the quality of cured fish. Twenty-five dried

fish were gathered from Dhaka and each sample was separated into three parts for bacterial isolation and identification using culture, staining, and biochemical characteristics. In 25 dried fish samples, *Escherichia coli*, *Bacillus*, *Staphylococcus*, *Salmonella*, and unidentified bacteria were isolated at rates of 44%, 56%, 80%, 48%, and 24%, respectively. The presence of *E. coli* and *Salmonella* spp. in dried fish samples suggests poor hygiene during processing. Future research might involve molecular identification, pathogenicity, and antibiogram confirmation of isolated bacteria.

Jaman et al. (2021) used aerobic plate count techniques to compare the microbiological quality of dried fish obtained from the market and drying center at Kuakata in Patuakhali, Bangladesh. Chinese pomfret had higher APC, TEC, and TSC levels (1.96×10^6 , 3.98×10^5 , and 1.62×10^5 CFU/g) from the market, while Bombay duck had lower counts (5.05×10^5 , 2.22×10^5 , and 0.81×10^5 from the drying center). Ribbon fish lacked *Salmonella*. Higher microbiological loads, particularly pathogenic TSC and TEC, indicate the need for greater cleanliness, sanitary methods, and storage facilities for safe and high-quality dried fish products.

Nur et al. (2020) conducted a comparative analysis of the microbiological counts in raw fish and sun-dried fish obtained from the Kawran bazaar in Dhaka, Bangladesh. Each of the samples contained bacteria and fungi at quantities of up to 10^6 CFU/g. For raw fish, the total viability count (TVC) and total coliform count (*E. coli*) were measured at 2.5×10^6 CFU/g and 5.2×10^4 CFU/g, respectively. *Staphylococcus* spp. as well as *Pseudomonas* spp. were detected at concentrations of up to 5×10^2 CFU/g and 1.8×10^2 CFU/g, respectively. In a

similar manner, the total viable count (TVC), the overall coliform count (*E. coli*), and fungal load in dry fish were quantified at 3.50×10^5 CFU/g and 1.2×10^3 CFU/g, respectively. This study shown that dried fish contained fewer microorganisms than raw fish, indicating that sun drying remains an effective method for fish preservation.

Ginigaddarage et al. (2018) accomplished microbial and chemical quality of selected dried fish varieties available in Sri Lankan market. The quality of chosen dried fish kinds at the local market was assessed as dried fish is commonly part of regular meals. Locally manufactured, imported, and retail-distributed dried fish samples of nine kinds were gathered. Additionally, sample water activity was assessed. The samples were negative for *E. coli*, *S. aureus*, and halophilic bacteria. Most samples had acceptable Aerobic Plate Count, yeast, and mold counts. Histamine exceeded 100 mg/kg in 33% of imported and 13% of domestic samples. Samples had water activity <0.75 , except for imported prawns from retail stores.

Paul et al. (2018) conducted an evaluation of the microbiological quality of Bangladeshi traditionally dried sea fish. However, no coliform bacteria were found in these samples, and the microbial load varied from 0.95×10^4 to 1.9×10^5 CFU/g, indicating different amounts of viable bacteria in those products.

Pradhan et al. (2016) evaluated the quality of dried fish products in Nepal. Ten varieties of sun-dried fish and six species of smoked fish were sampled to investigate their microbial load. In dried fishes, the total plate count (TPC) varied from $5.3 \times 10^2 \pm 2.3 \times 10^2$ to $41.9 \times 10^2 \pm 39.1 \times 10^2$ CFU/g. The content of mold varied between $0.1 \times 10^2 \pm 0.1 \times 10^2$ and

$8.6 \times 10^2 \pm 6.9 \times 10^2$ CFU/g. In smoked fishes, the mold content varied from $0.9 \times 10^2 \pm 0.1 \times 10^2$ CFU/g to $22.7 \times 10^2 \pm 0.1 \times 10^2$ CFU/g, while the total viable count (TPC) varied from $0.1 \times 10^4 \pm 0.00$ to $3666.7 \times 10^4 \pm 3179.7 \times 10^4$ CFU/g. While sun-dried fish samples did not have TPC or mold levels that were too high, smoked fish samples had levels that were too high due to heavy contamination with bacterium and mold.

Sanjee and Karim (2016) assessed the microbiological quality of frozen fish and fish processing materials from Bangladesh. The standard plate count technique is used to determine the total viable aerobic count in microbiological analysis, and the most probable number approach is used to count the total coliforms and fecal coliforms. Investigations were also conducted on the occurrence of certain fish diseases, including *Vibrio cholerae* and *Salmonella* spp. All samples had a TVAC estimated below 5×10^5 cfu/g, whereas the counts of fecal and total coliforms were below 10 and 100 MPN/g, respectively. The study's findings indicate that the frozen fish under investigation were both safe for human eating and suitable for export.

Jianadasa et al. (2014) evaluated the comparative quality of five varieties of fish obtained from retail markets in Sri Lanka. Samples were examined for chemical and microbiological quality, encompassing total reactive base nitrogen, histamine, mercury, as well as plate count. Furthermore, pathogens such as *Escherichia coli* along with *Salmonella* spp. were identified. In microbiological analysis, specimen plate counts varied from 7×10^3 to 1.2×10^8 cfu/g, with 28% of samples exhibiting $< 5 \times 10^5$ cfu/g. Eight percent of samples

exhibited > 103 MPN/g of *E. coli*, one sample contained 500 MPN/g, and the rest had < 200 MPN/g, leaving 33% being devoid of *E. coli*. The proportion of *Salmonella*-positive samples reached 12%. Among the total visible base nitrogen (TVB-N) range of 15-4883 mgN/100 g, 33% of samples over the allowable limit.

Sultana et al. (2010) enumerated microbial quality of dried fish in Chittagong and Mymensingh districts of Bangladesh. The mean TVC and TSC were determined to be 90.00 ± 1.00 and 86.33 ± 1.52 , respectively among the dried fishes of Chittagong in Churi. Meanwhile, in Rikshaw, the lowest TVC was 30.67 ± 0.58 and in Chingry, it was 31.67 ± 1.53 . In the same way, Mymensingh district had the highest TVC and TSC values of 113.00 ± 2.65 and 83.00 ± 2.65 in Chapa, respectively, and the lowest values of 94.67 ± 0.58 and 53.00 ± 2.65 in Challa. Compared to TSC, TVC was noticeably different. Dried fish samples taken from several locations did not contain any coliform bacteria.

2.10 Water Reconstitution Properties of Fish Products

Majumdar et al. (2023) assessed the physicochemical quality of sun-dried marine fish sourced from the Bay of Bengal in Bangladesh. They collected five distinct sun-dried marine fish species-White Sardine, Longjaw Thryssa, Double spotted Queenfish, Chinese Pomfret, as well as Indian Threadfin (IT) from Cox's Bazar to assess their physicochemical quality. In comparison to LT, DQ, CP, and IT, WS exhibited superior quality in terms of physical properties. Sun-dried WS showed relative superiority regarding pH value and water

reconstitution capabilities. Considering sensory, and physicochemical evaluations of white sardine concluded that it is perfectly safe for human consumption.

Paul et al. (2018) completed an evaluation of the organoleptic quality of Bangladeshi traditionally dried marine fish products from Cox's Bazar and Teknaf, two of Bangladesh's major fish drying zones. Eight species were discovered to be often utilized as raw materials to make traditional dried fish. The majority of the conventional sun-dried items had a slower rate of water reconstitution, whereas organoleptic criteria such as color, odor, texture, insect infestation, and the presence of fragmented pieces suggested poor to somewhat acceptable condition.

Rana et al. (2018) determined that the water rehydration capacity of the fishes named tengra (*Mystus tengra*) and batashi (*Neotropicalis atherinoides*). Maximum Rehydration capacity obtained from salt-smoke-dried batashi and minimum value obtained from traditional dried tengra before storage at ambient temperature and its range varied between 17.68 to 50.38 %. After two-month storage at 40°C the water reconstitution capacity was in the range of 38.24 to 54.78% with lowest value for control dried (CD; treated without salt and smoke) tengra stored at ambient temperature after soaking 15 min and highest value obtained from SSD batashi stored at refrigeration temperature after soaking 60 min in water. The reconstitution percentage was completely high at 60°C after soaking for 60 min for most of the samples.

2.11 Comparative Analysis of Fish Preservation Methods

Tamzi et al. (2024) evaluated the quality of improved and traditionally dried Bombay duck through biochemical, microbiological, and organoleptic analysis. While the traditionally made dried fish had a rotten odor, a soft and delicate texture, and an insect infestation, the enhanced dried fish had an exceptional organoleptic quality. The enhanced dried sample's water reconstitution qualities were greater than those of the conventional dried goods, at 75.71% and 89.39% at room temperature and 80 °C, respectively. Compared to market-dried samples, the lipid and total volatile base nitrogen (TVB-N) contents were much reduced in improved dried fish products, while the protein, ash, and contents were significantly greater. The conventional items had far higher total viable counts of bacteria, a symptom of low quality.

Mithun et al. (2021) evaluated the quality of both conventional and enhanced dried Bombay duck over various storage conditions. The sensory quality results indicate that the dried fish produced using the enhanced process is superior to that obtained through conventional methods, both at the outset and under storage circumstances. While traditionally dried fish over the permissible limit, the microbial load of improved dried fish conformed to internationally accepted microbiological standards. The biochemical composition of improved dried fish, including protein, fat, ash, as well as moisture, exhibited more nutritious value than that of standard varieties. Although putting dried fish in HDPE conditions extended shelf life, the data confirmed that the solar chimney dryer produced superior quality dried fish compared to the traditional open-air drying method, both initially and post-storage.

Patterson et al. (2018) monitored the effect of drying technologies on the biochemical properties of *Stolephorus commersonnii*. Solar drying is a speedier and more sanitary alternative to the old-fashioned sun-drying process. Both drying procedures produced goods with different biochemical contents and sensory evaluations. The organoleptic quality of solar-dried fish is superior to that of conventionally dried fish. In comparison to conventionally sun-dried salmon, solar-dried fish had superior overall quality.

Nagwekar et al. (2017) compared biochemical and microbiological analyses of dried fish prepared using various drying techniques. This study compared three methods of drying fish: hot air dryer (HAD), freeze dryer, and a recently created and patented solar conduction dryer (SCD). A total of four parameters-the viable count, the fungal count, the total volatile nitrogen, and the concentration and color of trimethylamine (TMA) are examined. Experimentally dried fish outperform TSD fish in terms of microbiological and biochemical quality. This study delves into unsanitary open sun drying and handling of dried items, as well as the necessity of utilizing dryers based on relevant, newly-developed drying technologies like SCD, which are anticipated to become environmentally friendly.

Relekar et al. (2014) examined the impact of enhanced drying techniques on the biochemical along with microbiological quality of desiccated small head ribbon fish. This study included advanced drying technologies for fish, including solar tent dryers (STD), rising bamboo platforms (RBP), plus black polythene sheets (BPS). Fish subjected to various drying methods required 58, 82, with 130 hours for STD, RBP, followed by BPS, respectively. The first moisture level of ribbon fish dried in STD was 17.85%, RBP was 19.35%, and BPS was

19.95%. Dried ribbon fish samples from STD, RBP, BPS, and market had starting plate counts of 2.96×10^3 , 3.80×10^3 , 1.12×10^4 , and 2.30×10^4 CFU/g, respectively, which increased to 5×10^3 , 6.30×10^3 , 4.80×10^4 , and 5.80×10^4 CFU/g after 120 days of store.

Haque et al. (2013) compared the quality of solar tunnel-dried Bombay duck and silver pomfret with traditional sun-dried samples to determine their relative quality. Both the Bombay duck and the silver pomfret had moisture contents that were within the permitted limit, measuring 15.25% and 13.43%, respectively. There was an improvement in water reconstitution power and protein content in solar dried fish samples compared to conventional sun-dried samples. Samples dried in a sun tunnel had peroxide levels within the typical range of 10- 20 meq/kg of oil and TVB-N values of up to 30 mg/100 g, respectively. Although the aerobic plate count was lower, neither of the dried samples tested positive for *Salmonella* or *Coliform*. Samples of Bombay duck and silver pomfret dried in a solar tunnel outperformed those dried in a conventional sun dryer.

Chavan et al. (2011) observed drying performance and quality characteristics of Indian Mackerel dried by a solar tunnel dryer. Each solar tunnel drier (STD) was subjected to eight drying experiments, while open sun drying (OSD) was compared to it. Both STD and OSD needed 27 and 48 hours to dry, correspondingly. The STD and OSD had an overall drying efficiency of around 19.87% and 12%, respectively. Histamine, total volatile bases nitrogen (TVB-N), free fatty acid (FFA), peroxide value (PV), and trimethylamine nitrogen were some of the biochemical features of dried mackerel that were greatly affected by STD. The sensory panel gave the best ratings to the fish which dried at temperatures between 40 and

46°C for 20 to 30 hours. Panelists favored fish dried with STD across all sensory qualities, as shown by contour plots of dried mackerel.

Oparaku et al. (2010) evaluated proximate and organoleptic characteristics of sun and solar dried fish. At 14.00 hours, the solar dryer reached its maximum mean temperature of 70°C, with insulation at 857.6 w/m² and ambient temperature of 33.5°C. The sun and solar-dried goods were tested for their proximate and organoleptic properties. The results showed that the solar drier produced higher-quality fish products than the sun-dried ones. In terms of organoleptic qualities, solar dried items fared better than sun dried ones. This was particularly true concerning odor and moisture reduction. When compared to sun-dried fish products, which take seven days to dry, the solar drier dried the fish in just three days.

Chavan et al. (2008) investigated on biochemical, microbial and sensory properties of mackerel dried by solar-biomass hybrid cabinet dryer. Open sun drying (OSD) and solar biomass hybrid cabinet dryer (SBHCD) were used in drying studies for mackerel at air temperatures of 32.4-57.7°C, relative humidity levels of 23.9-85.8%, and airflow rates of 0.20-0.6 ms⁻¹. The experimental solar radiation varied from 287 to 898 Wm⁻². Drying was accomplished at night by burning biomass. The processed mackerel's initial moisture content of 72.5±0.44% decreased during 24 and 44 hours of drying, respectively, to 16.7±0.52% in SBHCD and 17±0.54% in OSD. Free fatty acid (FFA), peroxide value (PV), thiobarbituric acid (TBA), total volatile bases nitrogen (TVB-N), trimethylamine nitrogen (TMA-N), and histamine levels all exhibit a significant linear correlation with drying duration for SBHCD drying.

2.12 Environmental Consideration of Fish Processing

Bhattacharya et al. (2022) studied environmental impacts and mitigation measures of fish processing. The fishing industry includes a lot of wastewaters thrown out as effluent from processing industries and low-value, underused fish taken as by-catch in commercial fishing operations. The by-catch, effluents, and discards are rich in minerals, carotenoids, proteins, and amino acids. Thus, fish wastes are a substantial contributor to nitrogen loss and other environmental hazards. The trash must undergo secondary processing and valorization to resolve the difficulties. Biological therapies are safe, effective, and eco-friendly, transforming nutrients into single-cell proteins that may be utilized for biodiesel manufacturing and other vital components. New developments in algae biotechnology have made this a real possibility.

Thrane et al. (2009) monitored the status and possible future strategies in Danish fish processing. Analyzing the evolution of the implemented solutions from the late 80s to the present day, they offered suggestions for future strategies at both the corporate and policy levels. Significant improvements in water consumption, wastewater emissions, and the use of fish 'waste' for valuable by-products have been achieved by the examined enterprises. Reducing energy use, changing container materials, and other environmental consequences across a product's life cycle might still need more attention. However, companies and authorities have mostly concentrated on reducing wastewater emissions at the source.

Arvanitoyannis and Kassaveti (2008) inspected fish industry waste about treatments, environmental impacts, current and potential uses. One of the biggest environmental issues is

fish waste management after processing. Fish farming's harmful consequences on the marine environment are a public concern. Many directives, decisions, and regulations were passed in the EU to reduce fisheries' environmental effects under Integrated Coastal Management. The main uses of treated fish waste are animal feed, biodiesel/biogas, natural pigments (after extraction), food-packaging applications, cosmetics (collagen), enzyme isolation, Cr immobilization, soil fertilizer, and food moisture maintenance.

2.13 Prospect and Potentiality of Marine Fish Products

Islam et al. (2024) examined the contributions and prospects of marine fishing to the economy of Bangladesh, as well as the problems of a sustainable blue economy. Due to their diverse usage and high worldwide demand, fin fish, mollusks, crustaceans, and seaweeds in the marine water area have great economic potential. The study found that maritime fisheries are vital to Bangladesh's economy, job creation, and food security. Expanding mariculture and using marine resources would boost Bangladesh's economy. Bangladesh's marine fisheries production has expanded during the previous two decades, but its share has fallen. Limited research, technology, skilled labor, undeveloped local seafood markets, and financial restraints hamper mariculture growth.

Manik (2022) observed the current marine fisheries production status and opportunities in Bangladesh. Almost 81% of Bangladesh's total area 118,813 km² is located in the Bay of Bengal. Just 15% of the country's total output comes from marine fishing while the marine industry accounts for almost 60% of global fisheries production. The percentage of

production that came from marine sources fell from 22.0% in 2002 to 14.7% in 2021. Between 2002 and 2021, artisanal fisheries contributed an average of 88.1% to marine productivity, whilst industrial fisheries contributed just 11.9%. The government of Bangladesh has to set up a distinct marine strategy and provide more resources for research and technology if it wants to expand its marine fisheries.

Sarker et al. (2018) investigated the prospects of the blue economy for improving the financial stability in Bangladesh. Following the establishment of a stable maritime boundary with adjacent nations, Bangladesh has prioritized the blue economy. The blue economy in Bangladesh depends on living, non-living, as well as renewable marine and coastal assets. The primary impediments to blue economy advancement encompass rising sea levels, climate-induced disasters, pollution, human interference, and insufficient law enforcement. The research indicates that advancing the blue economy and achieving Sustainable Development Goals (SDGs) must be integrated to prevent the prioritization of the blue economy over environmental sustainability.

Islam (2003) studied perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. The country's coastline area is one of the most productive in the world due to its location and climate. Coastal and marine fisheries contribute to the country's social and economic growth and ecological balance. Many valuable export fishes have been exploited. Shrimp farming has become a major export business in recent decades. Marine aquaculture, stock augmentation, and sea ranching have promising promise, but commercial

development is lacking. Although it has great stock enhancement potential, the Bay of Bengal and its coasts are one of the least researched places in the world. Exploitation, handling, processing, export and institutional management must be carefully considered.

2.14 Consumer's Acceptability of Marine Fish Products

Appiani et al. (2024) compared consumer perception, acceptance, and attitudes regarding plant-based fish analogues vs. fish. According to generalized linear models, samples made from plants had a very low acceptance rate (<40 VAS score), but goods made from animals had a high acceptance rate (63.6-75.2). In terms of liking, Principal Coordinate Analysis showed that pink color, tuna/fish flavor, and dryness were positively associated with tuna samples, whereas plant-based samples were negatively associated with liking due to unattractive appearance, off-flavor, legume/vegetable flavor, bitterness, gelatinousness, and gumminess. This study emphasizes the significance of sensory optimization in developing plant-based alternatives to satisfy consumer preferences, and it shows that the use of plant-based components impacts all sensory aspects of plant-based canned tuna.

Delfiya et al. (2024) compared clam drying in solar, solar-hybrid, and infrared dryers. The clam's moisture content dropped significantly, within a range of 9-17%wb, in different dryers. The moisture level of dried clams was lower than that of fresh clams regardless of the drying, while the protein, ash, and fat content were all higher. Infrared drying generally produced the greatest physical, quality, sensory, microbiological, and drying features of clams. It has a drying efficiency of 35.66%, an ultimate drying rate of 1.26 kg water/kg dry matter.

Birch and Lawley (2012) studied barriers to purchasing seafood across consumption segments. Most people like seafood and think it's part of a balanced diet. When buying fish, people may consider dangers that may prevent intake. This report presents the results of an online survey of 899 Australian consumers on seafood consumption motivations and obstacles. Seafood intake poses functional, social, physical, psychological, and economic concerns. Lighter fish consumers were more likely to perceive functional risk associated with being less knowledgeable and comfortable with fish, experiencing greater difficulty selecting, recognizing freshness, and preparing and presenting fish than regular fish eaters. Regular seafood eaters saw less social risk from household members not liking fish than lighter seafood consumers.

Selmi et al. (2010) observed the impact of the drying procedure on the biochemical as well as microbiological quality of the silverside fish, *Atherina lagunae*. The fresh sample of silverside had 5.42 g/100 g of total fatty acids and 10.9 g/100 g of amino acids, respectively. There were 0.59 g/100 g of fresh silverside N-3 and 0.62 g/100 g/n-6 polyunsaturated fatty acid levels, respectively. The peroxide value as well as thiobarbituric acid reactive components of the total lipids significantly increased to 2.58 and 3.41 meq active O₂ kg⁻¹ oil and 0.87 and 1.27 mg MA kg⁻¹, respectively, after hot air plus solar drying treatments. Nevertheless, the polar lipid's PUFA reduced noticeably throughout both drying processes, with solar drying resulting in lower levels.

Rortveit et al. (2009) evaluated the influence of convenience with consideration set size on fish consumption in Norway. This study sought to examine the correlations between

participants opinions towards fish and their consumption of fish. A structural equation model (SEM) developed from the integration of two previous studies is employed. Convenience orientation and perceived product inconvenience adversely affect both the size of the consideration set and the frequency of consumption, as indicated by a SEM analysis utilizing Lisrel 8.72 on data collected in a Norwegian consumer survey (n = 1630). The results indicate that attitude, consideration set size, consumption frequency, and reported product discomfort are all strongly affected by this variable. Findings from the study indicate that the consideration set's size influences consumption frequency.

Scholderer and Trondsen (2008) investigated the dynamics of consumer behavior on habit, discontent and other fish to fry. According to cross-lagged panel research, consumers' perceptions of the product supply became more unfavorable as their intake of traditional seafood increased. In response to these unfavorable reviews, processed seafood products were more widely used and aqua-cultured species became more dominant in the seafood market. The theoretical debate centers on how static theories of consumer behavior, like the idea of planned behavior, fail to account for these ever-changing impacts. It lays out the policy and marketing ramifications of the shifting seafood market structure.

Leek et al. (2000) analyzed situational determinants of fish consumption. Consumers and non-consumers are known to have different opinions about fish. According to the results of the analyses, environmental elements are the most important ones when it comes to consumer choice. To explain this, a theoretical framework called the behavioral perspective

model (BPM) is suggested. Three kinds of fish products were collected from consumers: fresh, frozen, and canned. These views on fish may be categorized into five groups according to factor analysis: adaptability, situational relevance, negative qualities, economics, and convenience. According to multiple regression analysis, there is a distinct relationship between these and the consumption of fish.

CHPATER 3

MATERIALS AND METHOD

3.1 Experimental Design

The experiment entitled “Biochemical, Microbiological and Sensory Properties of Some Commercial Marine Fish Products Processed by Hybrid Solar Sun Drying and Small-Scale Canning Method” addressed the critical challenges in processing and preserving the marine fish products. The necessity of this research trunks from the growing demand of sustainable techniques of marine fish products processing cost effectively. This experiment mainly focusses on two different types of techniques of marine fish preservation viz drying and canning. At first the livelihood conditions of the marine fish processors need to be assessed to understand the existing challenges faced by them during the operational period. The dry fish producers faced multiple challenges to produce safe dry fish products, to solve the challenges an innovative hybrid solar-sun dryer was developed and installed. Two types of marine fish viz churi and loitta were processed using this dryer and quality and shelf life of the products were tested and compared with conventional dried products. The hybrid dryer offers an eco-friendly and sustainable approach utilizing renewable energy for processing of quality and safe dry fish products with minimal environmental impact. On the other hand, some novel recipes were developed for long-term preserving the hilsa fish through small canning process, this method involved the semi-automatic sealing the fishes into the can followed by high pressure sterilization to eliminate the microbial contamination and extending the shelf-life.

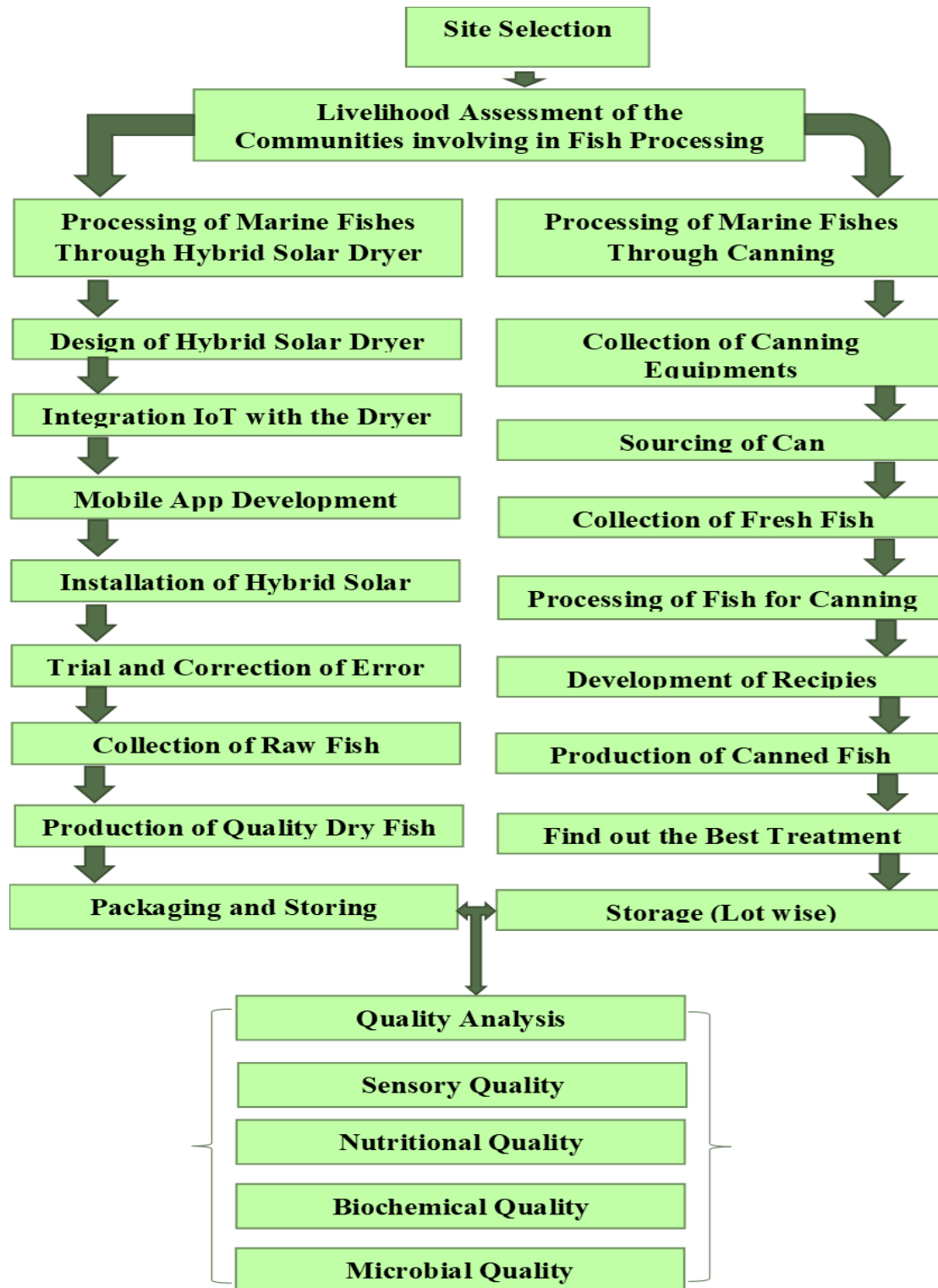


Figure 3.1: Diagram showing the entire experimental design of the research

The nutritional, biochemical and microbial quality of the processed hilsa can were tested on regular manner for confirming that the contents are nutritionally intact and safe for consumption. The whole experimental design represented in Figure 3.1, provides a comprehensive overview of the research protocol.

3.2 Site Selection

In research, site selection was a critical factor due to the success of the study depended on where it was conducted. Nazirartek in Cox's Bazar Upazila was considered a suitable site for this research. One of the primary reasons for selecting Nazirartek was that approximately 65-70% of Bangladesh's dried fish production took place there. The fishermen of this area harvested a significant volume of marine fish, but lack of modern technology, they were unable to obtain the desired market value for their products. Since this research was centered around the dried fish community of Nazirartek in the Cox's Bazar Sadar Upazila, it was expected that the local population would be able to produce premium quality products and market them effectively, thereby improving their livelihoods. The geographical location of the study area demarcated in Figure 3.2.

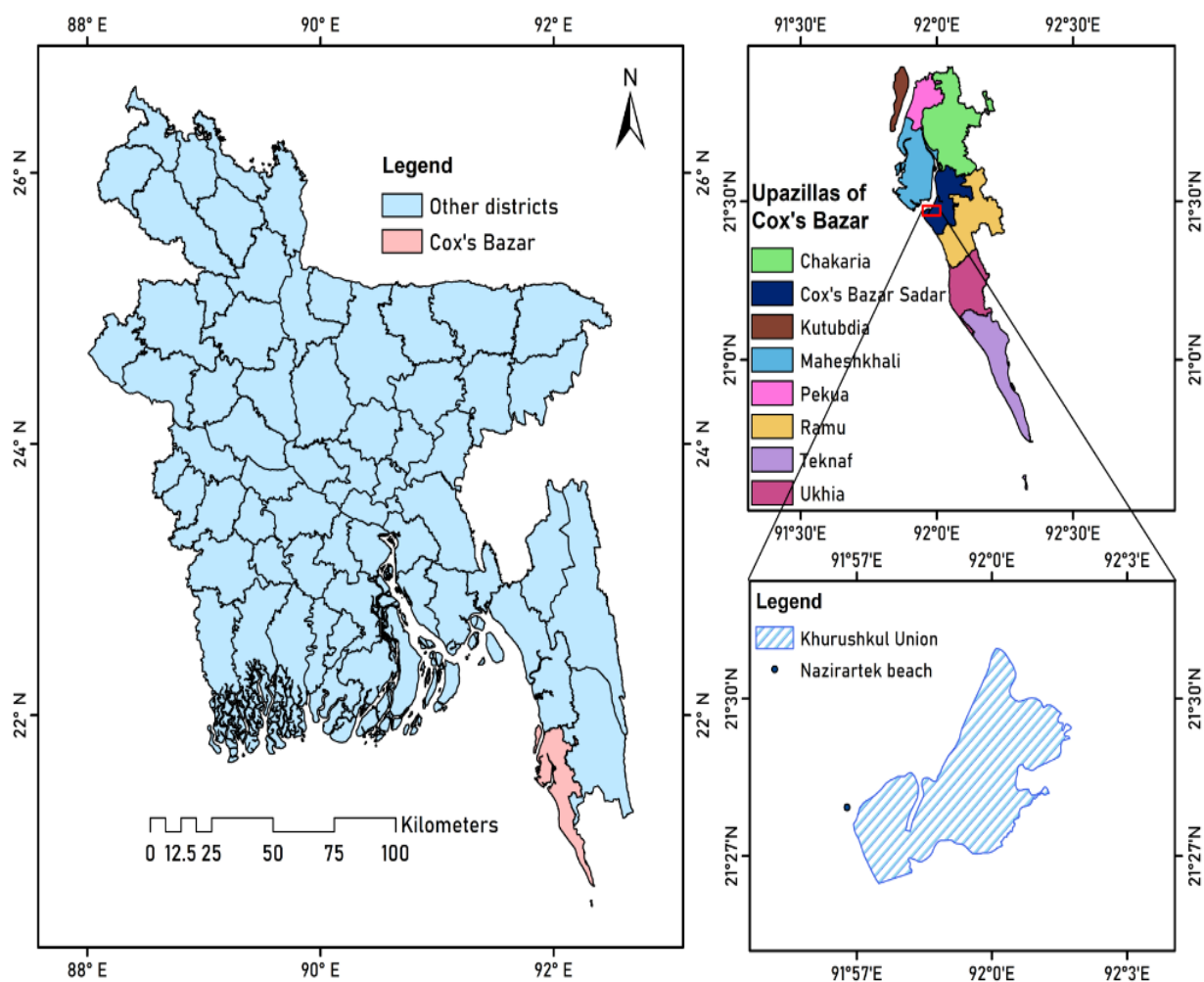


Figure 3.2: Geographical location of the study area

3.3 Assessment of Livelihood Status of Marine Fish Processors

A structured survey was meticulously designed and conducted (Figure 3.3) to gather data from fishermen engaged in marine fish processing, the parameters of survey are presented in Table 3.1. The survey targeted a total of 2,200 respondents, comprising 70% males and 30%

females. This survey comprised three distinct segments, each tailored to capture specific dimensions of the fishermen's lives and work:

i. Occupational information's: This segment was dedicated to gathering detailed information about the occupational practices of the fishermen, including their methods, tools, and the economic aspects of marine fish processing. This section aimed to uncover the nuances of their work and the challenges they face in their occupation.

ii. Personal information: In this part of the survey, the focus shifted to the personal and socio-economic aspects of the respondents' lives. Information regarding their family background, educational status, living conditions, and other personal attributes was collected. This segment aimed to paint a holistic picture of the fishermen's socio-economic status and living conditions.

iii. Production information: This final segment delved into the specifics of the dry fish production process. It included questions about the species of fish dried, marketing facilities, storage facilities, and other relevant production details. The goal here was to understand the technical aspects of dry fish production and how they intertwine with the fishermen's occupational and personal lives.

The selection of respondents was conducted through a stratified sampling technique, ensuring a representative cross-section of the fishing community in Cox's Bazar. Data collection was carried out via a combination of in-person interviews and self-reported surveys, facilitating an in-depth understanding of the fishermen's perspectives and experiences. The methodological rigor employed in this study ensures the reliability and validity of the data, providing a solid foundation for subsequent analysis and interpretation.

Table 3.1: Parameters of livelihood assessment of the processors

Modern Facilities	Personal Information	Production Information
1. Use of phone	1. Age	1. Species drying
2. Network facility	2. Education status	2. Marketing facilities
3. Internet support	3. Status	3. Storage facility
4. Internet browsing info	4. Home status	4. Drying yard workers info (male)
5. Have Facebook account	5. Marital status	5. Drying yard workers info (female)
6. Learning from YouTube	6. Family size	6. Fish dried
7. Disaster information	7. Drinking water facility	7. Processing information
8. Govt. support during ban	8. Health support	7. Preservatives used
9. Work during banning period	9. Electricity facility	8. Chemicals used
10. Satisfaction level in work	10. Asset	9. Sunlight support



Figure 3.3: Data collection from the producers

iv. Data collection process

Data were collected through a combination of in-person interviews and self-administered questionnaires. The questionnaires were designed to be straightforward and user-friendly, allowing participants to provide detailed and accurate responses.

v. Data analysis

The initial phase of data analysis involved descriptive statistical methods to summarize and interpret the survey data. This analysis provided an overview of the socio-economic conditions, market dynamics, and production practices prevalent in the dry fish

industry. Key indicators such as income levels, education, market trends, and production methods were systematically analyzed to paint a comprehensive picture of the current state of the industry.

vi. Model selection

The choice of a regression model (Figure 3.4) for predicting the livelihood status of dry fish workers is grounded in the model's ability to handle multiple predictor variables and its effectiveness in forecasting continuous outcomes. In this context, the livelihood status is quantitatively assessed through indicators such as income levels, educational attainment, and access to resources. A regression model, particularly a multiple linear regression, is well-suited for this task as it can accommodate numerous independent variables and establish a linear relationship with the dependent variable (livelihood status).

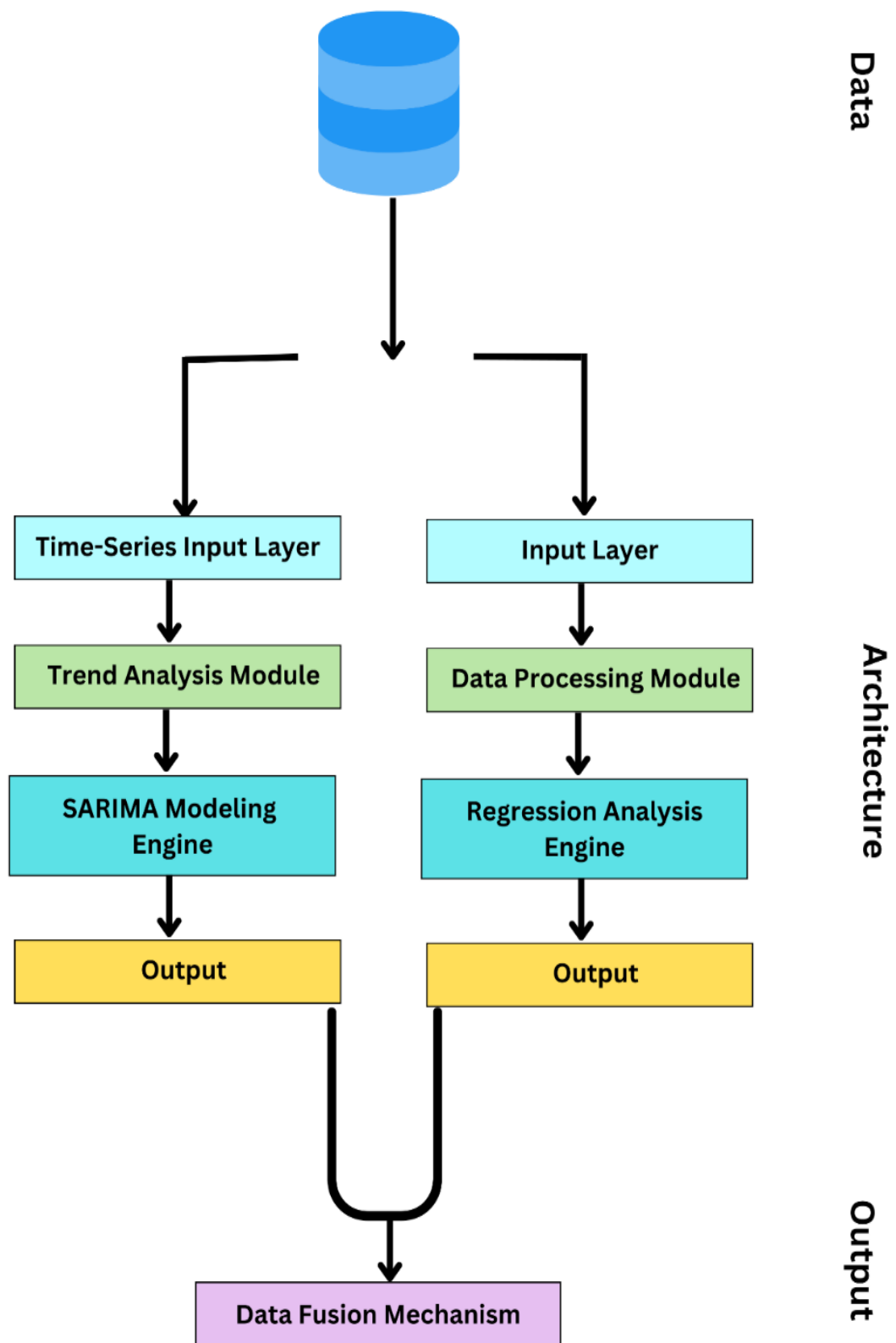


Figure 3.4: Model architecture

vii. Feature selection

The selection of features (independent variables) for the regression model was a critical step, informed by the comprehensive survey data. Variables were chosen based on their relevance to the livelihood status of the fishermen and the strength of their association with socio-economic outcomes. Key features included:

- a) **Income levels:** Representing the economic aspect of livelihood.
- b) **Education levels:** Indicating access to knowledge and skills.
- c) **Access to market information:** Reflecting the ability to make informed business decisions.
- d) **Family Size:** As an indicator of social and economic responsibilities.
- e) **environmental factors:** Such as weather patterns affecting fish availability. These features were selected for their potential impact on the livelihood of fishermen and their ability to provide a holistic view of their socio-economic status.

3.3.8 Dry fish price forecasting model

The SARIMA (Seasonal Autoregressive Integrated Moving Average) model was selected for forecasting dry fish prices due to its proficiency in handling time-series data with seasonal patterns. Dry fish prices exhibit seasonality, influenced by factors like fishing seasons, weather conditions, and market demand fluctuations. SARIMA effectively models such seasonal time series by integrating autoregression (AR), differencing (I), and moving averages (MA) along with a seasonal component. This model is particularly adept at capturing complex patterns in data, making it an ideal choice for predicting price trends in the dry fish market. Preparing the historical price data for time-series analysis involved several critical

steps: Historical price data of dry fish was gathered, ensuring a sufficient timeline to capture seasonal variations and long-term trends. The collected data was cleaned to handle missing values, remove outliers, and correct any inconsistencies. This step was crucial to ensure the accuracy of the model. The data was decomposed into its trend, seasonal, and residual components. This helped in understanding the underlying patterns and ensuring that the SARIMA model specifically addresses the seasonality aspect. A critical requirement for time-series analysis is that the data must be stationary. Techniques like the Dickey-Fuller test were used to check for stationarity, and transformations like differencing were applied if necessary.

3.3.9 Combining models

The integration of the regression model (for forecasting the livelihood status of dry fish workers) and the SARIMA model (for predicting dry fish prices) into a cohesive hybrid model was accomplished using a Python-based approach. This integration aimed to leverage the strengths of both models, providing a comprehensive tool for understanding and predicting key aspects of the dry fish industry in Cox's Bazar. The integration process involved the following steps:

i. Model output alignment: The first step was to ensure that the outputs of both models were aligned in terms of the time frame and granularity. The regression model's output, predicting the socio-economic status of the fishermen, was aligned with the time-series output of the SARIMA model, predicting dry fish prices over the same period.

ii. Data concatenation: The outputs of both models were concatenated into a single dataset. This dataset then contained predicted values of livelihood status alongside the corresponding forecasted dry fish prices for each time period.

iii. Correlation analysis: A correlation analysis was conducted on the combined dataset to understand the relationship between the predicted livelihood statuses and the forecasted fish prices. This analysis helped in identifying patterns and dependencies between the socio-economic conditions of the fishermen and the market prices.

iv. Python implementation: The entire integration process was implemented in Python, a programming language known for its robust data science and machine learning libraries. Python's libraries such as Pandas for data manipulation, Stats models for time-series analysis, and Scikit-learn for regression modeling were utilized. The integration of these two models into a hybrid framework represented a novel approach in predictive modeling for the fisheries sector. By combining socio-economic forecasting with market price predictions, the model offered valuable insights, not just in terms of individual predictions but also in understanding the complex interplay between different aspects of the fishermen's lives and the market dynamics.

3.4 Quality Analysis

For quality assessment the products, four major analyses were carried out on the fish samples. These were sensory assessment, nutritional quality assessment, biochemical and microbiological quality assessment.

3.4.1 Sensory quality assessment

A sensory test necessitates an individual, known as an assessor, to evaluate a sample utilizing one or more human senses-vision, smell, taste, and kinesthesia-aligned with the

product's attributes of appearance, odor, flavor, and texture. Sensory properties were analyzed for color, smell, texture, broken pieces, and insect infestation using the methodology outlined by Rasul et al. (2018). The sensory evaluation took place in dedicated sensory booths. The panel consisted of seven persons including fish processing experts, nutritionist and food scientist.

3.4.2 Nutritional quality assessment of dried and canned products

3.4.2.1 Determination of moisture

The moisture content was assessed using the oven-drying method at 105°C, by placing a properly weighed 2-3g homogenized ground sample in a pre-weighed porcelain crucible within a thermostat oven (Gallenkamp, HOTBOX, Model OVB-306) for 24 hours until a consistent weight was achieved. After that the samples were taken out from the oven with the help of tong and kept in desiccator for cooling. The reduction in moisture was quantified as percent moisture. The amount of moisture of the samples was calculated using the subsequent formula:

$$\% \text{ of moisture content} = \frac{E}{C} \times 100 \quad \text{Equation 3.1}$$

Where,

$$E = \text{Weight of moisture} = (\text{wt. of sample} - \text{wt. of dried sample}) \quad \text{Equation 3.2}$$

$$C = \text{Weight of sample}$$

3.4.2.2 Determination of protein

Protein (%) of the samples were estimated four stages, the total process of protein content estimation from fresh fish, dried fish and canned fish samples are stated in below-

i. Digestion: A 2g sample (chopped and ground), 4g of digestion mixture, 25ml of concentrated H₂SO₄, and 3-5 anti-bumping granules were placed in a Kjeldahl flask and digested in a digestion unit at 420°C until a light blue/green color appeared, which took approximately 1.3 hours.

ii. Distillation: After digestion, the flask was removed from the digestion unit and allowed to cool to room temperature. Once cooled, 100ml of distilled water, 25ml of Na₂S₂O₃, and 125ml of NaOH were added to the flask, which was then placed in a distillation unit. A 100ml distillate was collected in a conical flask containing 50ml of 2% boric acid (H₃BO₃) with 3-4 drops of mixed indicator solution.

iii. Titration: The distillate was then titrated with a standard HCl solution. Initially, the distillate had a dark green color, which changed to a light pinkish color at the endpoint.

iv. Calculation: The total nitrogen value was then obtained by using the following formula:

$$\text{Nitrogen (\%)} = \left[\frac{\{\text{Milliequivalent of N}_2 (0.014) \times \text{titrant value (ml)} \times \text{strength of HCl}\}}{\text{Sample weight (g)}} \right] \times 100$$

Equation 3.3

The quantity of crude protein was subsequently determined by multiplying the percentage of total nitrogen by the protein conversion factor (6.25).

3.4.2.3 Determination of lipid

The lipid content was quantified using a solvent extraction method with acetone as the solvent in a Soxhlet apparatus. A precisely measured 5g sample was placed in a paper thimble and positioned in the Soxhlet apparatus. The round-bottom flask was filled to one-third of its capacity with acetone and prepared for the system, subsequently positioned for distillation at 70°C. Lipid was removed from samples using acetone for 2 to 2.5 hours. The acetone-extracted lipid is subsequently evaporated by placing it in a pre-weighed beaker at 60°C in an electric oven.

The following formula was used for lipid determination:

$$\text{Crude Lipid (\%)} = \frac{\text{Weight of beaker with lipid (g)} - \text{Weight of empty beaker (g)}}{\text{Sample weight (g)}} \times 100 \quad \text{Equation 3.4}$$

3.4.2.4 Determination of ash

The principle of ashing is to incinerate organic waste and ascertain the residual inorganic particles. Ash concentration was assessed by subjecting the sample to a muffle furnace at 550°C for 6 hours. The specimen was subsequently chilled in a desiccator. The average weight percentage of each sample of the residual material was designated as ash. The subsequent formula was employed to ascertain ash content:

$$\% \text{ of ash content} = \frac{E}{C} \times 100 \quad \text{Equation 3.5}$$

Where, E = Weight of ash

C = Weight of sample

3.4.2.5 Determination of fatty acid profile of the products

After two hours of refluxing with a solution of KOH and EtOH at a concentration of 2 M, the lipids were eventually saponified. Through a reflux reaction that lasted for forty-five minutes and involved 3% methanolic hydrogen chloride that was dissolved in hexane, the fatty acids that were received were converted into methyl esters. After that, they were purified by either employing thin-layer chromatography (TLC) with the identical eluent or silica gel column chromatography with a mixture of hexane and diethyl ether. Direct treatment of methyl esters with a mixture of pyrrolidine and acetic acid (10:1, volume/volume) for a period of two hours while reflux was present resulted in the production of N-acyl pyrrolidines. The resultant mixture was then purified using thin-layer chromatography (TLC) on a layer of silica gel measuring 0.5 millimeters in thickness. The developing solvent used was a mixture of hexane and diethyl ether with a volume-to-volume ratio of 1:2. For the purpose of conducting GC/MS analysis of methyl esters and N-acyl pyrrolidines, a Hewlett Packard HP-5890 (GC) and 5989A (MS) apparatus that was coupled to an HP 9000/345 integrator was utilized. The GC column known as DB1 has dimensions of 30 meters by 0.32 millimeters by 0.25 micrometers. The column temperature was brought up to 300 degrees Celsius at a pace of three degrees Celsius per minute. The function of the carrier gas was performed by helium. Temperatures of 250 degrees Celsius were recorded for both the injector and the detector. The raw and final products samples were tested in such a way.

3.4.2.6 Estimation amino acid profile of the products

The amino acid composition was assessed using a slightly modified version of the Moore and Stein (Moore, 1951) technique. At first, a 25 mL acidic hydrolysis solution

containing 1 g dried biomass of each microalga was heated to $110 \pm 2.0^\circ\text{C}$ for 24 hours. The solution had been previously prepared with 6 M HCl and 0.1% phenol. Sample dilution buffer (SDB/Na) was used to stabilize the samples after they cooled. After that, a basic neutralization agent was used to bring the sample pH down to a range of 2.1 to 2.3. After that, the hydrolysates were filtered and then diluted with SDB/Na before being transferred to the injection vials. A UV detector was included in the SYKAM S433 amino acid analyzer for the analysis. The procedure had a 3% repeatability, and it employed nitrogen gas as the carrier gas while keeping the flow rate at 0.5 mL/minute at 60°C . The amino acid concentration was determined using the AA-S-18 standard Wease, which is manufactured by Sigma-Aldrich in Germany. The amino acid contents were calculated in mg/kg and subsequently converted into a percentage of the total amino acids.

3.4.3 Biochemical quality analysis

3.4.3.1 Determination of TVB-N content

The TVB-N values of fish muscle were measured using the method reported by Rana et al., (2020) with a slight modification. Approximately 10 g of fish samples were immersed in 90 mL of 6% HClO_4 . The mixture was mixed using a homogenizer for two minutes before cooling. Then, 6 drops of phenolphthalein indicator solution and 100 mL of extract were mixed in a Kjeldahl flask for titration and steam distillation. Added 20 mL of 20% sodium hydroxide (NaOH) and some glass beads to the flask then carefully placed on the distillation apparatus. Following that, the distillate was collected into a conical flask with 50 mL of 3% boric acid (H_3BO_3) and one drop of mixed indicator. Distillation was carried out at 70°C until the color turned from violet to green. Finally, 0.01 (N) HCl was used to titrate the

distillate, and the endpoint was confirmed when the mixed indicator once again took on its violet color. The following formula was used to determine the TVB-N:

$$TVB\ N\ (mg / 100g) =$$

$$\frac{\text{ml of acid titrant} \times \text{milli equivalent of N (0.014)} \times \text{normality of acid titrated (0.01)}}{\text{Sample weight}} \times 100 \quad \text{Equation 3.6}$$

3.4.3.2 Determination of peroxide value

The peroxide value of the desiccated fish was assessed with the AOAC method (1984). In a conical flask, 0.5 g of total lipids was combined with a 3:2 volume/volume mixture of glacial acetic acid and chloroform. Subsequently, 0.5 mL of saturated potassium iodide was introduced and incubated in darkness for 10 minutes. Afterwards, 30 mL of distilled water as well as 0.5 mL of 1% starch solution were incorporated, and the mixture was agitated completely before being titrated with 0.01 mol/L sodium thiosulphate. The results are ultimately presented as meq/kg of lipid.

3.4.4 Microbiological quality analysis

3.4.4.1 Sample preparation

Approximately 10 grams of muscle along with skin were swabbed from all dried and canned fish samples. The collected sample was ground in a sterile mortar using 10 ml of sterile water. A 1 ml aliquot from the crushed mixture was then transferred to a clean, dry, sterile beaker containing 9 ml of water to achieve a 1:10 dilution. This procedure was applied to all dried and canned product samples. Each sample underwent serial dilution, and aliquots from each dilution were plated to determine the microbiological count.

3.4.4.2 Determination of Total Viable Count (TVC)

The total microbial load of fish was assessed by Plate Count Agar (PCA), utilizing a slightly modified version of the methodology described by Rana et al. (2020). Firstly, 1 ml of the serially diluted (10^{-1} to 10^{-4}) sample was taken from the homogenate and placed into test tubes in 9 ml of sterile peptone water by using separate sterile pipettes.

A vortex mixer was used to mix the dilutions, and 1 ml of the appropriate dilution was placed into separate duplicate Petri dishes that were previously marked and sterilized. Following the original dilution, 15 minutes were given for PCA to cool to $45\pm 1^{\circ}\text{C}$ and 15-20 ml of the medium was added to each plate. Subsequently, the agar medium and sample dilutions were thoroughly and uniformly mixed (Figure 3.5) using the method of back-and-forth rotation and plate movement on a level surface. The Petri dish was quickly rotated and incubated for 48 ± 2 hours at 35°C after the agar had chance to solidify for 15 minutes. Finally, the total colonies forming units per gram of sample were determined by counting the colonies and multiplying the resultant number by the dilution factor. The whole protocol of TVC estimation is shown in Figure 3.6.



Figure 3.5: Microbiological quality assessment

The process of Total Viable Count (TVC) is shown hereby-

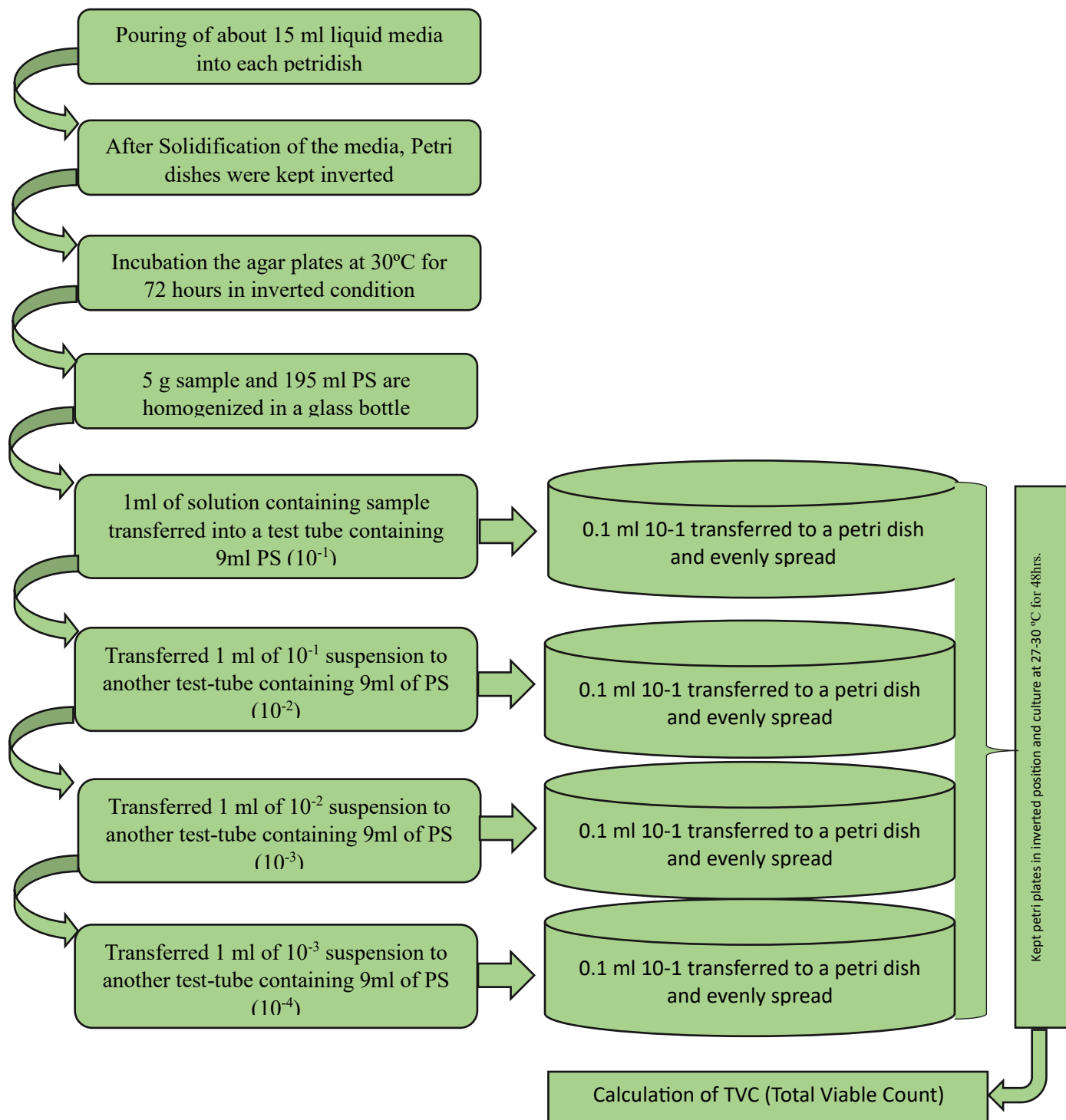


Figure 3.6: Schematically showing the Total Viable Count (TVC) method

3.4.4.3 Preparation of Nutrient Broth (NB) media

Different parts of fish samples were taken to culture in nutrient broth, which served as the principal growth medium for the species like *Salmonella*, *E. coli* and *Staphylococcus*. After dissolving 13 g of dehydrated Nutrient Broth (HiMedia, India) in 1000 ml of distilled water, the mixture was sterilized by autoclaving it at 121°C under fifteen pounds per square inch (1 kg/cm²) under high pressure for fifteen minutes.

3.4.4.4 Preparation of Eosin-Methylene-Blue (EMB) Agar media

36 g of EMB agar-based powder (HiMedia, India) was combined with 1000 milliliters of distilled water. To ensure that the powder was completely dissolved in the water, the resultant suspension was brought to boil on hot plate and allowed to continue cooking for a few minutes. After that, the medium was sterilized by autoclaving it for 15 minutes at 121°C. After autoclaving, the medium ranging from 10 to 20 ml were put onto sterile petri dishes in order to make EMB agar plates. After the medium had cooled and hardened, the plates were checked for sterility by spending the night in an incubator set to 37°C in an inverted position. EMB agar medium was used to detect *E. coli*.

3.4.4.5 Preparation of MacConkey (MC) agar media

51.5 g of dried MacConkey agar (HiMedia, India) was dissolved in a conical flask up to 1000 ml of distilled water. After being boiled in hot plate it was autoclaved at 121°C (15 lbs pressure for 15 minutes to ensure sterility, the medium was then put into sterile glassware petri dishes in increments of 15-20 ml for bigger dishes to produce a layer that was sufficiently thick. It took the medium around two hours to set completely and kept in a refrigerator at a

temperature of 4°C for later use. MC agar medium was used to detect coliform in the fish sample.

3.4.4.6 Preparation of *Salmonella-Shigella* (SS) agar media

In 1000 ml of distilled water, 63.1 g of SS agar substrate powder (HiMedia, India) was dissolved. The suspension was brought to a boil at hot plate for a very quick period of time in order to completely dissolve the powder. In order to sanitize the distilled water, it was subjected to an autoclave process that lasted for 30 minutes and had a pressure of fewer than fifteen pounds per square inch (1 kg/cm²). The agar media was not autoclaved as the uniqueness of the medium can be thrown off if it is overheated or autoclaved. After that, 10-20 ml of the medium was poured into sterile petri dishes of various sizes in order to create SS agar plates. After the solution had set, the plates were left in an incubator overnight at 37°C to ensure the sterility. SS agar medium was used to detect *Salmonella Shigella* spp. from the experimented samples.

3.4.4.7 Preparation of Mannitol Salt (MS) agar media

In order to produce MS agar plates, 55.6 g of MS agar base powder (HiMedia, India) was combined with 500 ml of distilled water and brought to the hot plate for uniform heating for a few minutes. The magnetic stirrer helps to mix the solution vigorously. This was done until the powder was completely dissolved. In order to guarantee that the medium was sterile, it was next subjected to an autoclaving process. After being autoclaved, the medium was poured onto sterile petri dishes. Following the completion of the solidification process, the

plates were put through an overnight incubation at 37°C to ensure their sterility. MS agar medium was used to detect *Staphylococcus* spp.

3.4.4.8 Enumeration of bacteria

To determine bacterial counts, a 1-milliliter sample was mixed with 9 milliliters of PBS solution, and eight sequential dilutions were prepared. Counts for each microorganism type were conducted using the three most suitable dilutions. Total viable bacterial cells were assessed using nutrient agar and the pour plate technique. The inoculated plates were incubated at 37°C for 24 hours. MC agar was used to enumerate total coliforms, with the plates inverted and incubated under the same conditions. For *Salmonella* and *Shigella* counts, SS agar was used, and plates were incubated upside down at 37°C overnight. *Staphylococcus* counts were conducted on MSA media, incubated at 37°C for 24 hours, while EMB agar was utilized for culturing *E. coli*. Colony counts ranging between 30-300 were recorded, and the total bacterial load in CFU/ml was calculated using the formula:

$$\text{CFU/ml} = (\text{Average number of colonies} \times \text{Reciprocal of dilution factor}) / \text{Amount of inoculate.}$$

Equation 3.7

3.5 Statistical analysis

The data was collected, documented, and structured in Microsoft Excel 2019 and statistical programming R software. Statistical analyses, particularly one-way analysis of variance (ANOVA) and Tukey's multiple range tests have been conducted by using SPSS software version 25 to determine the statistical significance of differences. The analyses were conducted with a significance level of $p < 0.05$. The student's t-test was used to compare the variations in the storage conditions.

CHAPTER 4

PROCESSING AND QUALITY ANALYSIS OF MARINE FISH PRODUCTS THROUGH HYBRID SOLAR DRYING METHOD

4.1 Overview of the Chapter

Dried fish products are widely recognized and cherished food across the globe, celebrated not only for its distinctive flavor but also for its numerous health benefits. It is an excellent source of protein, omega-3 fatty acids, and several essential vitamins and minerals, making it an important dietary staple in many regions. The process of drying fish, which involves removing moisture from the fish to preserve it for long-term storage, is essential in areas where fresh fish may not be easily accessible even where the peoples are sufferings malnutrition. Traditionally, fish drying is carried out by spreading the fish on mats in open spaces, usually under the sun, where the heat and wind help to evaporate the water content of the fish. While this method has been used for centuries, it comes with several challenges that affect both the quality and quantity of the dried fish produced.

One of the primary issues with the traditional, drying process can take several days or even weeks, depending on the weather conditions, making it a slow and labor-intensive operation. Furthermore, the prolonged exposure to the open environment can lead to a reduction in the quality of the dried fish. The fish may become exposed to various environmental factors such as dust, dirt, and contaminants, all of which can spoil the product and make it unfit for consumption. This prolonged drying time also contributes to a higher risk of spoilage, which can lead to financial losses for producers (Figure 4.1). Another significant

issue with the traditional method of fish drying is the risk of insect infestation. Flies and other pests are naturally attracted to the drying fish, and without proper protection, they can quickly contaminate the product. In order to safeguard the fish from these pests, many producers resort to using pesticides and chemical repellents. Prolonged exposure to these toxic substances can lead to various health complications, making the entire drying process potentially harmful.

Additionally, the lack of technological advancements in the traditional drying process hampers the ability of producers to meet the growing demand for dried fish. The open-air drying method limits the scale at which fish can be dried, and as a result, producers are often unable to meet the market demands, particularly in the international market. The lack of a hygienic and controlled drying environment also means that the dried fish produced cannot meet the standards required for export. This not only affects the financial viability of producers but also restricts their ability to tap into broader markets that could bring in greater profits.

These challenges can be effectively addressed through the use of hybrid solar dryers. These modern drying systems combine the power of solar energy with other methods such as forced ventilation to create a controlled and efficient drying environment. Hybrid solar dryers are capable of drying fish in a fraction of the time required by traditional methods, significantly improving the quality of the final product. The controlled environment of these dryers also ensures that the fish are protected from contaminants and insect infestations, reducing the need for harmful pesticides (Figure 4.1). As a result, producers can create safer, cleaner, and more hygienic dried fish in a shorter period of time, which can be sold both locally and internationally. In addition to improving the quality of the dried fish, hybrid solar

dryers also provide significant economic benefits for producers. By reducing drying time and minimizing losses due to spoilage or contamination, these dryers increase the overall efficiency of the production process. Producers can dry larger quantities of fish in a shorter amount of time, boosting their output and potentially increasing their income. Furthermore, the ability to produce hygienic and high-quality dried fish opens up new opportunities for export, which can greatly enhance the financial well-being of producers.

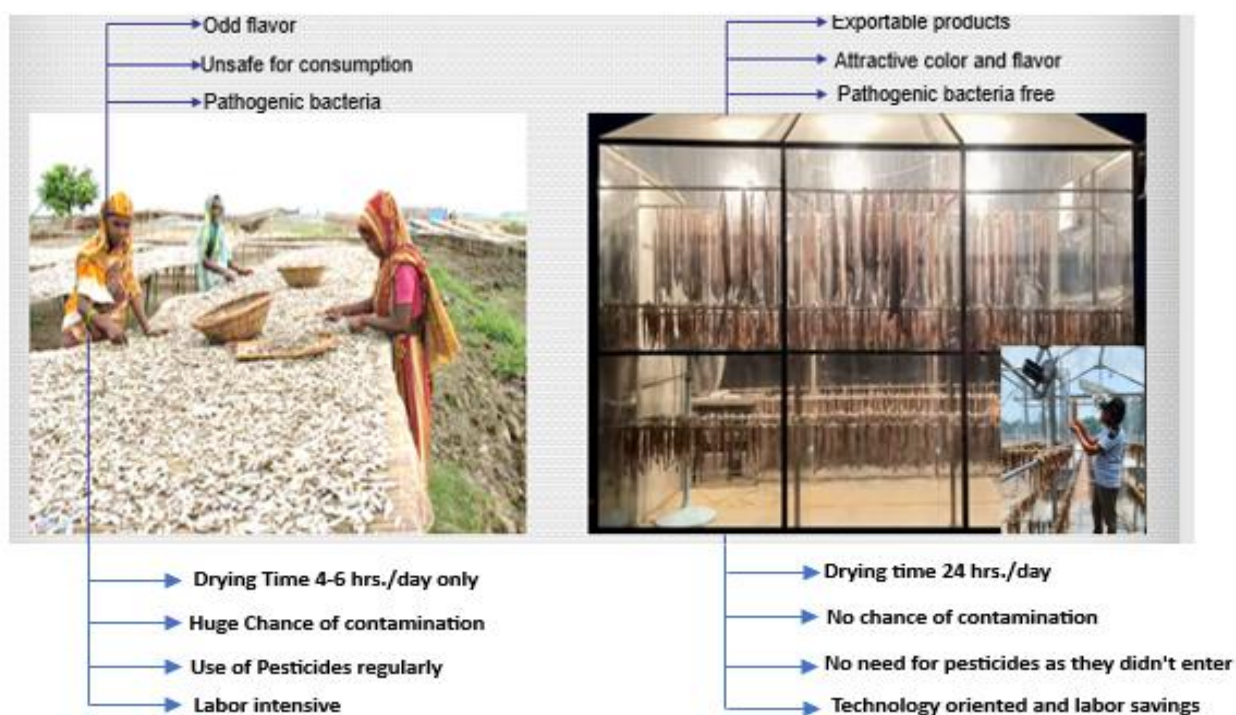


Figure 4.1: Comparison between conventional drying and hybrid solar drying methods

Focusing on Cox's Bazar, one of Bangladesh's largest dried fish production areas, we can see the potential for improvement in the standard of living of local producers. Many of the fish drying practices in this region still rely on traditional methods, which limit productivity and income. By introducing hybrid solar dryers to the area, producers in Cox's Bazar could see

significant improvements in both the quality and quantity of their dried fish, ultimately elevating their economic standing. Additionally, the adoption of modern drying technologies could lead to healthier working conditions, reducing exposure to harmful pesticides and improving the overall well-being of workers in the industry.

4.2 Methods

4.2.1 Design of Hybrid Dryer

4.2.1.1 System design and implementation

The development of an IoT-based eco-friendly smart fish dryer represents a pioneering effort to address the challenges faced by the traditional fish drying industry. By embracing smart technology and sustainability principles, this research aimed to foster safe, efficient, and eco-friendly fish drying practices, which lead to improved exports, economic growth, and environmental preservation for the fishing communities. This innovative IoT-based solar power fish dryer design is novel and eco-friendly. The methodological steps encompass system design, programming of IoT controller, installation, experimental procedure, data collection and analysis, validation, and documentation, this system could provide a sustainable and hygienic solution for fish processing in developing nations like Bangladesh (Siam et al., 2023; Akib et al., 2021).

The key components such as solar panels, batteries, inverters, charge controllers, fans, and IoT controllers are selected and integrated. The controller is programmed to maintain the optimal temperature for fish drying and respond quickly to any deviation from this value. The

drying time for fish is measured under various conditions, and the performance of IoT controller to maintain optimal conditions is evaluated. The temperature in the heating area was calculated from the air flowing.

A battery of 800 Amps, 36 volts for energy storage; solar power panels generating a total of 1200 watts; 30 Amp charge controller for managing the energy storage process; An IPS of 1500-watt, 220 volts for converting the stored DC power to AC; An 80-watt exhaust fan for venting the air from inside; An 18-watt DC fan for internal air circulation. The system primarily consists of four parts: - as follows solar panels, battery and controller, heating unit, and IoT controller. The panels convert sunlight into electrical energy, which is stored in the battery for later use. The stored energy from solar panels is regulated by a 30 Amp charge controller and stored in an 800 Amp, 12 volts battery. This setup ensures the smooth operation of the system even in the absence of sunlight. The heating unit consists of a 1500-watt, 220-volt IPS that converts the stored DC power to AC power to heat up the unit. This heating unit is responsible for maintaining a suitable temperature inside the dryer during nighttime or cloudy weather.

4.2.1.2 Programming the IoT controller

The IoT controller was connected to the exhaust fan and DC fan. The controller adjusted the inside temperature of the dryer by controlling the fans' operation. During the day, the greenhouse-like structure trapped sunlight, creating a warm environment conducive to drying. The exhaust and DC fans were regulated by the IoT controller, which maintained the optimal temperature and airflow. At night or during insufficient sunlight conditions, the

heating unit was used to continue the drying process. The overall schematic diagram and design of the IoT-based smart hybrid solar dryer were shown in Figure 4.2.

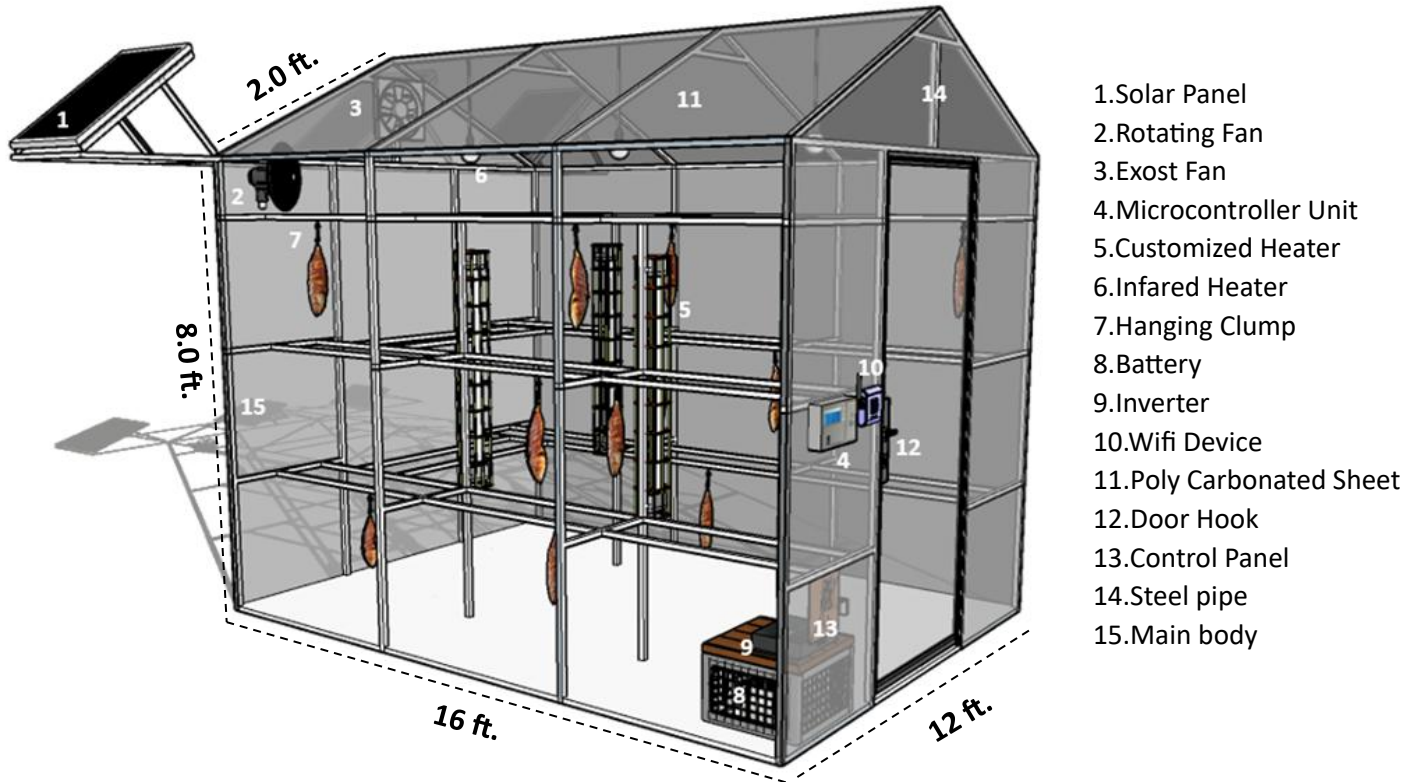


Figure 4.2: Design of hybrid solar dryer

4.2.2 Installation and Set-Up

i. Establishment of basement

The foundation of the solar sun dryer plays a critical role in ensuring structural stability, longevity, and resilience to environmental factors. The basement structure was designed with dimensions of 18 feet in length, 16 feet in width, and 8 feet in height. An additional 2.5 feet was allocated for the upper triangular section of the hut to optimize airflow

and heat dissipation. A cemented basement, elevated 1.5 feet above ground level, was constructed to provide a robust and moisture-resistant platform. The elevation ensures protection against ground-level moisture, flooding, and pest intrusion, critical for maintaining the hygienic environment required for food drying. The concrete base was mixed with high-quality Portland cement, sand, and gravel in a standard ratio (1:2:4) to ensure strength and durability. It was reinforced with iron rods arranged in a grid pattern for added support and resistance to heavy loads. The surface was leveled meticulously, and waterproofing treatments were applied to prevent seepage and cracking over time. This foundational structure not only supports the weight of the dryer but also enhances its overall operational efficiency by maintaining stability during adverse weather conditions.

ii. Structural development

High strength iron angles were used to fabricate the solar sun dryer primary framework to cater for the structural integrity and external forces like wind and mechanical stress. The main frame used iron angles with thickness of 6 mm which gives a frame solid enough to carry the weight of solar panels, racks and the coverings. The framework was reinforced and the hanging racks were to hold the materials being dried by using sub-angles, thickness 2 mm. High grade plastic fiber sheets covered the structure's walls and roof. Lightweight yet durable high-density polyethylene (HDPE) sheets, good for transmitting sunlight but protecting from the rain and dust and insects, were chosen for these sheets. It's triangular and 2.5 feet high, making for superior airflow and heat circulation to evenly dry what's below. In addition, corrosion resistant materials and protective coatings are employed to enable the long life of the framework in humid and high temp storage environments. The

structure is also designed modularly to make it easy to disassemble and move if such a need is produced (Figure 4.3).

iii. Solar panel setup

A sustainable energy source was established for the solar sun dryer through the integration of a 450-watt solar panel system. The solar panel, mounted at an optimal angle on the roof, was positioned to maximize exposure to sunlight throughout the day. The placement and tilt angle were calculated based on the geographic location and seasonal variations to ensure efficient energy capture. An inverter was incorporated into the system to convert the DC power generated by the solar panel into AC power, suitable for operating electrical components such as the heating and cooling units, sensors, and IoT controllers. Additionally, a 200 Ah battery was installed to store excess energy generated during peak sunlight hours. This storage system ensures uninterrupted operation during periods of low sunlight, such as cloudy days or nighttime.

The solar energy system was equipped with a charge controller to regulate the flow of electricity, preventing overcharging and deep discharge of the battery. This enhances the lifespan of the battery and maintains the efficiency of the energy system. The integration of the solar panel system not only reduces reliance on external power sources but also aligns with sustainability goals by utilizing renewable energy for dryer operation. The energy-efficient design of this setup is critical for minimizing operational costs and environmental impact.

iv. Heating unit installation

A dual heating system with four 100-watt heaters and four 110-watt infrared heating lamps was installed in the new solar sun dryer, a critical component within its heating unit (Figure 4.3). The solar panel and battery system charged and powered these elements, guaranteeing even and reliable operation. To provide an even heat distribution, the drying chamber heaters and lamps were placed and supported by high conductivity aluminum heat absorbing plates placed.



Figure 4.3: Installation of hybrid solar dryer

The unit was then mounted securely to its structural frame and insulated heat-resistant materials to retain the heat and protect the structure. To ensure consistent product quality, and control temperature according to the drying needs, an adjustable thermostat was incorporated. The system was rigorously tested under multiple conditions and fine-tuned for best performance and reliability.

v. Cooling unit installation

Four 30w traditional cooling fans, two 35w intake fans, and two 35w exhaust fans were used to cool the unit which was powered from a solar panel and battery system. On the fans, we strategically organized them to draw the fans from one side to the other, and there's an intake fan as well as taking in fresh air, and then on the other hand, the fans will blow them out and also on the other fans. Fan operation was automated when temperature thresholds were exceeded using temperature sensors to ensure a consistent drying environment. Efficiency, energy use, and noise levels of the system were tested and adjustments made to gain optimal performance.

vi. Development of mobile application

A mobile application was developed to enable remote monitoring and control of the solar sun dryer. The app was designed with a user-friendly interface, accessible on both Android and iOS platforms, ensuring compatibility and ease of use for operators. The application integrates functionalities such as real-time temperature and humidity monitoring, operational status updates, and energy usage statistics. Users can adjust parameters such as drying temperature and duration directly through the app. It also features notifications and

alerts for system faults or when drying is complete, enhancing the overall convenience and efficiency of the operation (Figure 4.4).

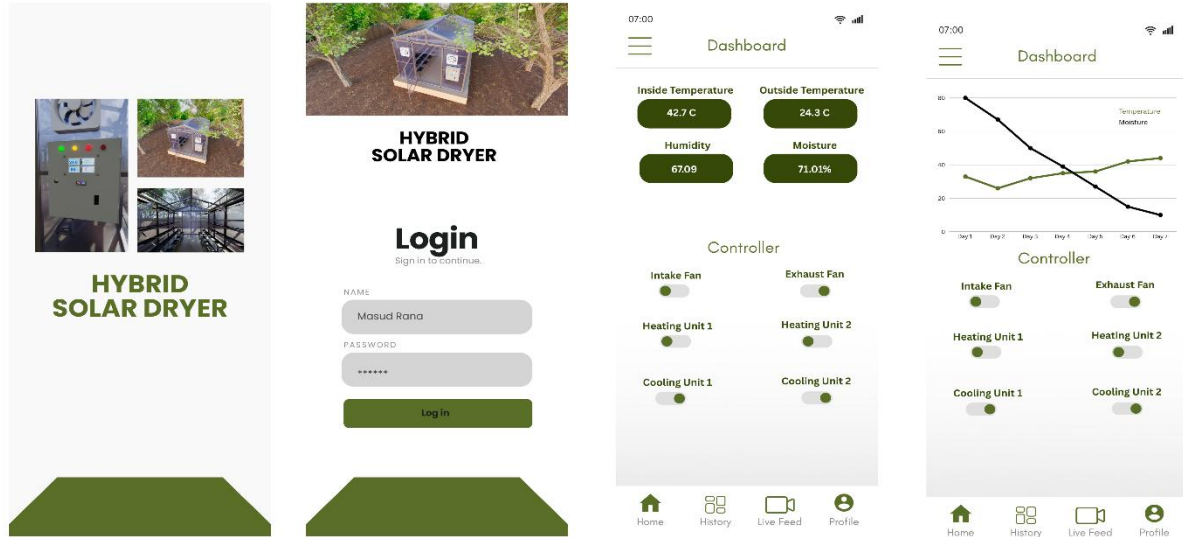


Figure 4.4: Features of mobile application

The development process involved the use of cross-platform frameworks such as flutter, ensuring seamless performance across devices. The app was rigorously tested to address any compatibility issues and to validate its integration with the IoT controller.

vii. Setting of sensors and IoT controller for automation

Automation of the solar sun dryer was achieved by integrating a network of sensors and an IoT controller. Temperature sensors, humidity sensors, and airflow sensors were strategically placed within the drying chamber to provide real-time data.

The IoT controller, programmed with advanced algorithms, processes sensor data and autonomously adjusts the heating and cooling units to maintain optimal drying conditions. A Wi-Fi module was included to facilitate connectivity between the dryer and the mobile app, enabling remote monitoring and control. The installation process involved wiring the sensors and controller securely to prevent interference or damage. The IoT system was calibrated and tested to ensure accurate data collection and responsive adjustments. Automation significantly enhances operational efficiency, reducing manual intervention and ensuring consistent drying quality.

viii. Trial and correction of error

The trial phase was involved comprehensive testing of the entire system under various operational conditions. Drying tests were conducted using different fishes viz loitta (*Harpodon nehereus*), churi (*Trichiurus lepturus*), rupchanda (*Pampus chinensis*), shrimp (*Penaeus monodon*) and surma (*Scomberomorus cavalla*) for evaluating parameters such as drying time, energy efficiency, and product quality. During the trial phase, potential errors such as uneven heating, sensor inaccuracies, and app connectivity issues were identified. Corrective measures included recalibrating sensors, fine-tuning the IoT controller, and updating the mobile app's software. Additionally, adjustments were made to the structural setup and positioning of heating and cooling units to improve performance. The iterative process of testing and correction ensured that the solar sun dryer operates reliably and efficiently. This phase validated the design and functionality of the system, making it ready for deployment. This detailed approach not only documents the technical aspects but also demonstrates the iterative

problem-solving and integration of advanced technologies, emphasizing the system's innovation and practicality for a doctoral-level report.

4.2.3 Production of Dry Fish Products

4.2.3.1 Collection of fish

Fresh churi (ribbon fish) and loitta (bombay duck) fish were collected from the fish landing center of Cox's Bazar, with churi averaging 180-200 grams each and loitta averaging 100-120 grams each. The total weight of the churi was 500 kg, while the loitta totaled 450 kg. During sample collection, carefully observe the damaged areas, color, and overall quality of the fish. Fish that exhibited vibrant color and freshness were selected, whereas those with diminished quality were discarded. Immediately after collection, the fish were preserved with flake ice before dressing to maintain their quality.

4.2.3.2 Preparation of fish for drying

The fish were graded based on size, weight and thickness, then gutted, bled, and thoroughly washed with clean water to ensure high-quality preparation. After draining out water from washed raw materials, the fishes were prepared for salt and other ingredients treatment. Following that, the fish were soaked in a 10% salt and 1.5% turmeric powder solution for 5 minutes. During brining it was ensured that all fishes were completely immersed into salt solution. Two plastic buckets were used for two species of fish. After brining the fishes were taken out of the salt solution and kept them on a plastic tray for drying at room

temperature for about 15 minutes. The drying was necessary for conditioning of the fishes with salt solution.

4.2.3.3 Hanging of Fish

The prepared churi and loitta fish were placed inside the hybrid solar dryer using dryer hooks, ensuring that none of the fish overlapped during placement. Two species were placed separately on the hanging line (Figure 4.5). At the time of hanging the fish made sure to arrange them in a way that the two churi fish were tied together by their tails, and the loitta fish passed through one fish's mouth into the other's mouth.



Figure 4.5: Production of quality dried fish products through hybrid solar dryer

This way, once hung, they are securely positioned and firmly fastened in the hanging yard. I hung the fish in a specific pipe, ensuring that air and temperature reached each fish evenly.

4.2.3.4 Dryer operation for efficient drying with complete phase functionality

Immediately after loading the dryer, the gate was locked, and the main switch was turned on to begin the drying process. It was ensured that all sensors, particularly the temperature and relative humidity sensors, were functioning correctly. The optimum drying temperature (35-40°C) and relative humidity (40-50%) were set, and a program was installed to maintain these conditions throughout the entire operational period. After the full operational phase, temperature, relative humidity, and other parameters were checked manually to verify whether the data displayed were accurate.



Figure 4.6: Parameters checking during operation

4.2.3.5 Recording the temperature, relative humidity (RH) values, and sample weight

The temperature inside and outside the dryer, relative humidity values, and the weight of the experimental fish were measured every hour using a temperature sensor, RH sensor, and digital balance, respectively (Table 4.1 & Figure 4.6). All data were meticulously recorded for future assessment of the dryer's performance.

Table 4.1: Temperature and RH profile of the hybrid dryer in a single operation (Winter season: November)

Time	Environmental Temperature (°C)	Inside Temperature (°C)	Relative Humidity (%)
08.00 AM	19.22	38.52	45.6
09.00 AM	20.23	39.88	48
10.00 PM	20.88	37.45	44.8
11.00 AM	21.33	38.00	52.4
12.00 PM	21.67	42.35	50.2
13.00 PM	22.65	46.56	55
14.00 PM	22.78	54.60	42
15.00 PM	23.22	49.44	43.7
16.00 PM	22.45	38.28	52.3
17.00 PM	20.43	37.66	48.7
18.00 PM	20.04	39.66	40.8
19.00 PM	19.32	38.77	44.2
20.00 PM	18.00	39.45	48
21.00 PM	18.05	36.54	42.4
22.00 PM	18.17	38.66	54.3
23.00 PM	17.67	38.45	47.5
24.00 AM	17.54	37.88	44.5
01.00 AM	17.33	38.23	49
02.00 AM	17.45	36.74	52.5
03.00 AM	16.88	35.87	50
04.00 AM	16.72	37.24	47.4
05.00 AM	17.53	38.34	44.8
06.00 AM	18.40	40.22	42.7
07.00 AM	18.76	38.09	47.3

4.2.3.6 Final products harvesting, packaging and storing

Once the experimental fish reached the desired moisture level (<16%), the drying operation was halted, and the final products were carefully collected. The dried fish were then left to rest with proper air circulation to allow the products to mature, it was taken 5 hrs. to complete the process. During the harvesting time dry fishes were handled smoothly to avoid the broken. From 410 kg of raw churi and 540 kg of raw loitta processed separately, 68.5 kg and 92 kg of dried products were obtained, respectively. After full maturation, the fish were kept in three different types of packaging-polythene bags, plastic jars, and cartons-and stored at room temperature to evaluate which packaging material is best for long-term preservation of dried fish and to determine the shelf life of the experimental dried fish products (Figure 4.7).

4.2.4 Collection and Preservation of Traditional Dried Products

To compare the quality of market dried fish of the same species another experiment was planned. For this purpose, traditional dried churi and loitta fish which was reported dried in the current season, were collected from shutki fish market, Cox Bazar and stored at ambient condition (26-28°C) with same packaged condition as was for solar dried fish products. At the time of collection these dried fishes showed good general appearance. The proximate composition, sensory properties, rehydration capacity, chemical and microbiological analysis of the traditional dried fish samples were done as were in the experimental dried fish.

4.2.5 Quality Testing Period

The physiological, nutritional, biochemical, and microbiological qualities of the products were evaluated at 30-day intervals, and monitoring continued until the products no

longer met acceptable levels, as determined by sensory analysis. The products dried using the smart dryer were tested for 360 days, while those dried using traditional methods were tested for 90 days. This extended evaluation was necessary because the smart dryer products met all quality standards in nutritional, biochemical, and microbiological aspects, whereas the traditionally dried products showed fungal growth and higher microbial levels after 90 days. Due to the reasons mentioned, products dried with the smart dryer were evaluated over a period of 360 days, while traditionally dried products were considered unsuitable after 90 days of storage at ambient temperature (Figure 4.7). Consequently, the shelf life of the smart dried fish products was determined to be 360 days, compared to 90 days for the traditionally dried fish products.



Figure 4.7: Packaging of dried churi and loitta fish

4.2.6 Determining the Dryer Efficiency, Moisture Removed of the Smart Solar Dryer

The efficiency of a drying chamber, solar collector, and other system improvements are all featured in the entire thermal assessment of a smart solar dryer.

The efficiency of the designed smart solar dryer is estimated using the following formula (Leon et al., 2002; Bennamoun, 2012):

$$\text{Efficiency, } \eta = \frac{W \times L}{(I \times A) + P_f + P_h} \quad \text{Equation 4.1}$$

Where,

η = Smart solar dryer efficiency.

W = Weight of water evaporated from the fish (kg)

L = Latent heat of vaporization of water (J/kg)

I = Radiation of solar (W/m^2)

A = Solar collector area (m^2)

P_f = Power consumption of fan ($watt$)

P_h = Power consumption of heater ($watt$)

The quantity of moisture removed is estimated using the following formula: (Reza & Hossain, 2023)

$$\text{Moisture Removed, } M_R = \frac{M_p \times (M_i - M_f)}{(100 - M_f)} \quad \text{Equation 4.2}$$

Where,

M_p = Weight of fish before testing (kg)

M_i = Moisture content of fish before testing

M_f = Moisture content of fish after testing

4.2.7 Physiological Quality Analysis of Dried fish products

4.2.7.1 Determination of water reconstitution properties of dried fish products

Moisture absorbed by dried fish immersed in water at a certain temperature and time is called water reconstitution or rehydration. It is one of the most important physical parameters to assess the quality of the dried products and expressed as percent water reconstitution under the defined condition. The behavior of water reconstitution was explored using the approach described by Hasan et al. (2016) including minor modifications. Firstly, 8-10 g of substance were measured and immersed in water for 60 minutes at room temperature (26-28°C), 40°C, and 60°C. The soaking dry fish were separated from the water every 15 minutes and weighed again. Finally, the following formula was used to determine the percentage of water reconstitution:

$$\text{Water reconstitution (\%)} = \frac{W_r - W_i}{W_i} \times 100 \quad \text{Equation 4.3}$$

Where,

W_i = Initial weight of dried fish

W_r = Final weight of rehydrated dried fish

4.3 Results

4.3.1 Performance of Hybrid Solar Dryer

4.3.1.1 Efficiency of dryer and variation in drying rate

To evaluate the efficiency of the solar-powered, IoT-controlled fish dryer, we investigated its internal and external environment data:

(a) Exhaust fan power rating: 18 W

Operating hours: 20 hours

The power consumption for one (01) fan over 20 hours is:

Power Consumption for one (01) fan = $18\text{W} \times 20\text{hours} = 360\text{Wh} = 0.36\text{kWh}$ Equation 4.4

So, Total Power Consumption for 8 fans = $0.36\text{kWh} \times 8 = 2.88\text{kWh}$

and,

(b) Heater power rating: 300 W

Operating hours: 7 hours during nighttime

Power Consumption for one heater = $300\text{W} \times 7\text{hours} = 100\text{Wh} = 2.1\text{kWh}$ Equation 4.5

For 6 heaters, the total power consumption will be:

So, Total Power Consumption for 6 heaters = $2.1\text{ kWh} \times 6 = 12.6\text{ kWh}$

Here,

Weight of water evaporated from the fish (W) = 0.603 g

Latent heat of vaporization of water (L) = $22.6 \times 10^5\text{ J/kg}$

Radiation of solar (I) = 1380 W/m^2 Equation 4.6

Solar collector area (A) = $960 \times 660\text{ mm}^2 = 0.6336\text{ m}^2$

Power consumption of fan (P_f) = $2.88\text{kWh} = 2880\text{ Watt}$

Power consumption of heater (P_h) = $12.6\text{ kWh} = 12600\text{ Watt}$

and, Smart solar dryer efficiency (η) = ?

So, the Efficiency of the dryer is

$$\begin{aligned}\eta &= \frac{W \times L}{(I \times A) + P_f + P_h} \\ &= \frac{(0.603 \times 2260000)}{(1380 \times 0.6336) + 2880 + 12600} \\ &= 83.328\%\end{aligned}\quad \text{Equation 4.7}$$

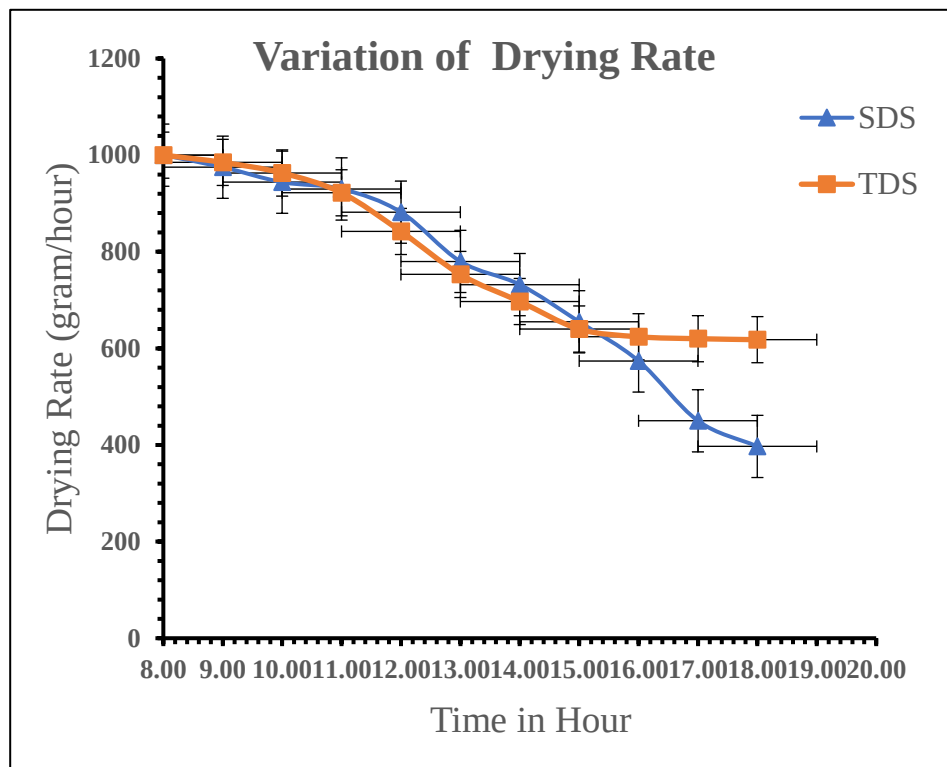


Figure 4.8: Variation of drying rate in smart and traditional dryers

Figure 4.8 illustrates the changes in drying rates that were observed. When the smart solar dryer is utilized to dry fish, it has been demonstrated that the drying rate of the fish decreases continuously with drying time. During the period of 11 hours of observation, the smart solar dryer (SDS) operated at an average drying rate of 0.058 kg/hour whereas an average drying rate of 0.022 kg/hour in the traditional drying process (TDS). Consequently, the rate at which fish were dried in the smart solar dryer (SDS) was 2.62 times more rapidly than the rate at which fish were dried in the traditional process (TDS).

4.3.1.2 Variation of moisture removed

The variation of moisture removed (%) with the drying time is illustrated in Figure 4.9, during the study period, moisture was removed from the dried fish more quickly with the smart solar dryer (SDS) than using the traditional drying method (TDS). The moisture removed from fish is more quickly during the first 9 or 10 hours in the smart solar dryer (SDS) than traditional dryer (TDS), but subsequently, the moisture removed decreases due to low moisture content. Throughout the 11-hour observation period, the smart solar dryer (SDS) removed an average of 24.373 % of the moisture, which was higher than the TDS (21.20 %).

The investigation took place at 8:00 AM on a day with an estimated air velocity was 1.4 m/s and an ambient temperature was 28 °C. Throughout the evaluation, it was found that the smart solar dryer (SDS) could obtain the highest temperature of 54.6 °C, whereas the traditional drying technique (TDS) could only reach the highest temperature of 36.5 °C. The range of temperature inside the smart dryer was considerably greater than the temperature in the surrounding environment during daytime hours.

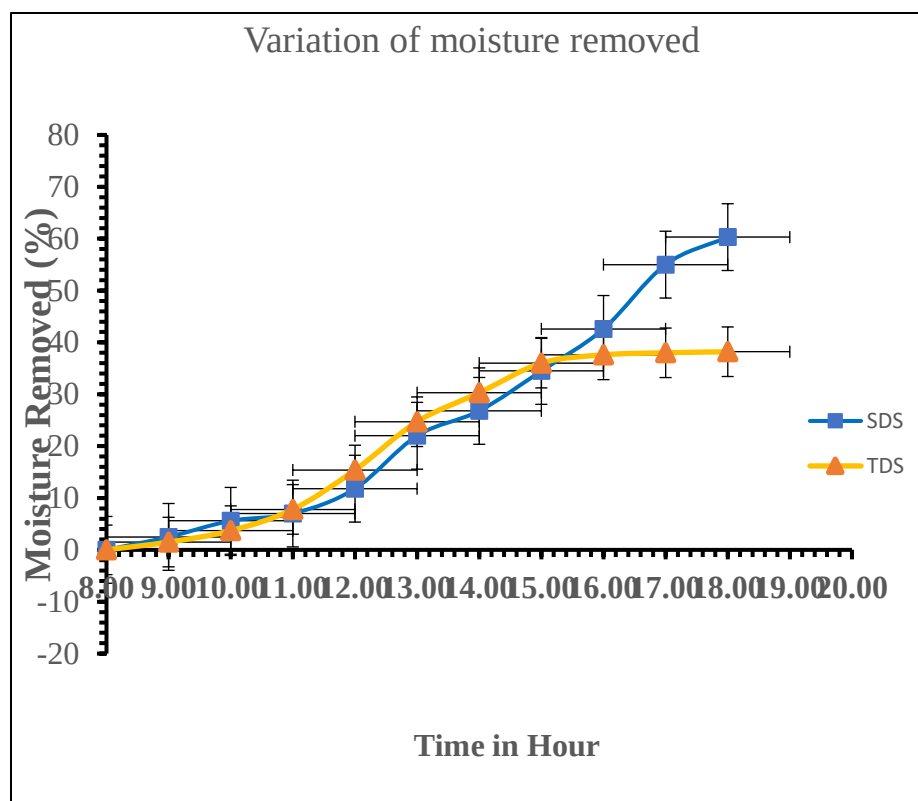


Figure 4.9: Variation of moisture removed (%) in smart and traditional dryers

4.3.2 Results of Quality Analysis

4.3.2.1 Physiological properties of the dried fish products

4.3.2.1.1 Sensory properties of traditional and smart dried churi and lo0itta

The sensory parameters such as color, odor, texture, insect infestation, presence of broken pieces and overall quality of solar dried churi, loitta and traditionally dried same products were examined on nine-point scale considering 9.0 as best and 1.0 as worst. The sensory quality and score of traditional and smart dryer churi and loitta fishes are presented in Figure 4.11, 4.12, 4.13 and 4.14 respectively. Smart dried churi and loitta were found the highest scores ($p < 0.05$) of color, flavor, texture, and general appearance when compared with

traditional dried churi and loitta. The color, flavor, texture, and general appearance of TD churi and loitta showed that they were of good quality for a storage period of up to 30 days. After being stored for up to 90 days, the product's colors changed to a slightly more intense shade of yellow or black. The texture and firmness of TD fish were lost after being stored for up to 60 days. After 90 days of storage, both types of traditionally dried products exhibited fungal growth and developed a rancid odor. However, during storage of 360 days, the color, flavor, texture, and general appearance of SD churi and loitta revealed that they were of high quality in plastic jars, followed by carton boxes and polythene bags respectively.

Quality deterioration was clearly observed in TD fish samples collected from market stored at ambient temperature (Figure 4.10). At 90 days of storage the fungal growth was found on the body surface of both TD fish samples and hence was rejected. The results of the sensory analysis indicated that the SD fish products were found better than the TD products. After three months of storage, SDC and SDL stored at ambient temperature remained good condition whereas traditionally dried churi and loitta become spoiled.



Figure 4.10: Checking of physiological quality of dried churi (1. SDC & 2.TDC)

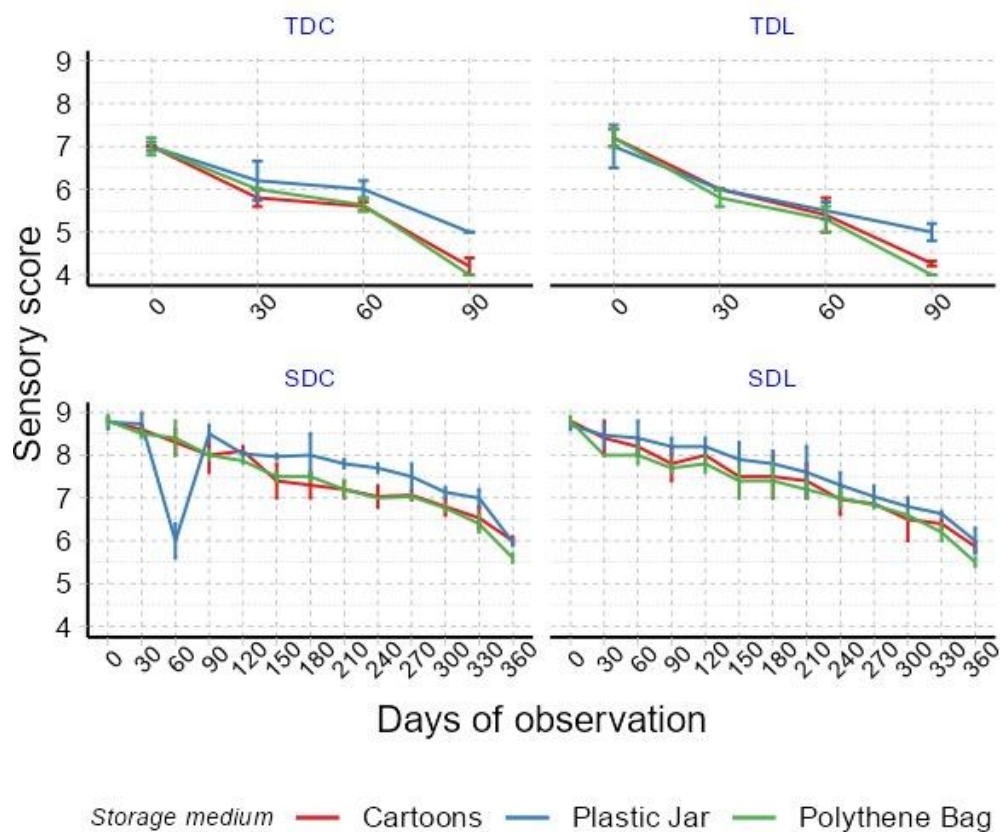


Figure 4.11: Changes in color of SDC, TDC and SDL, TDL during storage.

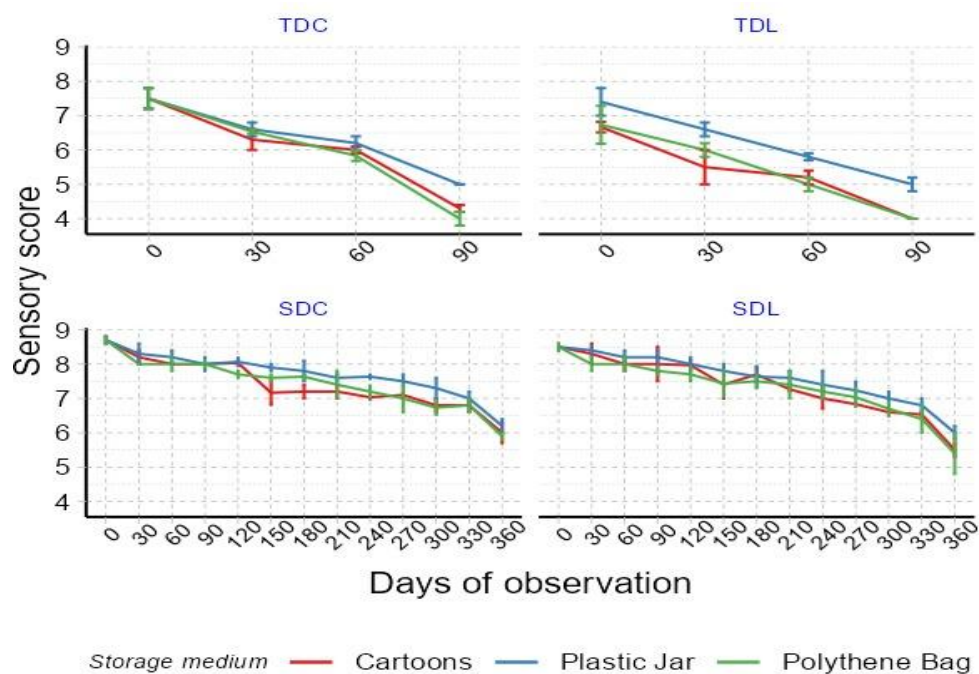


Figure 4.12: Changes in flavor of SDC, TDC and SDL, TDL during storage.

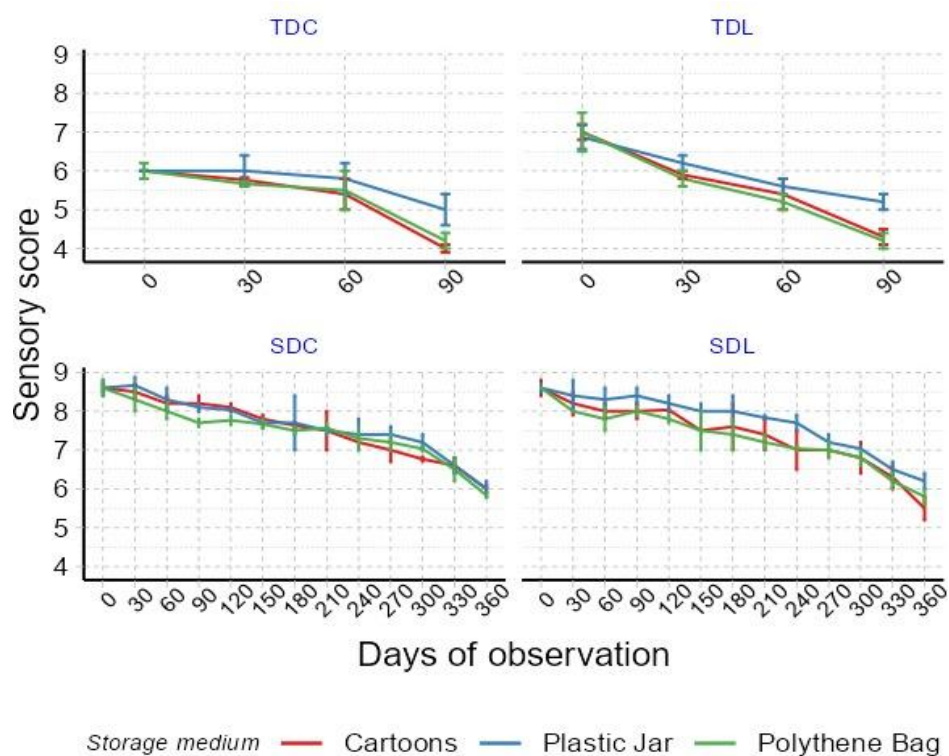


Figure 4.13: Changes in texture of SDC, TDC and SDL, TDL during storage

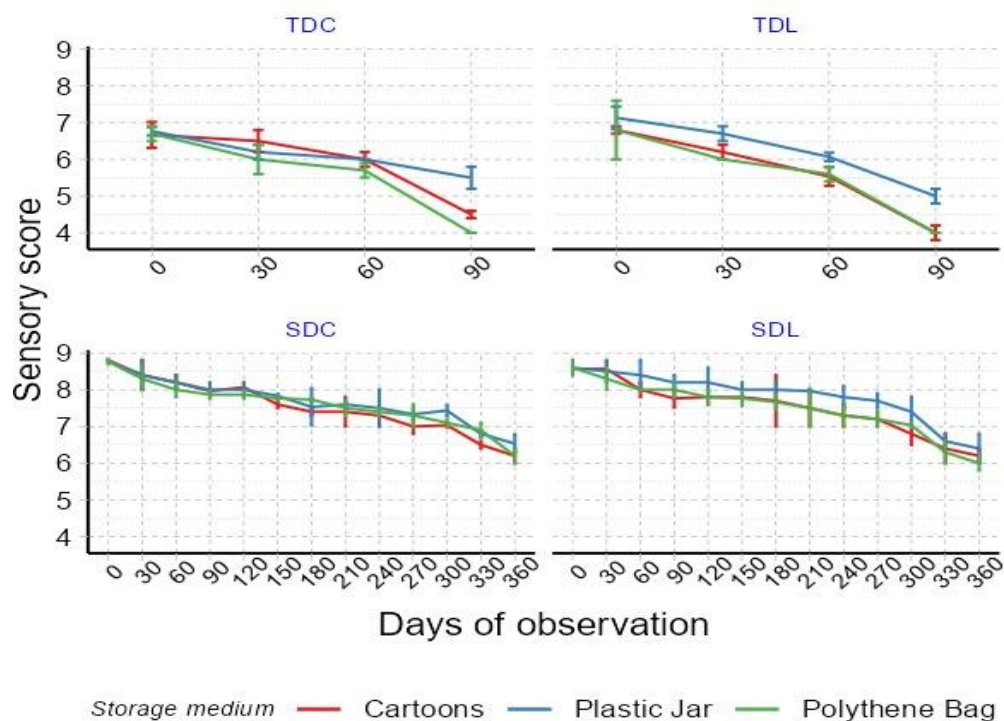


Figure 4.14: Changes in general appearance of SDC, TDC and SDL, TDL during storage.

4.3.2.1.2 Broken % during processing and storage

The number of broken pieces in the SD was significantly lower than in the traditional one. Furthermore, compared to dried churi, there were more broken pieces in dried loitta (Figure 4.15). During the processing period, the highest number (15%) of broken pieces was found in TDL, and the lowest (1%) in SDC. Furthermore, the highest number of broken pieces (5%) was observed in TDL, and broken pieces were absent both in SDC and SDL.

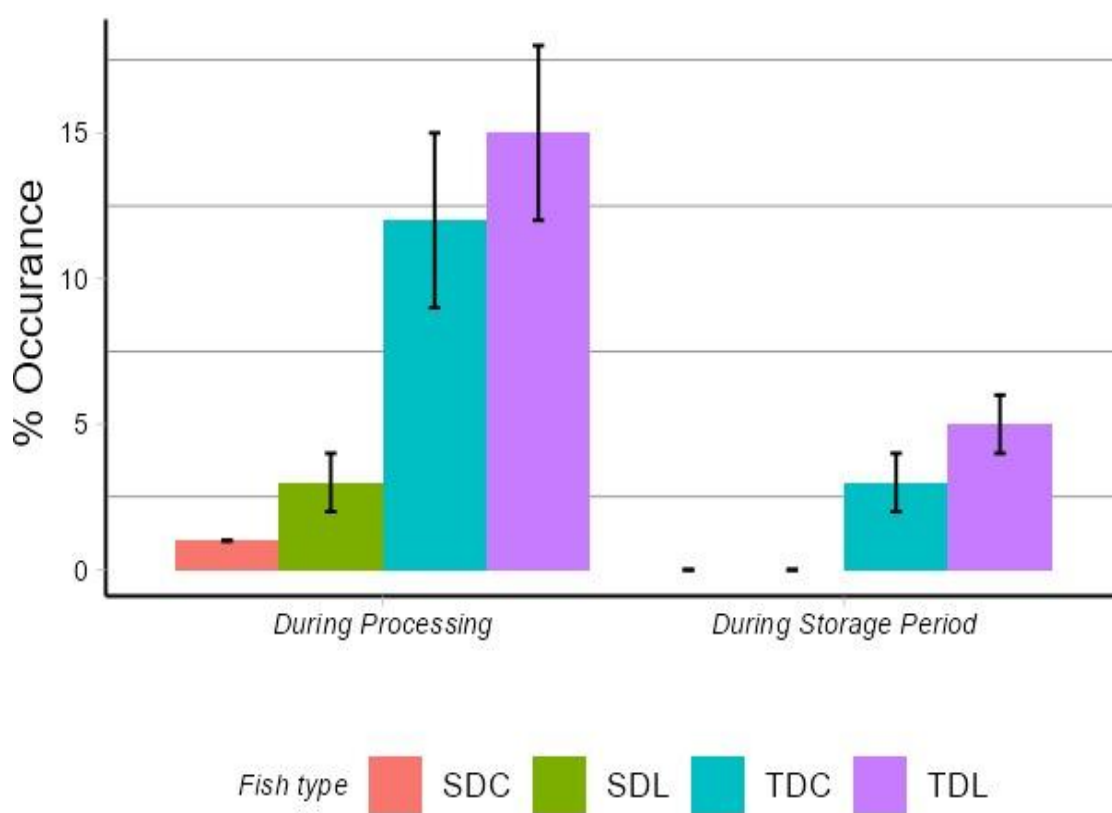


Figure 4.15: Broken (%) in TD and SD churi and loitta

4.3.2.1.3 Water rehydration properties of the products

The water reconstitution of collected smart dried and traditional dried fishes is illustrated in Figure 4.16. In general, when water temperature and soaking duration increase, dried fish products ability to retain water increases. In the present investigation, SDC was

found to consist of 50.23 % water after 60 minutes at ambient temperature, whereas SDL TDC and TDL fish were shown to have 49.38%, 30.35 and 28.57%, respectively. Moreover, during 60 minutes of soaking at 60°C, the SDC and SDL values are much higher than those of TDC and TDL, and the changes have become most prominent. The significant variations ($p < 0.05$) in water retaining capacity were detected across the time and temperature.

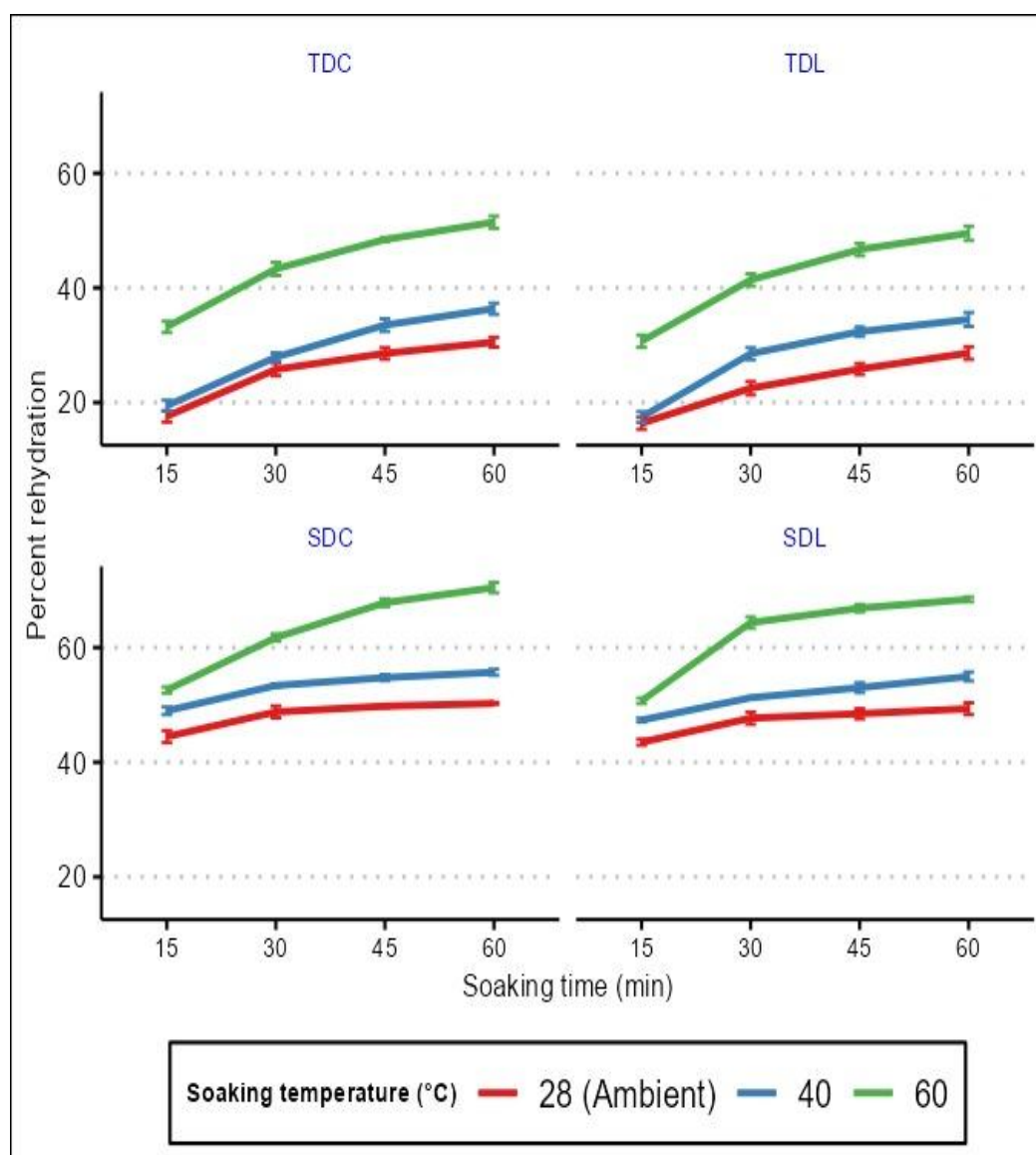


Figure 4.16: Water reconstitution at 28°C, 40°C, and 60°C of SD and TD churi and loitta fish

4.3.2.2 Nutritional quality of the dried marine fish products

4.3.2.2.1 Proximate Composition of traditional and smart dried churi and loitta fish

The proximate compositions of TD and SD churi and loitta fish were found to fluctuate significantly ($p < 0.05$) on a statistical level. The variations of proximate composition during the storage period shown in table 4.2 and Table 4.3. At the beginning, the highest initial moisture content was observed in TDC (28.88%) and TDL (27.54%). In contrast, solar-dried samples had significantly lower moisture content: 14.5% in SDC and 15.3% in SDL. Moisture levels in the traditional dried samples increased significantly, with TDC rising from 28.88% to 33.63% and TDL from 27.54% to 33.65% over the storage at ambient condition (Figure 4.17 and Table 4.3). Solar-dried samples also showed gradual moisture regain, though to a lesser extent, reaching 30.88% in SDC and 30.56% in SDL. Among the packaging materials, samples stored in polyethylene bags showed the highest rate of moisture absorption, followed by those in cartons. The slowest moisture reabsorption occurred in samples stored in plastic jars, across both traditional and solar products. Packaging plays a critical role in moisture retention, with plastic jars offering superior protection and thus extending the shelf life of dried fish products. The combination of solar drying and plastic jar packaging is thus optimal for prolonging the shelf life of dried fish, maintaining product quality and safety during long-term storage.

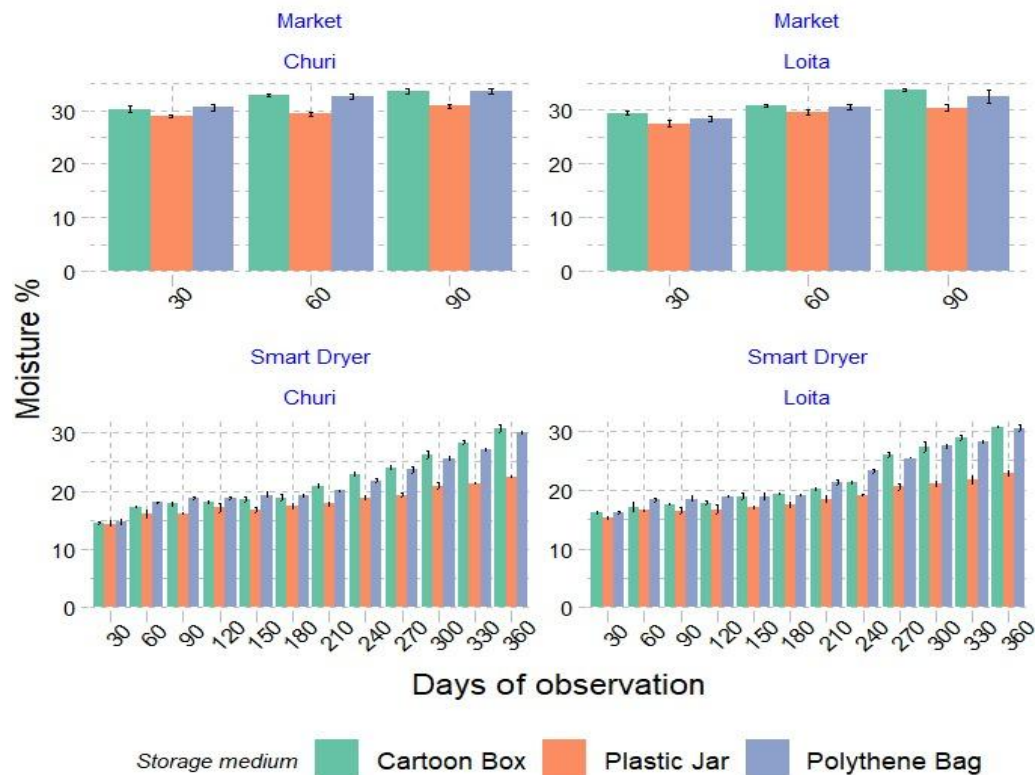


Figure 4.17: Changes in moisture (%) of TD and SD churi and loitta during storage

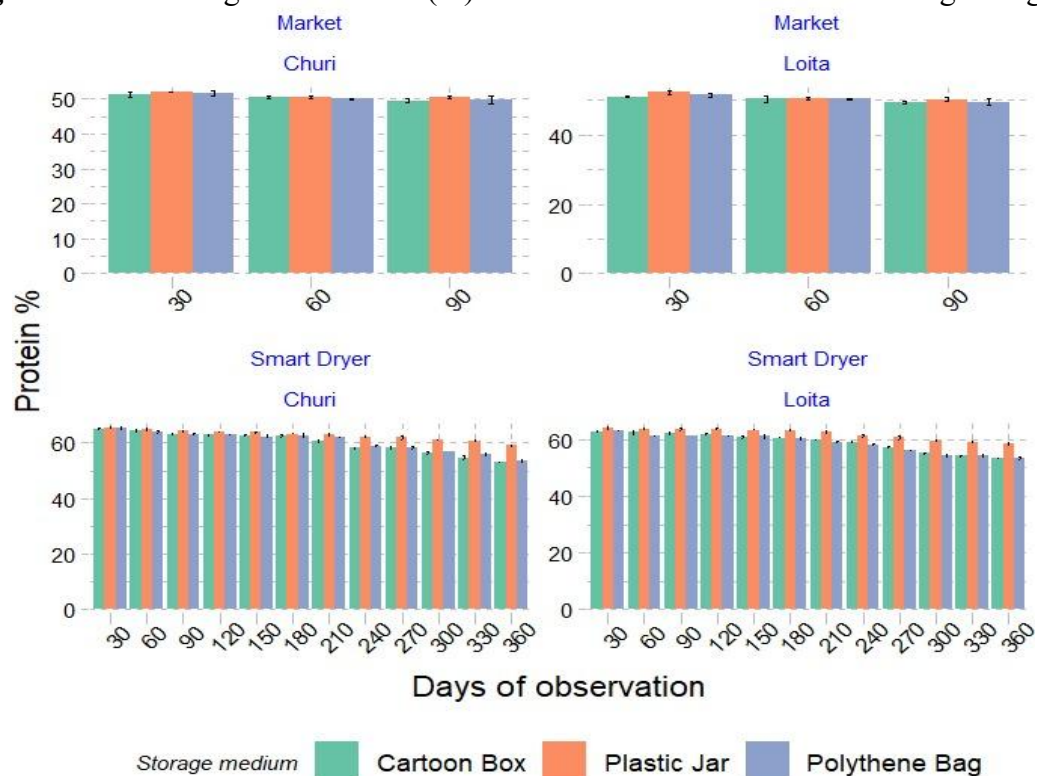


Figure 4.18: Changes in protein (%) of TD and SD churi and loitta during storage

Prior to storage, the highest protein contents were observed in SDC and SDL, at 65.36% and 64.13%, respectively. Conversely, the lowest protein levels were recorded in TDC and TDL, with values of 52.42% and 53.24%, respectively. An increase in moisture content in dried fish products led to a reduction in protein percentage, primarily due to dilution effects, protein degradation, and enhanced microbial activity. During storage, protein content remained higher in solar-dried samples (ranging from 53.11% to 59.16%) compared to traditionally dried counterparts (48.66% to 49.23%). Packaging materials significantly influenced protein retention throughout the storage period. By the end of the 360-day storage, the greatest protein loss occurred in samples stored in polyethylene bags, followed by those stored in cartons, while the least degradation was observed in samples packed in plastic jars. The highest retained protein content at the end of storage was recorded in SDC (59.16%) packed in plastic jars, whereas the lowest was in TDL (48.66%) stored in polyethylene bags. The trend of protein content changes across storage durations for all treatments is illustrated in Figure 4.18.

The lipid content in solar-dried products was initially recorded at 9.34% for SDC and 7.87% for SDL, while traditionally dried products collected from the market had lipid contents of 8.63% in TDC and 7.86% in TDL. Over the storage period, lipid levels declined, with SDL retaining the highest amount (7.12%) and TDC showing the lowest (6.0%) by the end of the study. Packaging played a significant role in lipid oxidation and retention. Products stored in polybags experienced the most lipid degradation, followed by those in cartons, while the least oxidation occurred in plastic jar packaging. The maximum lipid content was found in solar-dried loitta (7.12%) kept in plastic jars, whereas the minimum was seen in traditionally dried churi fish (6.0%) stored in polybags. These findings indicate that the hybrid solar dryer

effectively reduces lipid oxidation, leading to slower lipid degradation in solar-dried products compared to traditional drying methods (Figure 4.19)

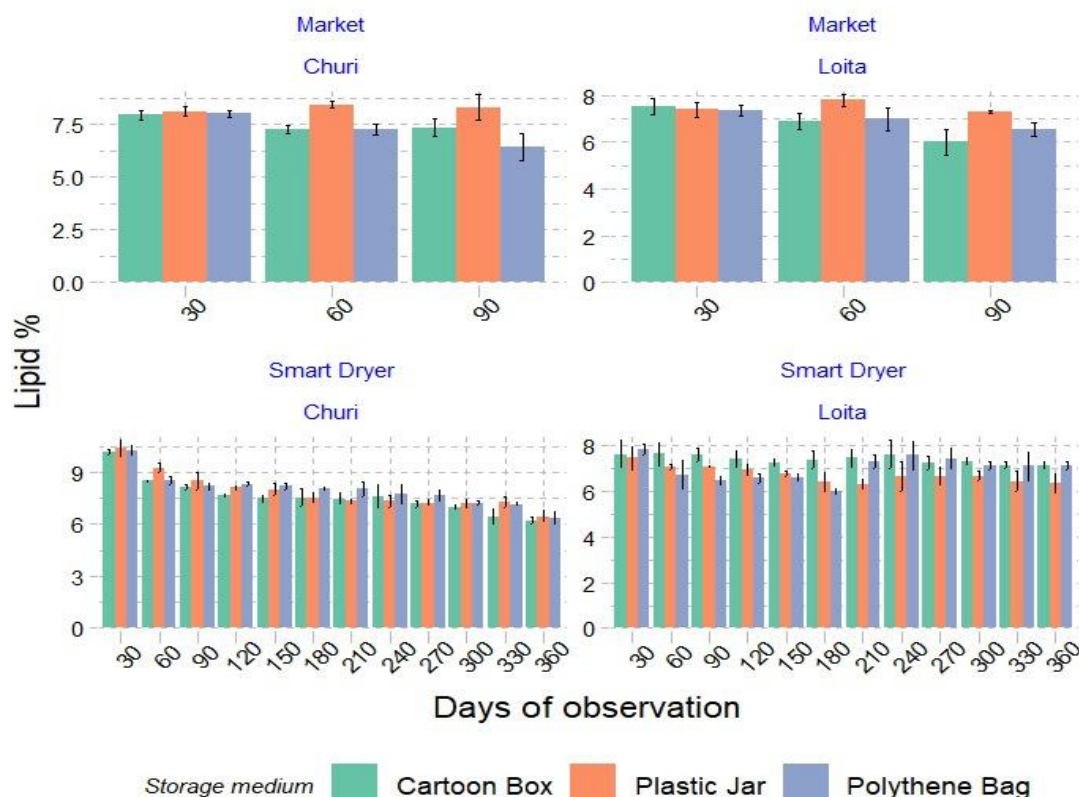


Figure 4.19: Changes in lipid (%) of TD and SD churi and loitta during storage

The ash content of the processed products was found 7.8% in SDC and 10.15% in SDL, in contrast ash content of the traditional dried samples were 6.88% in TDC and 9.55% in TDL just before the storage. The ash content was found in increasing pattern throughout the storage period. Ash content in solar dried products varied between 6.22-7.0%, at the end of experiment where maximum value was observed in SDC and minimum were observed in SDL, whereas ash content of the traditional dried products was varied between 6.2-8.34% at the end of the experiment and maximum value was found in TDC and minimum value was observed in TDL.

Packaging materials also influences the ash content both of the products, the highest level of ash increasing in the products that stored in polythene and valued

Prior to storage, the carbohydrate content of solar-dried products was 1.38% in SDC and 1.97% in SDL, while the carbohydrate content of traditionally dried products was 1.74% in TDC and 2.04% in TDL. Throughout the storage period, the carbohydrate (CHO) content showed a slight increase in both product types. At the conclusion of the experiment, the CHO content in solar-dried products ranged from 1.89% to 2.22%, with the maximum value observed in SDC and the minimum in SDL. In contrast, the CHO content in traditionally dried products ranged from 2.22% to 2.88%, with the highest value in TDL and the lowest in TDC. The impact of packaging materials on the CHO content was minimal. The most significant increase in CHO content occurred in TDL (2.88%), which was packaged in cartons, while only slight changes were noted in SDC (1.44%), which was stored in plastic jars.

The fiber content of SDC was 0.72% and that of SDL was 1.12% immediately after preparation, while the fiber content of TDC was 1% and TDL was 1.33% just before storage. Throughout the storage period, the fiber content of all products showed a slight increase, which was not statistically significant. By the end of the experiment, the fiber content in products processed using the hybrid solar drying method ranged from 1.76% to 1.88%, with the highest value found in SDC and the lowest in SDL.

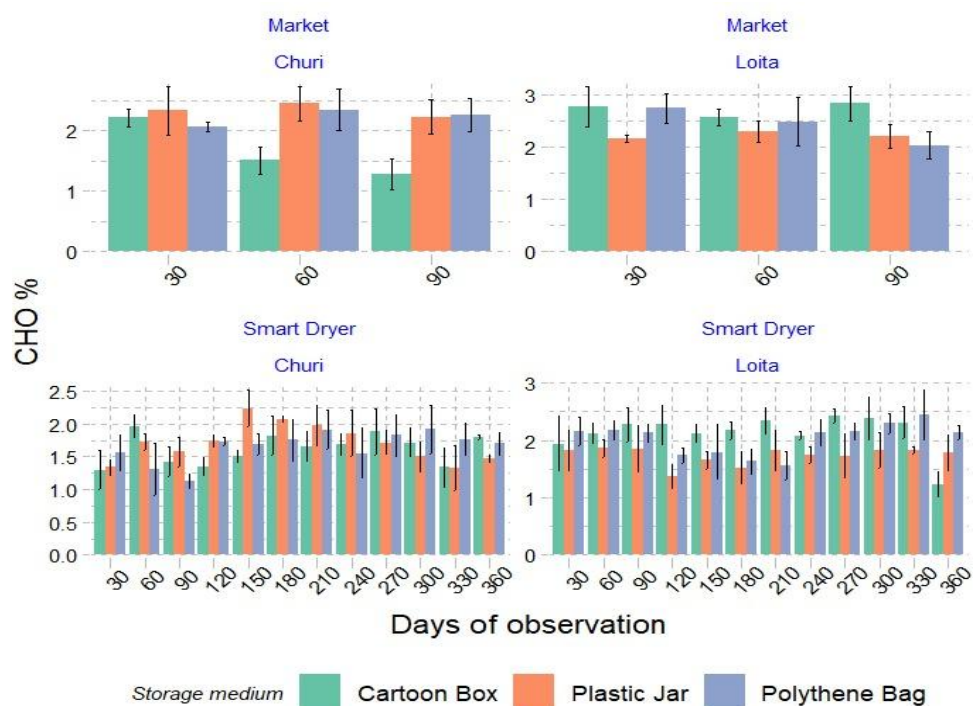


Figure 4.20: Changes in ash (%) of TD and SD churi and loitta during storage.

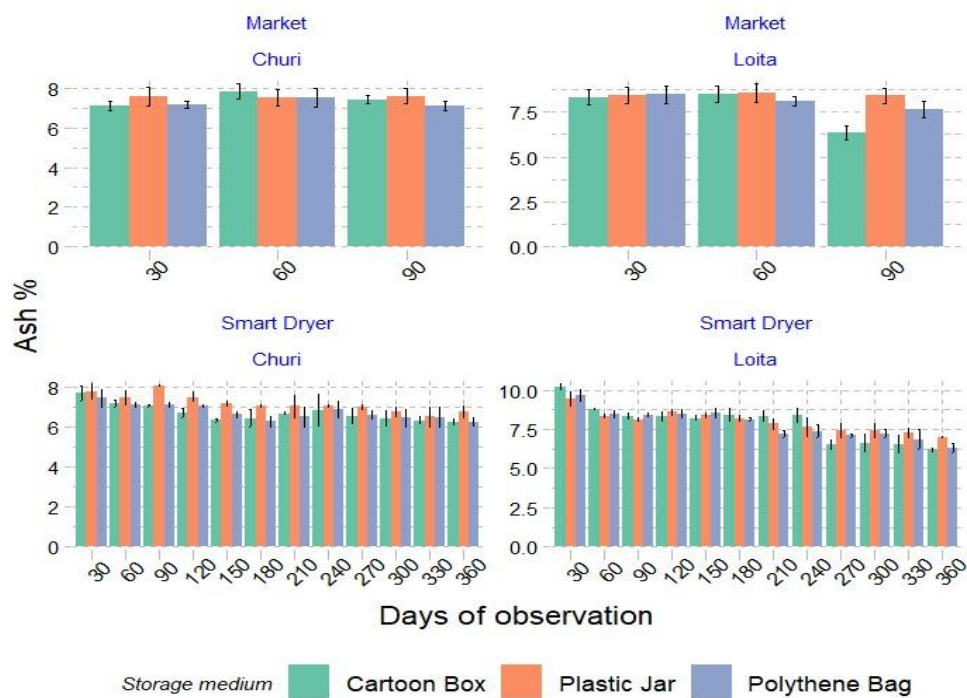


Figure 4.21: Changes in carbohydrate (%) of TD and SD churi and loitta during storage

In comparison, the fiber content in traditionally dried products ranged from 1.32% to 1.76%, with the highest value in TDL and the lowest in TDC. The current study revealed that packaging materials had no significant effect on changes in fiber content across all stored dried fish products. The most significant increase in fiber content was observed in TDL (1.76%), which was packed in carton boxes, while the smallest change occurred in SDC (1.32%), which was packed in plastic jars. (Figure 4.22).

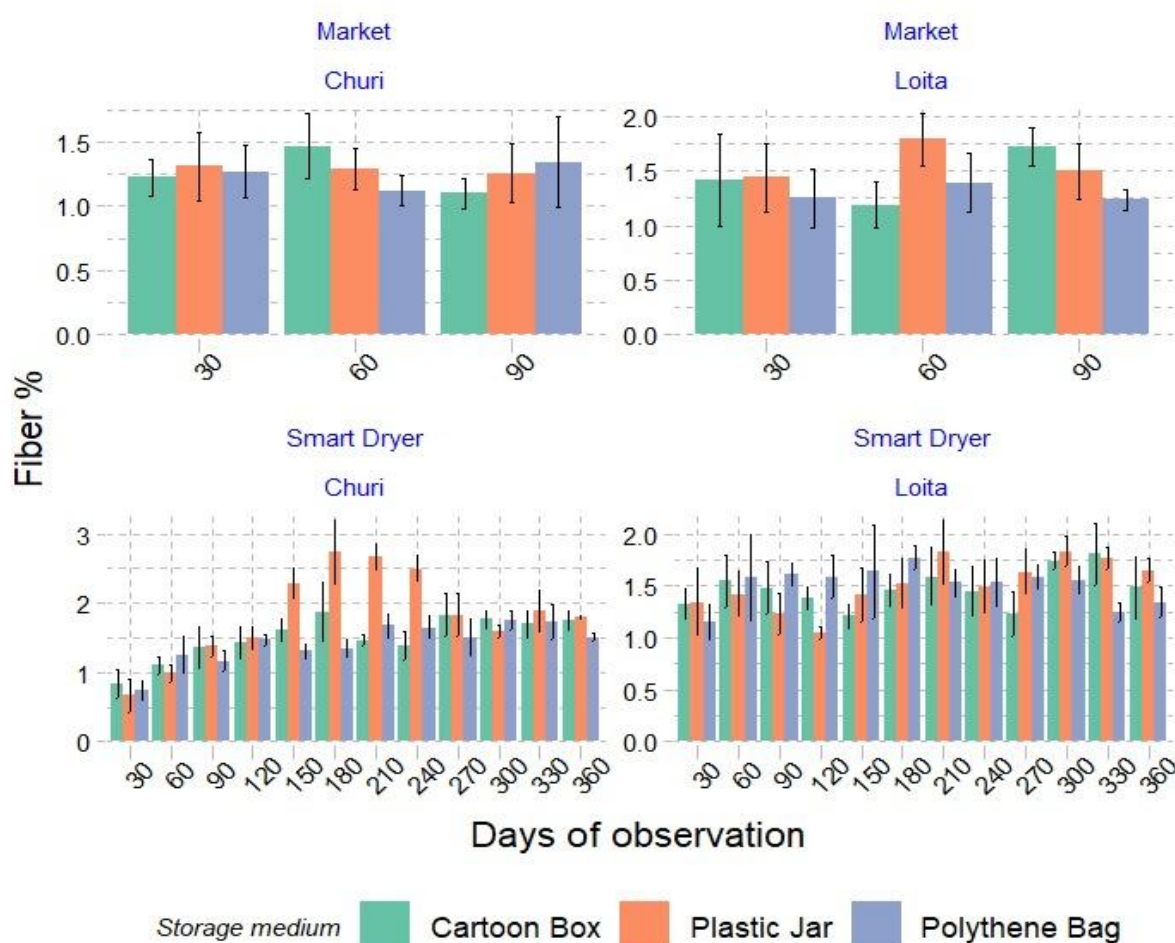


Figure 4.22: Changes in fiber (%) of TD and SD churi and loitta during stora

Table 4.2: Variations of proximate composition (%) of TD churi and loitta during storage period

Species	Packaging Type	Moisture% (Max.-Min.)	Protein% (Max.-Min.)	Lipid% (Max.-Min.)	Ash% (Max.-Min.)	Carbohydrate% (Max.-Min.)	Fiber% (Max.-Min.)
Dried churi	Plastic Jar	29.57±0.55 ^a (28.88-30.65)	50.97±0.58 ^a (50.00-52.00)	8.40±0.15 ^a (8.12-8.65)	7.36±0.04 ^a (7.28-7.43)	2.14±0.06 ^a (2.04-2.24)	1.25±0.06 ^a (1.13-1.32)
	Polythene Bag	31.82±0.86 ^b (30.18-33.11)	50.42±0.52 ^b (49.78-51.44)	7.27±0.48 ^{bc} (6.57-8.18)	7.08±0.03 ^b (7.03-7.12)	2.12±0.06 ^{ab} (2.02-2.22)	1.12±0.04 ^b (1.05-1.19)
	Carton-Box	32.13±0.90 ^c (30.44-33.50)	50.22±0.42 ^c (49.54-51.00)	7.52±0.23 ^b (7.25-7.98)	7.30±0.09 ^{ac} (7.12-7.44)	1.58±0.30 ^c (1.22-2.18)	1.24±0.10 ^{ac} (1.08-1.42)
Died loitta	Plastic Jar	29.09±0.82 ^a (27.54-30.33)	50.98±0.80 ^a (50.04-52.57)	7.43±0.11 (7.22-7.54)	8.45±0.06 (8.34-8.56)	2.16±0.04 (2.09-2.21)	1.66±0.06 (1.56-1.78)
	Polythene Bag	30.63±1.28 ^b (28.34-32.78)	50.41±0.52 ^b (49.56-51.34)	7.08±0.28 (6.65-7.60)	8.10±0.26 (7.60-8.48)	2.26±0.14 (2.00-2.45)	1.13±0.05 (1.06-1.23)
	Carton-Box	31.32±1.22 ^c (29.50-33.63)	50.15±0.58 ^c (49.23-51.23)	6.68±0.36 (6.00-7.20)	7.73±0.77 (6.20-8.54)	2.66±0.17 (2.33-2.88)	1.37±0.21 (1.03-1.76)

Note: Max. = Maximum, Min. = Minimum & superscript letters (a, b, c) indicate the significant differences (P<0.05).

Table 4.2 represents a comparative analysis of the nutritional composition of two dried fish species churi and loitta preserved in three different packaging types: plastic jar, polythene bag, and carton box. The parameters evaluated include moisture, protein, lipid, ash, carbohydrate, and fiber contents with their respective mean values and ranges. Moisture content increases progressively from plastic jar to carton box for both species, with the lowest in plastic jars. Protein content is highest in plastic jars and decreases slightly in polythene bags

and carton boxes across both species. Lipid content is higher in dried churi, particularly in plastic jars, while loitta shows decreasing lipid levels with less protective packaging. Ash content is consistently higher in dried loitta than in dried churi, regardless of packaging. Carbohydrate content is relatively stable in churi but increases notably in loitta, especially in the carton box. Fiber content remains fairly low in all samples but is higher in dried loitta compared to churi, with the highest value found in plastic jar packaging.

Table 4.3: Variations of proximate composition of SDC and SDL during storage period.

Species	Packaging Type	Moisture % (Max.-Min.)	Protein% (Max.-Min.)	Lipid% (Max.-Min.)	Ash% (Max.-Min.)	Carbohydrate% (Max.-Min.)	Fiber % (Max.-Min.)
SDC	Plastic Jar	18.16±0.69 ^a (14.50-22.45)	62.81±0.54 ^a (59.16-65.36)	7.85±0.30 ^a (6.44-10.22)	7.15±0.12 ^a (6.54- 8.02)	1.78±0.05 ^a (1.38- 1.94)	1.86±0.21 ^a (0.66- 2.88)
	Poly Bag	21.45±1.27 ^{bc} (14.78-30.04)	60.62±1.06 ^{bc} (53.66-65.21)	8.00±0.26 ^b (6.39-10.17)	6.73±0.10 ^{bc} (6.40- 7.45)	1.59±0.07 ^b (1.18- 1.87)	1.43±0.09 ^b (0.72- 1.83)
	Carton-Box	21.57±1.43 ^c (14.60-30.88)	60.20±1.14 ^c (53.08-65.14)	7.61±0.29 ^c (6.18-10.13)	6.73±0.13 ^c (6.32- 7.76)	1.65±0.06 ^c (1.28- 1.88)	1.52±0.10 ^c (0.88- 1.89)
SDL	Plastic Jar	18.59±0.69 ^a (15.30-22.75)	61.99±0.59 ^a (58.45-64.13)	6.73±0.10 ^{ab} 6.23- 7.44	8.01±0.20 ^a (7.00- 9.43)	2.00±0.08 ^a (1.56- 2.45)	1.54±0.08 ^a (1.03- 1.87)
	Poly Bag	22.11±1.36 ^b (16.09-30.56)	58.59±0.97 ^{bc} (53.11-63.03)	7.01±0.15 ^b 6.00- 7.87	7.82±0.28 ^b (6.34- 9.56)	2.16±0.10 ^b (1.22- 2.54)	1.55±0.07 ^{ab} (1.12- 1.88)
	Carton-Box	21.75±1.47 ^c (16.00-30.54)	59.12±0.97 ^c (53.19-62.66)	7.44±0.06 ^c 7.08-7.76	7.91±0.32 ^c (6.22-10.15)	1.81±0.09 ^c (1.30- 2.23)	1.47±0.06 ^c (1.22- 1.82)

Note: Max. = Maximum, Min.= Minimum & superscript letters (a, b, c) indicate the significant differences (P<0.05).

Overall, plastic jars preserve the nutritional quality more effectively for both species, while carton boxes show increased moisture and carbohydrate content but reduced lipid and protein, indicating potential quality degradation.

Both SDC (Solar Dried Churi) and SDL (Solar Dried Loitta) exhibited the lowest moisture content when stored in plastic jars 18.16% and 18.59% respectively indicating superior moisture control and product stability. In contrast, the highest moisture levels were recorded in poly bags and carton boxes, suggesting reduced barrier properties and higher susceptibility to moisture absorption during storage (Table 4.3). In terms of protein content, plastic jars again proved to be the most effective packaging, preserving the highest levels for both SDC (62.81%) and SDL (61.99%). However, a gradual decline in protein was observed in poly bags and carton boxes, likely due to greater exposure to environmental conditions, which may lead to protein degradation or denaturation over time.

Regarding lipid content, SDC maintained a relatively consistent level across all packaging types, indicating lipid stability. Conversely, SDL showed a slight upward trend, increasing from 6.73% in plastic jars to 7.44% in carton boxes, possibly due to moisture loss concentrating fat content or variations in fat oxidation dynamics. Ash content was consistently higher in SDL than in SDC, with the plastic jar packaging retaining the highest mineral content for both species, highlighting its effectiveness in preserving inorganic nutrients. For carbohydrates, levels showed a modest increase in poly bags and carton boxes for both species. Notably, SDL maintained higher carbohydrate content than SDC across all packaging

types, possibly due to intrinsic species differences or metabolic variations during drying and storage.

Fiber content was highest in SDC stored in plastic jars (1.86%), indicating better structural preservation. SDL showed less variation in fiber content across packaging types but experienced a slight decrease in carton boxes. In summary, plastic jars emerged as the most effective packaging method, ensuring better retention of key nutritional components such as protein, fiber, and ash, while minimizing moisture uptake. On the other hand, poly bags and carton boxes, though more economical, were associated with higher moisture content and nutrient loss, rendering them less suitable for long-term storage or quality-sensitive applications. These findings underscore the importance of choosing appropriate packaging materials to maintain the biochemical integrity of dried fish products during post-processing handling and marketing.

4.3.2.2.2 Fatty Acid composition of the dried fish products

Fatty acid estimation in dried marine fish products is vital for quality analysis, as it evaluates nutritional content, freshness, and lipid oxidation. This process identifies essential fatty acids, detects spoilage, and assesses storage stability, ensuring product safety, consumer satisfaction, and adherence to food quality standards. The most important fatty acids content of solar-dried and commercially available bombay duck (*Harpadon nehereus*) and ribbon fish (*Trichiurus spp.*) are shown in table 4.4. Regarding the overall fatty acid composition of samples saturated fatty acids (SFA) had the highest value, followed by polyunsaturated fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs). For every 100g of SDC had 47.35 g

of SFAs, 39.26 g of MUFAs, and 23.57 g of PUFAs, whereas the commercially available market samples had 42.08 g of SFAs, 34.23 g of MUFAs, and 20.22 g of PUFAs. Moreover, in contrast with commercially available market samples, which had 33.79 g of SFAs, 28.45 g of MUFAs, and 29.21 g of PUFAs per 100 g, while SDL contained 39.96g of SFAs, 36.56g of MUFAs, and 35.17g of PUFAs.

Table 4.4: Fatty acid composition of SD and TD churi and loitta

Fatty Acids	TDC (g/100 g)	SDC (g/100 g)	TDL (g/100 g)	SDL (g/100 g)
C 14:0 Myristic acid	3.74	6.88	3.28	6.21
C 15:0 Pentadecanoic acid	0.59	0.76	0.10	0.23
C 15:1 Pentadecenoic acid	0.67	0.63	0.75	0.48
C 16:0 Palmitic acid	26.15	28.73	21.41	24.82
C 16:1 Palmitoleic acid	6.95	9.19	5.79	8.19
C 17:0 Heptadecanoic acid	1.68	1.74	0.23	0.28
C 17:1 Heptadecenoic acid	0.67	0.78	0.72	1.08
C 18:0 Stearic acid	7.54	6.88	6.42	6.31
C 18:1 c9 Oleic acid	21.08	22.59	17.4	20.59
C 18:1 c11 Vaccenic acid	2.47	3.04	2.12	2.78
C 18:2c Linoleic acid (ω 6)	4.15	5.31	4.34	4.59
C 18:3 Alpha Linolenic acid (ω 3)	1.21	1.58	0.83	2.19
C 20:0 Arachidic acid	1.02	1.38	0.45	0.58
C 20:1 Eicosenoic acid	1.63	2.62	1.11	2.93
C 20:2 Eicosadienoic acid (ω 6)	0.18	0.26	0.48	0.51
C 20:3 c8, 11, 14 Eicosatrienoic acid (ω 6)	0.13	0.19	0.17	0.16
C 21:0 Henicosanoic acid	0.16	0.24	0.20	0.22
C 20:3 c11, 14 Eicosadienoic acid	1.82	1.69	0.55	0.79
C 20:4 Arachidonic acid (ω 6)	0.89	1.02	1.64	1.75
C 22:0 Behnic acid	0.98	0.48	0.96	0.42
C 20:5 Eicosapentaenoic (EPA) (ω 3)	7.1	9.71	9.22	12.49
C 22:2 Docosadienoic acid (ω 6)	0.15	0.2	0.62	0.24
C 24:0 Lignoceric acid	0.22	0.26	0.74	0.89
C 24:1 Nervonic acid	0.76	0.41	0.56	0.51

Table 4.4: Continued

C 22:5 Docosapentaenoic acid (DPA) (ω 3)	0.93	0.96	0.68	0.82
C 22:6 Docosahexaenoic (DHA) (ω 3)	3.66	2.65	10.68	11.63
Total	96.53	110.18	91.45	111.69
Unknown	2.13	3.69	2.15	3.7
$\Sigma \omega$ 3	12.9	14.9	21.41	27.13
$\Sigma \omega$ 6	5.5	6.98	7.25	7.25
Σ SFA	42.08	47.35	33.79	39.96
Σ MUFA	34.23	39.26	28.45	36.56
Σ PUFA	20.22	23.57	29.21	35.17

SFA: Saturated Fatty Acids; MUFA: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids

The total fatty acid content was found to be highest in Solar Dried Loitta (111.69 g/100 g) and Solar Dried Churi (110.18 g/100 g), suggesting better fat retention in solar-dried fish compared to Traditionally Dried Churi (96.53 g/100 g) and Loitta (91.45 g/100 g). In terms of saturated fatty acids (Σ SFA), solar-dried samples (SDC: 47.35; SDL: 39.96) contained more than the traditional ones (TDC: 42.08; TDL: 33.79), largely due to higher amounts of palmitic (C16:0) and myristic acid (C14:0). Similarly, monounsaturated fatty acids (Σ MUFA) were more prominent in solar-dried fish SDC: 39.26 and SDL: 36.56 compared to TDC (34.23) and TDL (28.45), driven mainly by increased levels of oleic (C18:1) and palmitoleic acid (C16:1). On the other hand, polyunsaturated fatty acids (Σ PUFA) were most abundant in SDL (35.17) and TDL (29.21), exceeding the amounts in SDC (23.57) and TDC (20.22). This was particularly influenced by the presence of high amounts of EPA (C20:5 ω -3) and DHA (C22:6 ω -3), especially in loitta samples. Omega-3 fatty acids ($\Sigma\omega$ -3) showed a clear advantage in solar-dried loitta (27.13), followed by TDL (21.41), SDC (14.9), and TDC (12.9), indicating that solar drying more effectively preserves or even enhances omega-3 content, especially in loitta.

Omega-6 fatty acids ($\Sigma\omega$ -6) were relatively stable across all samples (5.5 to 7.25), though solar-dried products still had slightly higher levels. Notably, the essential fatty acids EPA and DHA were significantly higher in SDL (EPA: 12.49; DHA: 11.63) and TDL, reinforcing loitta's status as a richer source of these heart- and brain-friendly nutrients. In summary, solar drying improves the overall fatty acid composition, particularly in enhancing omega-3 and PUFA levels, making solar-dried fish (especially loitta) nutritionally superior to traditionally dried alternatives.

4.3.2.3 Biochemical quality of the dried marine fish products

4.3.2.3.1 The peroxide values of smart dried and traditional dried products

The peroxide values of TDC fishes varied from 18.38 to 28.57 meq/g of lipid and TDL ranged from 18.44 to 26.21 meq/g of lipid in various packing techniques (figure 4.23). The values are increased for every package with the increase of storage time.

During the storage period, the lowest peroxide values ($p < 0.05$) of SDC (7.34 meq/g of lipid) and SDL (7.65 meq/g of lipid) were found in plastic bottle, and the highest peroxide values (18.57 meq/g of lipid for churi and 18.46 meq/g of lipid for loitta) were found significantly ($p < 0.05$) in polythene bag. The t-test values indicate a significant difference ($p < 0.05$) between TDC, SDC, and TDL, SDL throughout all observation days (Table 4.5). Furthermore, the peroxide value was measured as an effective way to evaluate the rate of lipid hydrolysis in dried fish products (Figure 4.23).

Table 4.5: The peroxide values of SD and TD fishes in different storage conditions.

Days	Packaging Type	TDC	SDC	t-Value	Level of Significance	TDL	SDL	t-Value	Level of Significance
30	Plastic Jar	18.38 ±0.13	7.34 ±0.2	106.66	*	18.44 ±0.1	7.65 ±0.01	40.32	*
	Polythene Bag	19.47 ±0.04	8.44 ±0.01			19.65 ±0.76	8.47 ±0.02		
	Carton-Box	19.85 ±0.02	8.50 ±0.04			19.98 ±0.10	8.23 ±0.2		
60	Plastic Jar	19.54 ±0.12	7.68 ±0.04	3.504	*	19.5 ±0.18	8.35 ±0.03	21.80	*
	Polythene Bag	20.12 ±0.12	9.46 ±0.06			20.57 ±0.09	9.5 ±0.50		
	Carton-Box	20.0 ±0.02	8.68 ±0.2			20.04 ±0.14	10.39 ±0.01		
90	Plastic Jar	22.57 ±0.09	8.57 ±0.19	13.590	*	21.68 ±0.18	9.21 ±0.19	21.75	*
	Polythene Bag	28.57 ±0.01	10.57 ±0.12			23.84 ±0.01	10.46 ±0.10		
	Carton-Box	27.46 ±0.17	10.46 ±0.02			26.21 ±0.07	11.6 ±0.01		

SDC = Solar Dried Churi & SDL = Solar Dried Loitta; TDC = Traditional Dried Churi & TDL = Traditional Dried Loitta TDC; *indicates the significant difference (p<0.05)

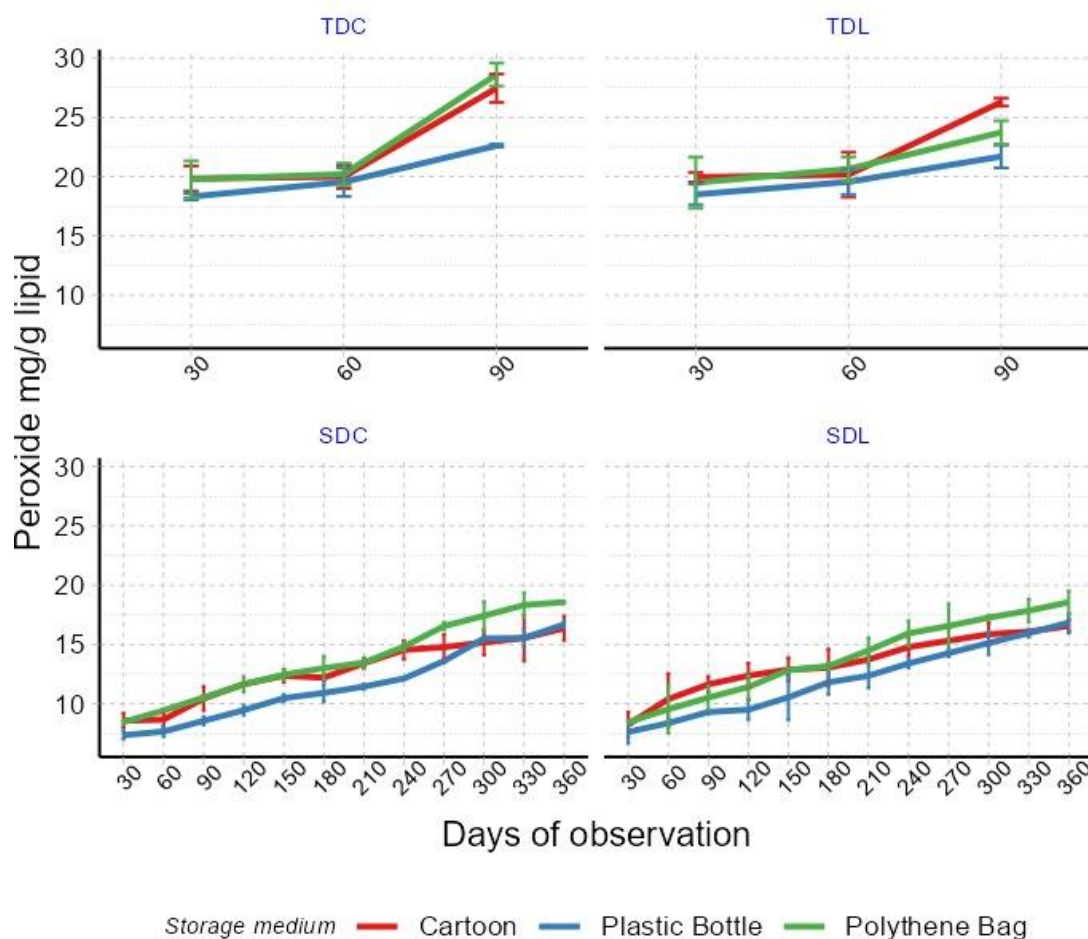


Figure 4.23: Changes in peroxide values of SD and TD fish products storage period

4.3.2.3.2 Total volatile base nitrogen (TVB-N) values of SD and TD products

TVB-N is an essential attribute in evaluating the acceptability of dried products as it measures the release of volatile base compounds during the drying process. The TVB-N values of SD and TD churi and loitta fishes are shown in Figure 4.24. TDC was found to range of TVB-N values at 38.84 to 72.57 mg/100 g over the 90-day storage period, whereas TDL was found to have values ranging from 39.46 to 78.14 mg/100 g in various packing

techniques. Throughout the storage period, the TVB-N values were observed to be the highest (78.14) in a polythene bag and lowest (38.84) in a plastic bottle in TDL and TDC respectively.

In addition, the polythene bag containing SD churi (45.76 mg/100 g) and loitta (46.78 mg/100 g) had the highest TVB-N values ($p < 0.05$), followed by the carton and plastic bottle, respectively while the lowest (20.46 mg/100 g for churi and 18.46 mg/100 g for loitta) were observed in a plastic bottle, then prior to carton and polythene bag during the storage period.

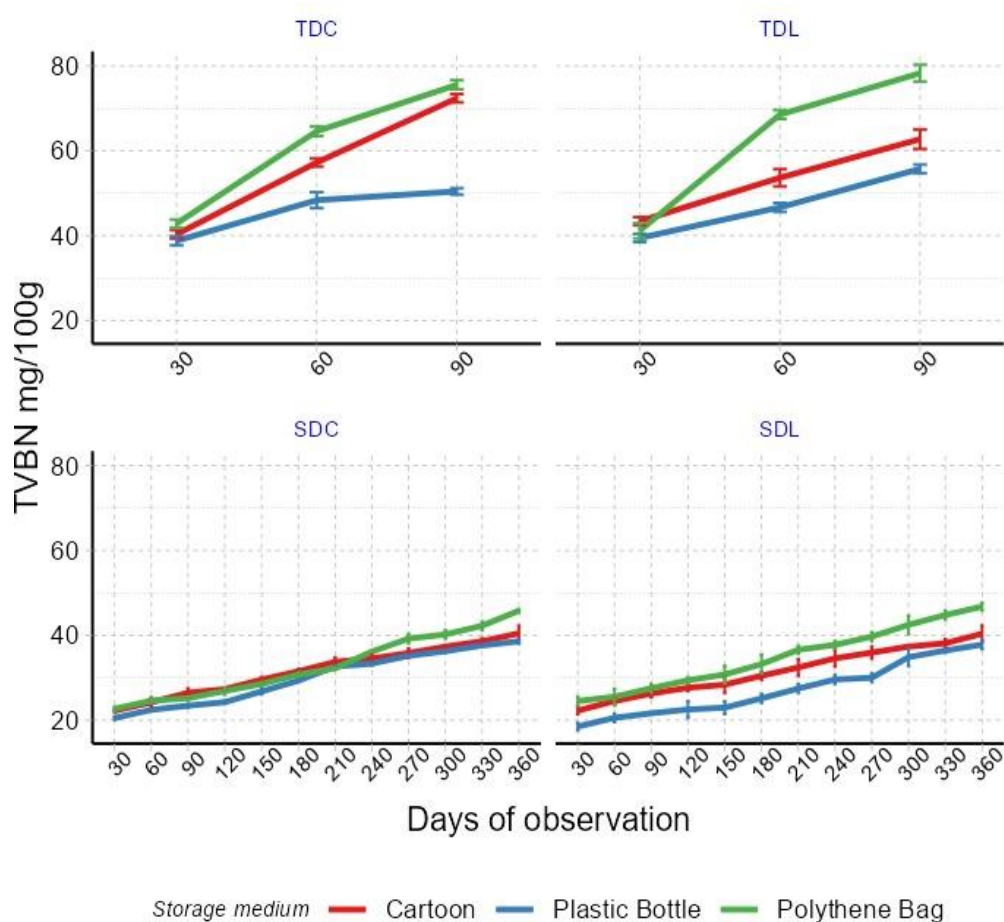


Figure 4.24: Changing pattern of TVB-N values of SD and TD products during storage

4.3.2.4 Microbiological Quality of the Dried Fish Products

4.3.2.4.1 Total viable count (TVC)

Figure 4.25 illustrates the total viable count (TVC) values of SD and TD churi and loitta stored for quality and shelf-life study. TVC values were found higher in TDC samples and the values were 1.73×10^7 , 2.44×10^8 , and 3.12×10^9 CFU/g at 30, 60, and 90 days, respectively. In comparison, TDL stored in carton boxes exhibited TVC values of 1.77×10^8 , 2.17×10^8 , and 3.18×10^9 CFU/g over the same time intervals. A significant increase in TVC was observed with extended storage duration ($p < 0.05$). For SDC samples stored in polythene bags, TVC ranged from 1.45×10^3 to 3.27×10^6 CFU/g over a 30-360-day period. Meanwhile, SDL samples stored in plastic jars showed a TVC range of 1.59×10^3 to 3.87×10^4 CFU/g over the same storage duration.

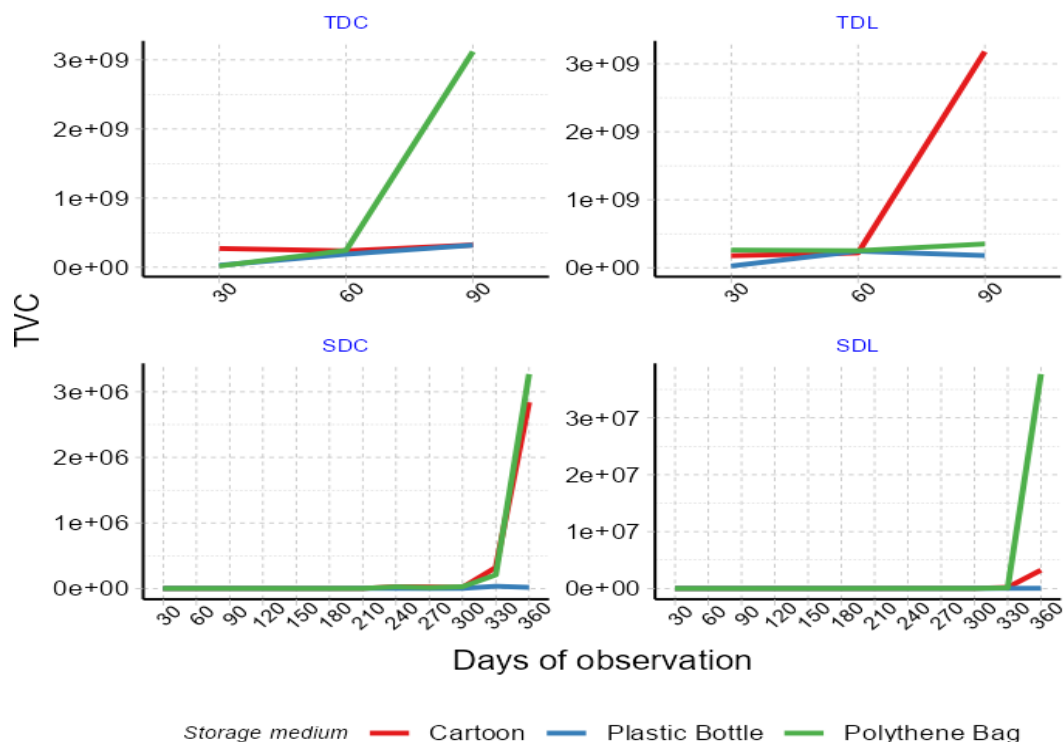


Figure 4.25: Total viable count (TVC) of TD and SD churi and loitta during storage

4.3.2.4.2 Total bacterial count

In contrast to the smart dryer, which demonstrated a substantial ($p < 0.05$) decrease in bacterial count, the traditional dryer's count was very high in churi and loitta fish. In churi and loitta of the smart dryer, only two isolates of *Salmonella* and *E. Coli* were found. The most common occurrences of *E. Coli* (2.86% SDC; 85.71% in TDC) were followed by *Staphylococcus* spp. (5.71% in SDC; 74.29% in TDC) and *Salmonella* spp. (5.71% in SDC; 80% in TDC) while *Salmonella* spp. was not found in SDL. The highest number (85.71%) of *E. Coli* was found in TDC whereas the lowest (2.86%) was in both SDC and SDL. When comparing *Staphylococcus* bacteria to traditional dryers, the smart dryer had a reduced bacterial count. Because the % of the occurrence of microbial count is much lower in this dryer (Figure 4.26), it was thus proposed as an effective dryer to minimize the bacterial count in the processed fish. The significantly higher microbial load of the dried fish during storage might be attributed to the product being stored at ambient temperature as well as reabsorbing air moisture, both of which promote microbial growth.

In addition, if the drying temperature is too low or insufficient, the bacterial spores may not be destroyed during the drying process, and they would continue to multiply while the product is in storage. In this study, the most common occurrences of *E. Coli* (2.86% SDC; 85.71% in TDC) were followed by *Staphylococcus* spp. (5.71% in SDC; 74.29% in TDC) and *Salmonella* spp. (5.71% in SDC; 80% in TDC) while *Salmonella* spp. was not found in SDL.

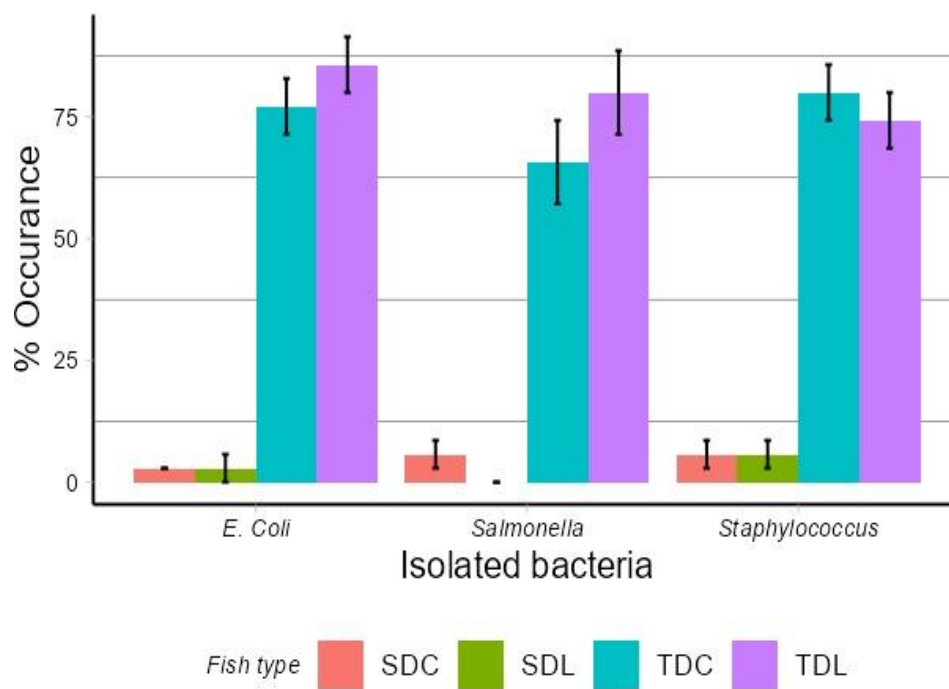


Figure 4.26: Microbiological characteristics of TD and SD churi and loitta

4.3.3 Forecasting the Livelihood Status of the Dry Fish Processors

The analysis of the survey data, based on a sample of 1657 fishermen in Cox's Bazar, yielded significant insights into their occupational practices, personal lives, and the nuances of dry fish production. The findings highlight pivotal trends and patterns, offering a comprehensive understanding of the interplay between various aspects of their lives and work.

4.3.3.1 Insights from occupational information

The occupational information survey revealed key aspects of the fishermen's work environment and their adaptation to modern technology. A notable majority, approximately 70%, reported the use of phones, indicating a substantial integration of technology into their daily lives (figure 4.27). About 65% had access to network facilities, although only around

40% had internet support, suggesting a digital divide in terms of internet accessibility. Intriguingly, about 30% of respondents actively engaged in online platforms like Facebook and YouTube, reflecting a gradual shift towards digital literacy.

4.3.3.2 Insights from Personal Information

The personal information survey provided profound insights into the socio-economic backdrop of the fishermen. A significant portion, nearly 60%, had a basic education, indicating moderate literacy levels. The majority, around 80%, lived in semi-permanent structures, reflecting a moderate standard of living. Family size varied, with about 50% having small families (2-3 members), indicating a trend towards smaller household sizes. Access to basic amenities like drinking water and health support was reported by 75% and 65% of respondents, respectively, suggesting reasonable access to essential services (Figure 4.27. 4.28, 4.29 and 4.30).

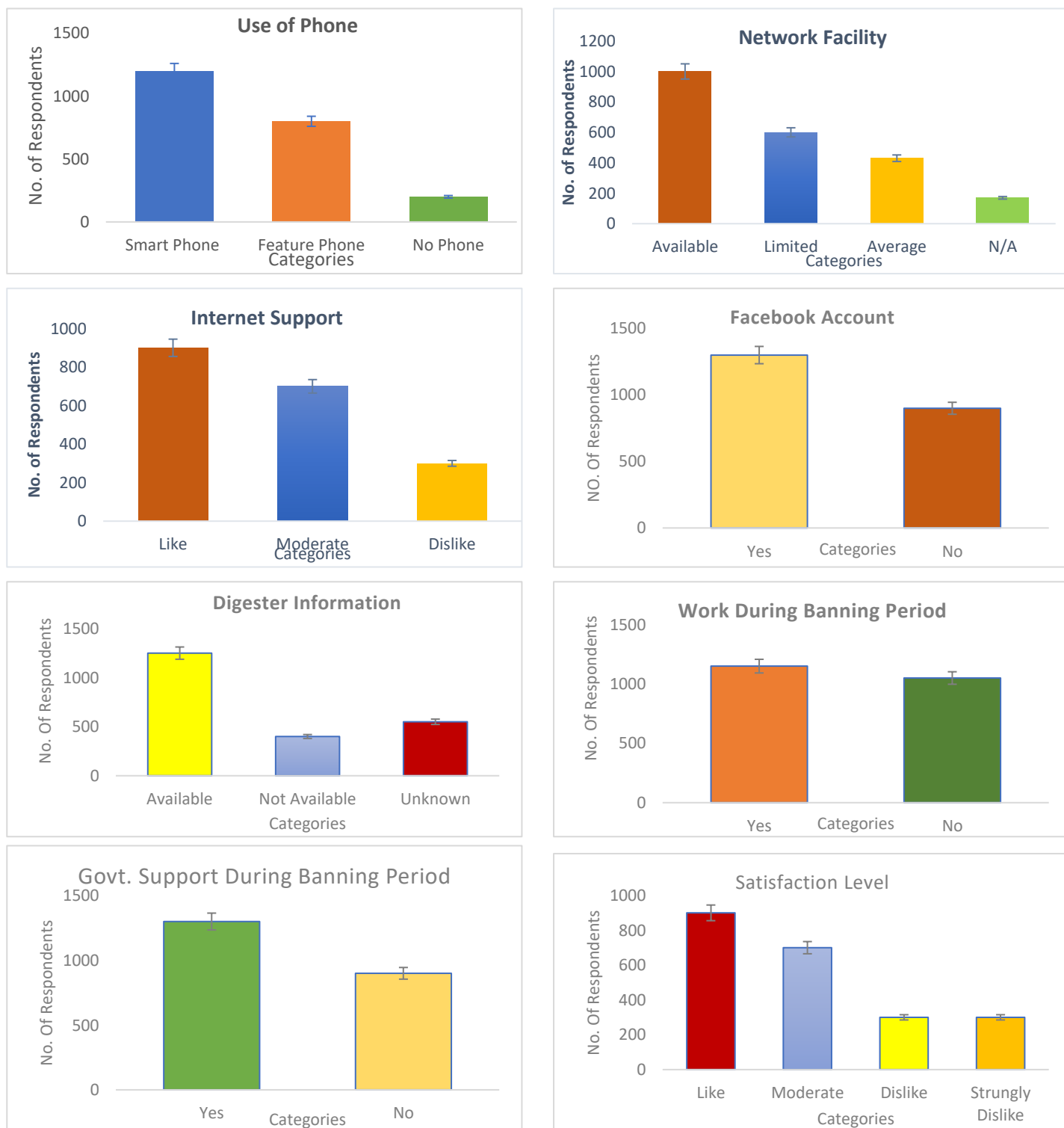


Figure 4.27: Modern facilities and Personal information's of dry fish processors

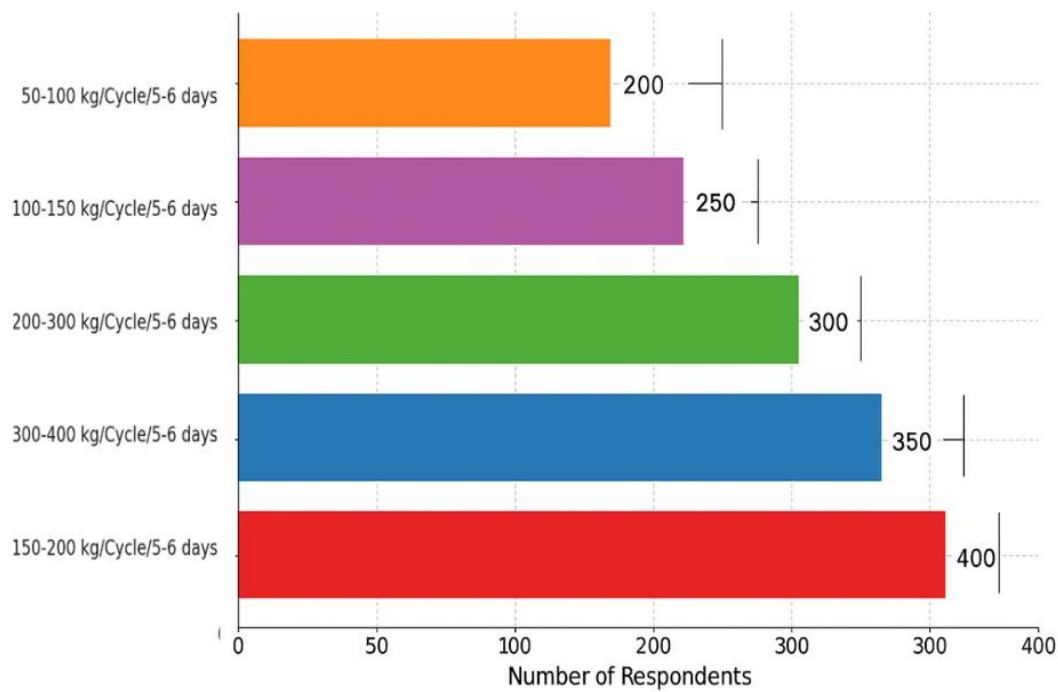


Figure 4.28: Level of dry fish producers

Figure 4.28 presents the categorization of marine fish processors in the study area according to their production volumes per processing cycle. The highest proportion of processors (26.67%) belong to the top producer group, handling between 150-200 kg of fish per cycle. Close behind, 23.33% produce between 300–400 kg per cycle, while 20% fall within the 200-300 kg range. A smaller segment, 16.66%, reports a fixed production level of 250 kg per cycle, and the remaining 13.33% represent the lowest category, processing only 50-100 g per cycle. This distribution highlights a diverse range of processing capacities among marine fish processors, indicating variability in access to resources, market demand, and processing infrastructure.

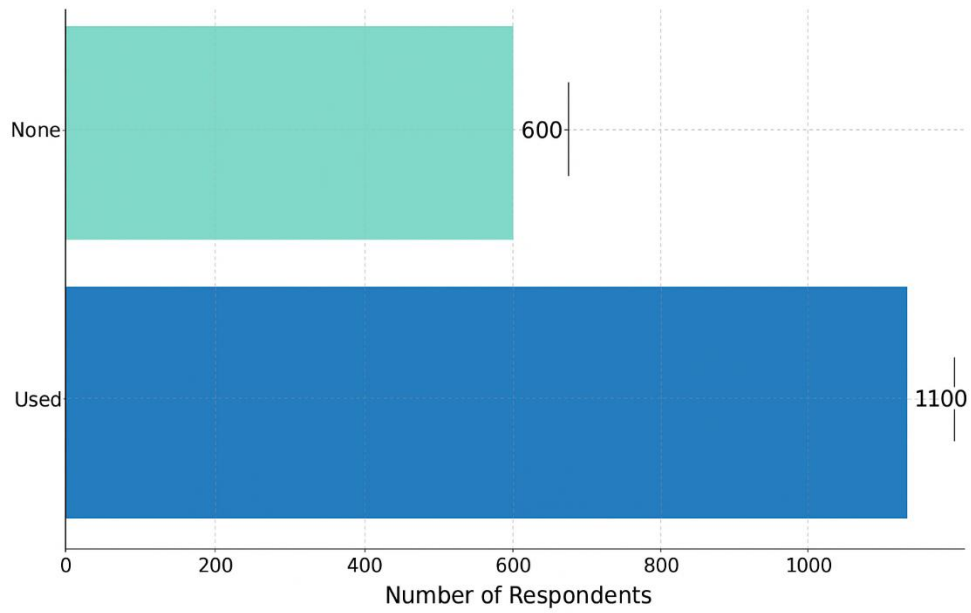


Figure 4.29: Pesticides or others chemicals used during processing and preservation

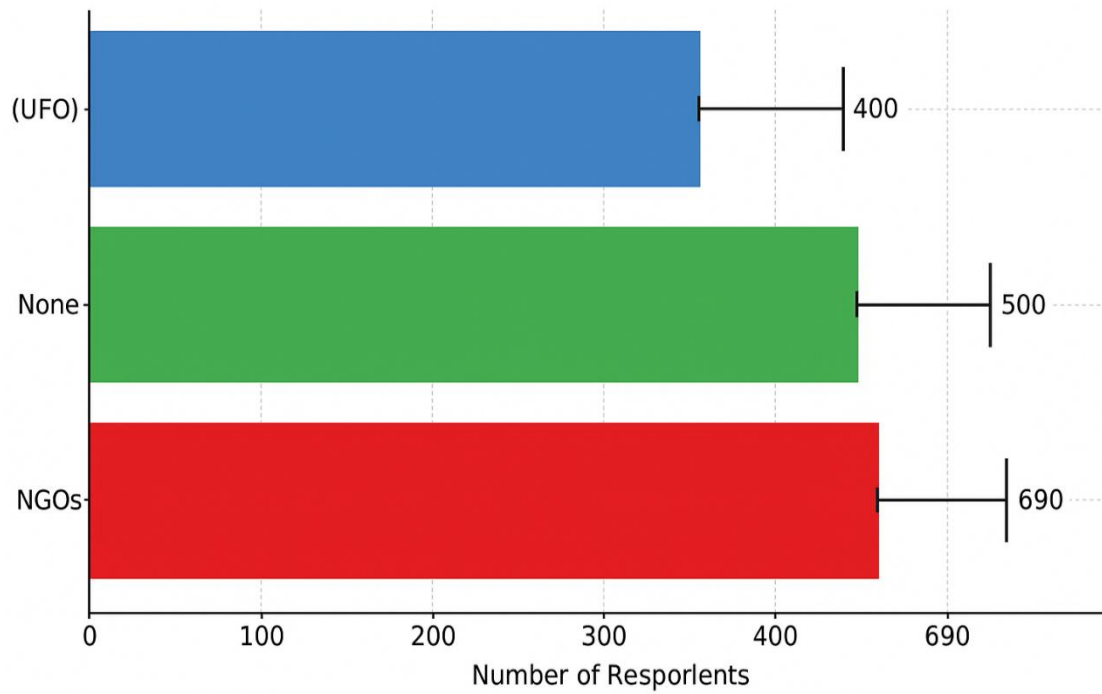


Figure 4.30: Support from GOs and NGOs

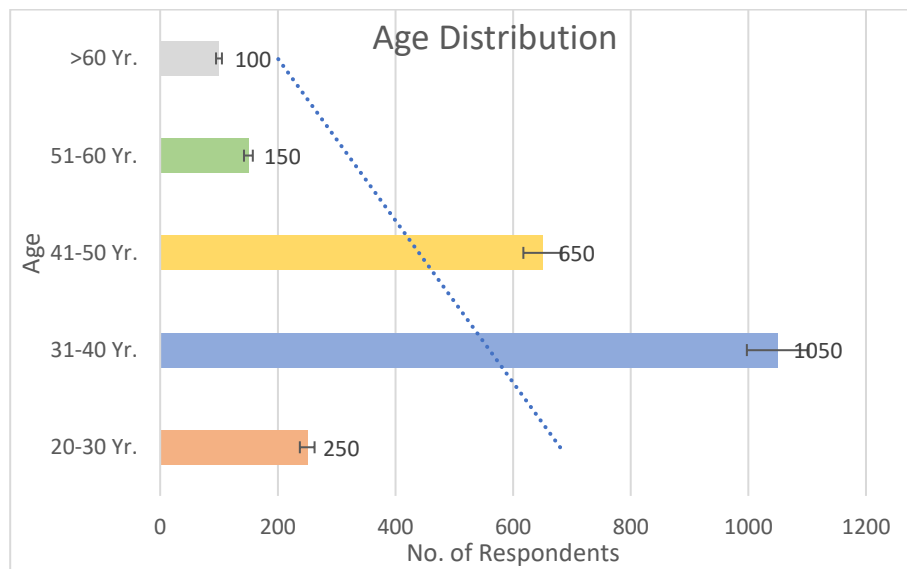


Figure 4.31: Age distribution of the processors

In addition, Figure 4.29 reveals that a significant portion 64.71% of the dry fish processors in Cox’s Bazar resort to the use of various pesticides during the drying process. These chemical agents are employed primarily to prevent infestation by pests and insects, which pose a major risk to the safety and quality of dried fish products.

In the present study it was found that, the 31-40 years age group dominates, accounting for nearly half (48.9%) of the total respondents (Figure 4.31). This suggests that the most active or involved demographic in the survey falls within the early middle-aged population, who may be more economically active, engaged in community development, or responsive to outreach. The second-largest group is 41-50 years (28.9%), further reinforcing the trend that middle-aged individuals are most represented. Younger respondents (20–30 years) make up 11.1%, indicating moderate participation from the younger working

population. Older age groups (51–60 and >60) together constitute just over 11%, suggesting lower involvement or accessibility, possibly due to health, mobility, or digital literacy barriers. This age distribution has implications for program design, outreach, and service delivery indicating a need to tailor interventions primarily for the 31-50 age bracket, while finding inclusive strategies to engage both younger and older populations more effectively (Figure 4.31).

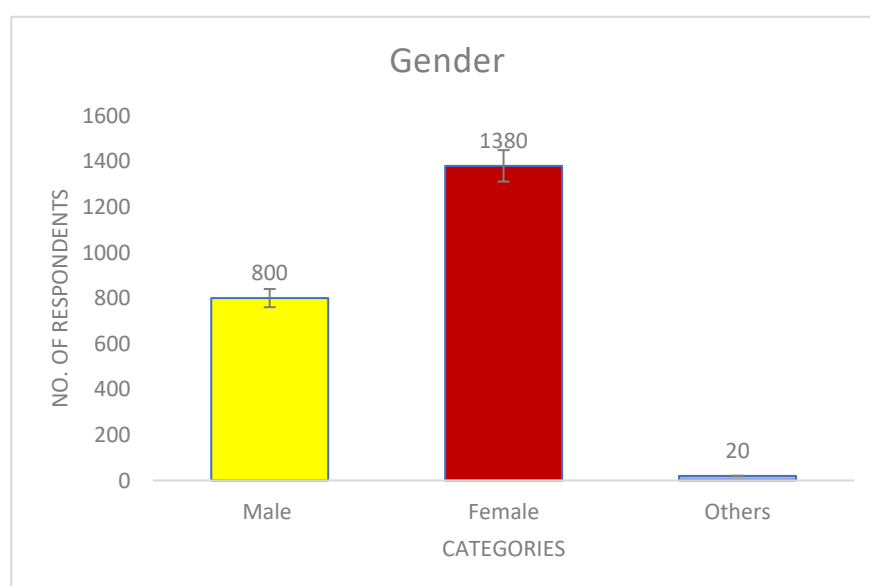


Figure 4.32: Gender index of the community

The gender distribution indicates a female-dominated sample, with 62.7% of the respondents identifying as female. In contrast, males represent 36.4%, and a small minority (0.9%) identified as "Others." This distribution may suggest that the survey or program was more accessible or appealing to women, or that women represent a larger proportion of the target population. The strong female presence could also reflect changing social dynamics, such as increased female participation in community programs, education, or workforce

initiatives. The small representation of the "Others" category may highlight a need for more inclusive data collection strategies that encourage gender-diverse participation. Future surveys may consider gender sensitivity training for enumerators and inclusive communication to better reflect diversity in society (Figure 4.32).

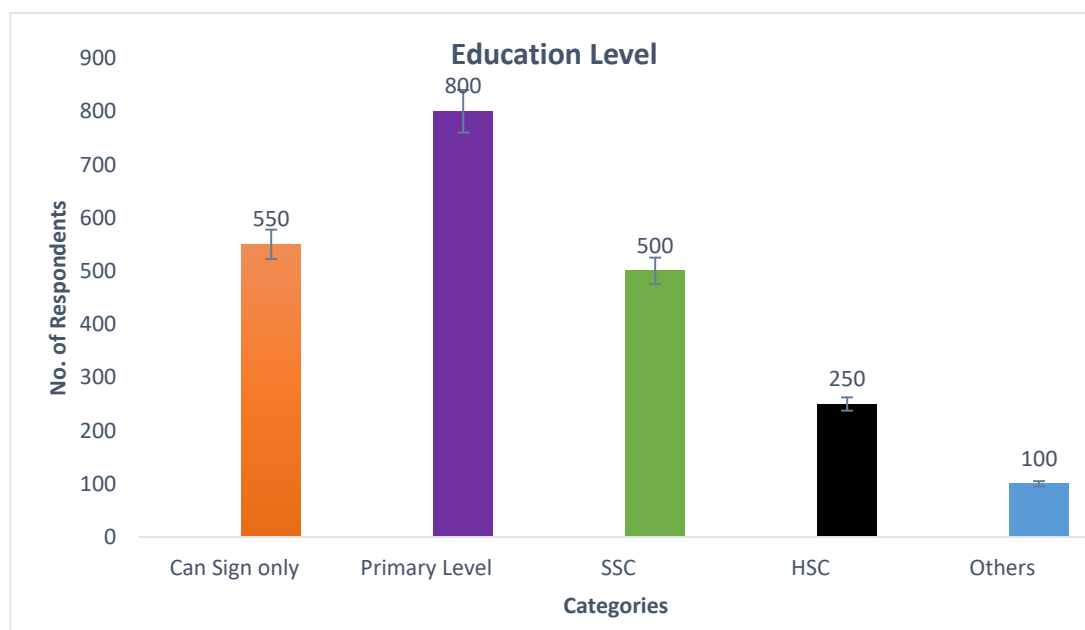


Figure 4.33: Educational level of the fish processors

The data reveals that the majority of respondents (36.4%) have only completed primary level education, which suggests limited educational attainment. A significant portion (25%) can only sign their names, indicating a high number of semi-literate individuals. SSC-level education is the third most common (22.7%), while only 11.4% of the population have completed HSC (higher secondary). A very small segment (4.5%) falls into the “Others” category, which may include vocational or informal education. These findings highlight a concerning trend of low formal education levels in the surveyed group. The predominance of

primary or below-primary education may reflect socio-economic barriers, lack of access to education, or dropouts before secondary levels (Figure 4.33).

4.3.3.3 Insights from production information

The production information survey shed light on the technicalities and economic aspects of dry fish production. Approximately 55% of the respondents were involved in drying a diverse range of fish species (Figure 4.34), indicating versatility in production. Marketing facilities varied, with 50% selling locally and 35% selling to larger markets or 'Arots' (Figure 4.32) Storage facilities predominantly consisted of wooden boxes and plastic bags, used by 40% and 30% of respondents, respectively. The use of preservatives and chemicals was common, with 60% using salt as a preservative and 50% employing chemicals in processing (Figure 4.34)

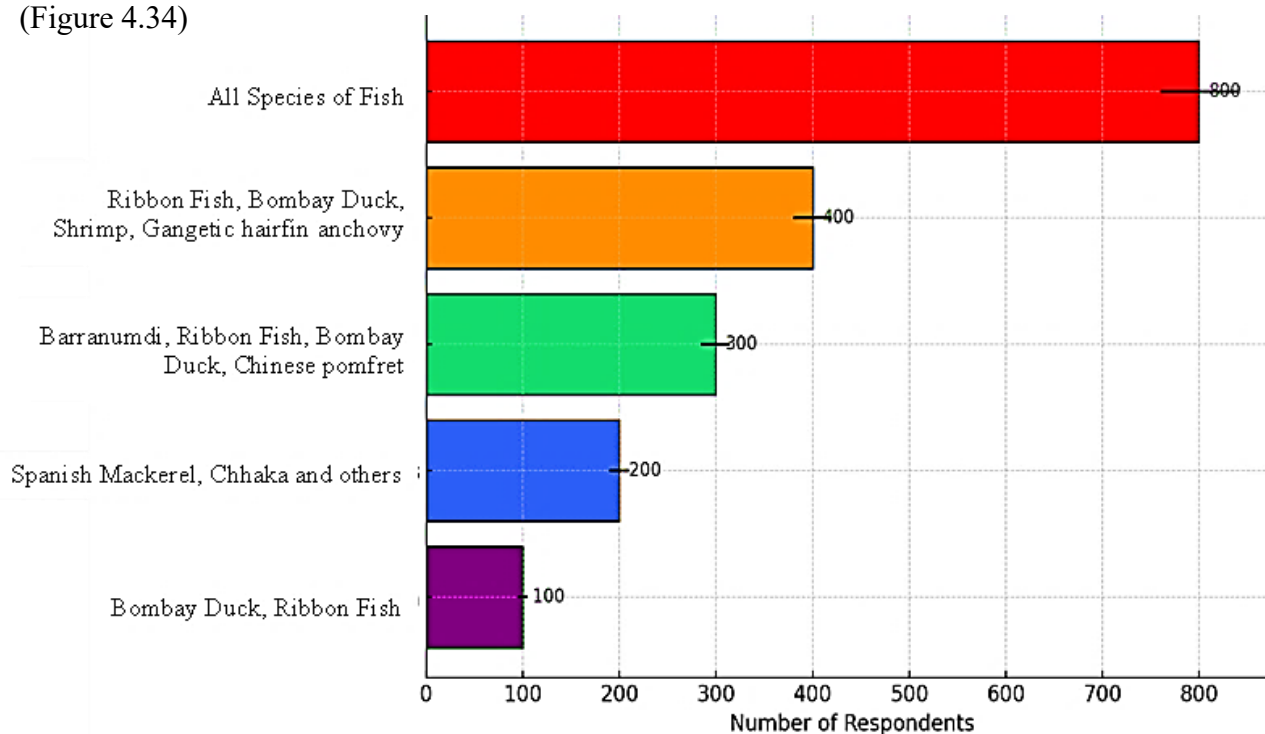


Figure 4.34: Species combination in the existing drying yard

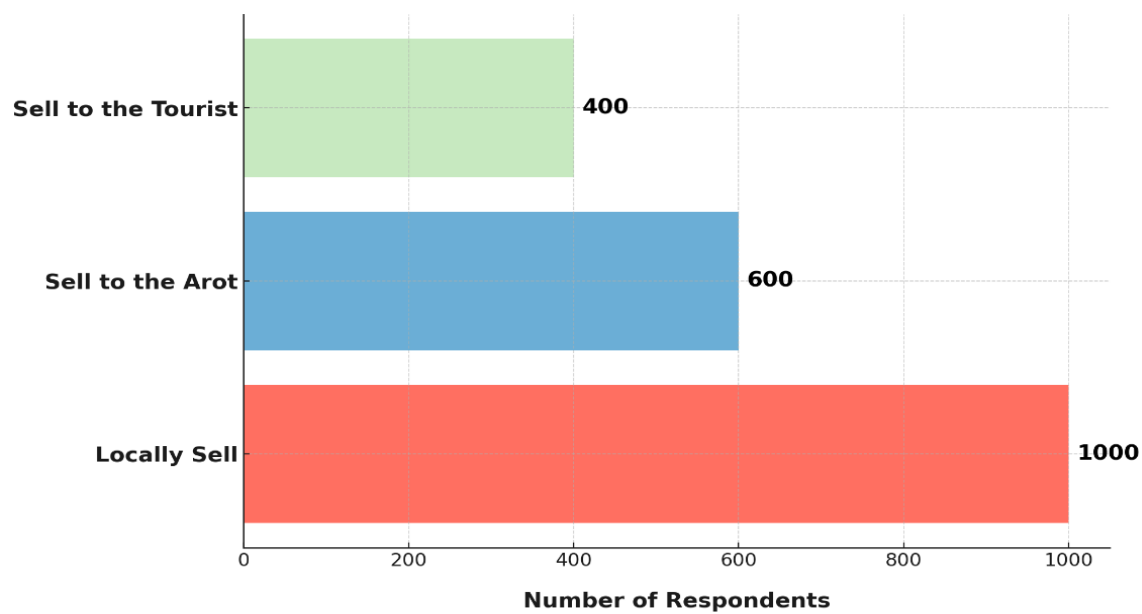


Figure 4.35: Existing marketing system of the processors

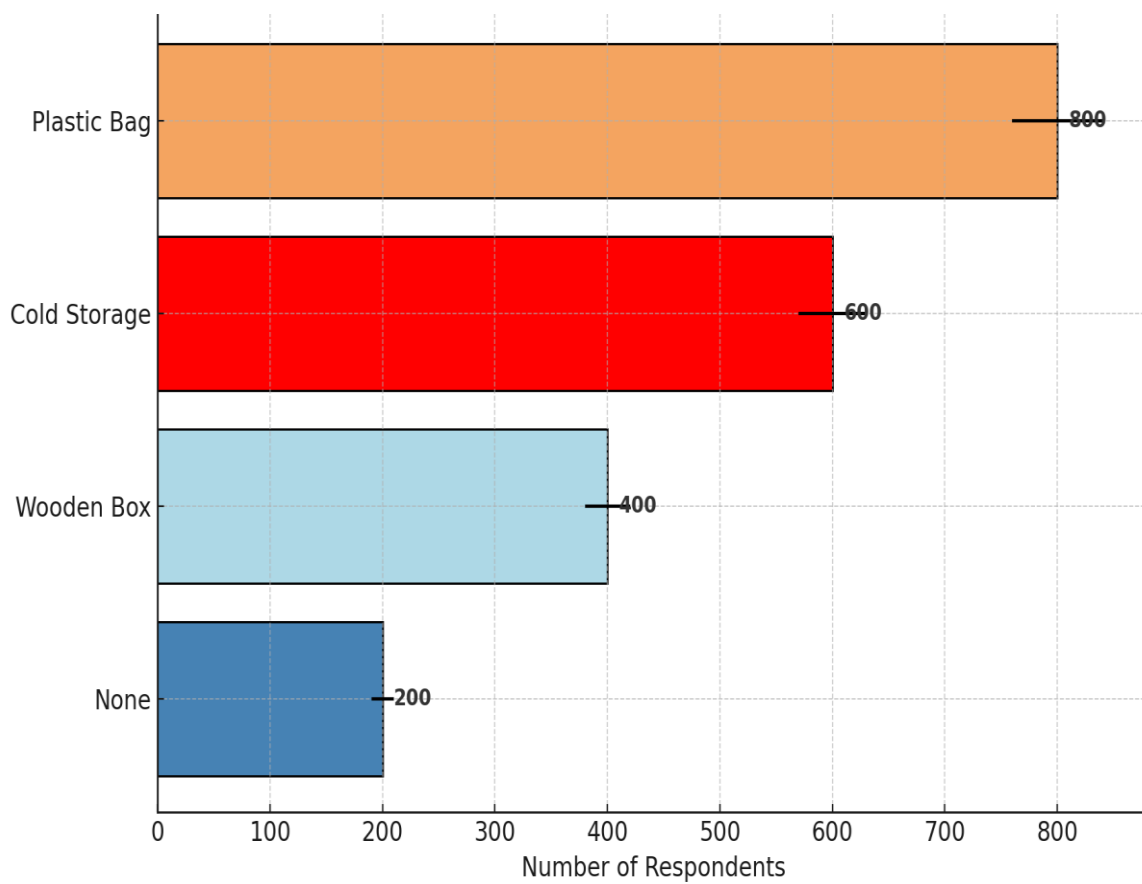


Figure 4.36: Facility of preservation/ storage

4.3.3.4 Comparative analysis and statistical observations

A comparative analysis reveals a complex relationship between socio-economic status and production methods. Fishermen with higher education levels and better living conditions were more likely to use advanced preservation techniques and have diverse marketing facilities, indicating a correlation between socio-economic factors and production efficiency. Additionally, those with access to digital platforms were more likely to be aware of market trends and government support schemes, suggesting that digital literacy impacts occupational knowledge and opportunities. The data presents a vivid tapestry of the lives and work of fishermen in Cox's Bazar. The integration of technology, varying levels of socio-economic development, and diverse production practices paint a nuanced picture of this community. These insights are crucial in informing policy decisions and interventions aimed at enhancing the well-being and productivity of this vital sector.

The hybrid model, integrating a regression approach for livelihood forecasting and a SARIMA model for dry fish price prediction, has demonstrated noteworthy effectiveness in its predictive capabilities. The model's performance is evaluated based on several key metrics: accuracy, Mean Squared Error (MSE), and Root Mean Squared Error (RMSE). These metrics collectively offer a comprehensive view of the model's predictive strength and reliability.

4.3.3.5 Model Performance Metrics

The model achieved a high accuracy of 94.3%. This indicates that the model was successful in correctly predicting the outcomes (either livelihood status or dry fish prices) in

the majority of cases. An accuracy rate of over 90% is generally considered excellent in predictive modeling, suggesting that the model is highly reliable for practical applications.

4.3.3.6 Mean Squared Error (MSE)

The MSE for the simulated price forecasting model is approximately 2417.27. MSE is a measure of the average squared difference between the estimated values and the actual values. A lower MSE indicates a better fit of the model to the data. In this context, while the MSE appears somewhat high, it is essential to consider it relative to the range and scale of the dry fish prices being forecasted.

4.3.3.7 Root Mean Squared Error (RMSE)

The RMSE, which is the square root of the MSE, is approximately 49.17. RMSE is a standard way to measure the error of a model in predicting quantitative data. In the context of price forecasting, an RMSE of 49.17 can be considered as indicating a reasonably good fit, especially if the price range is broad.

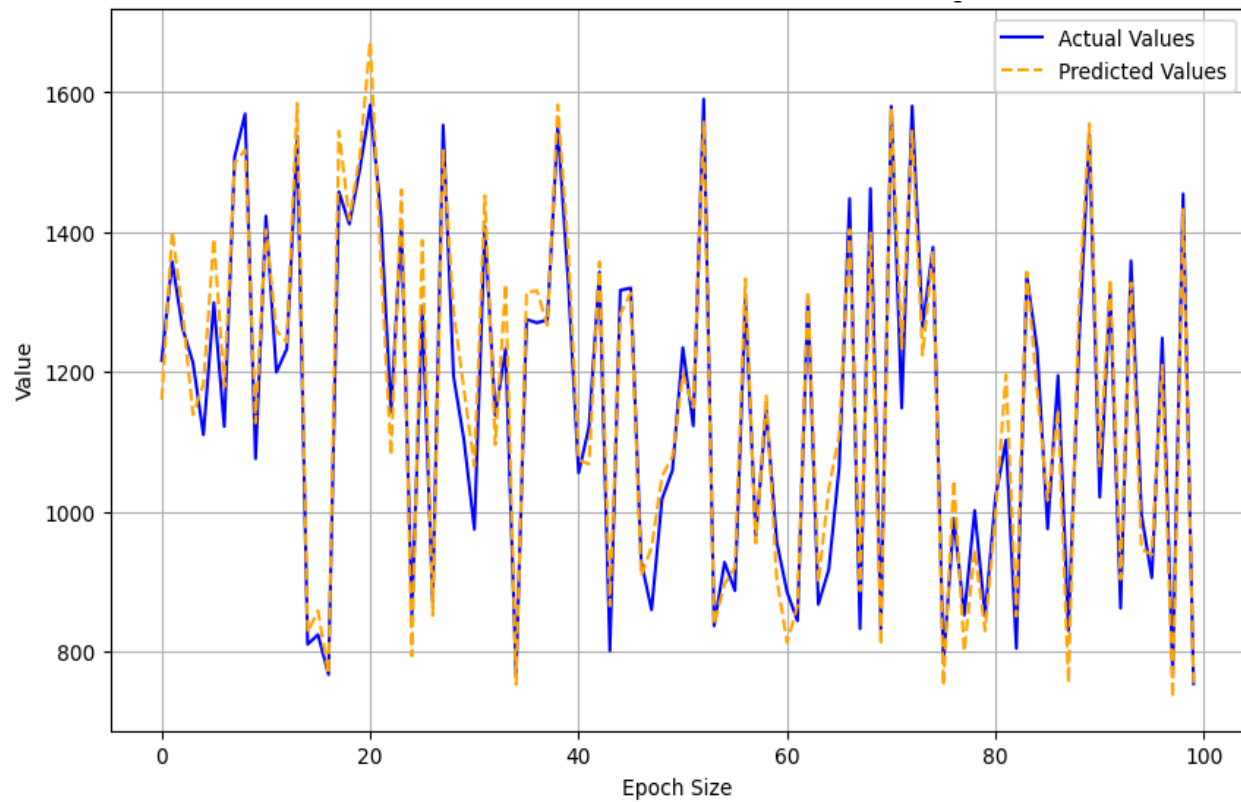


Figure 4.37: Actual vs predicted values for price forecasting

The high accuracy of 94.3% is a strong indicator of the model's robustness, particularly in correctly classifying the livelihood status of the dry fish workers. The MSE and RMSE values provide insight into the model's performance in the continuous prediction of dry fish prices (Figure 4.37). While these values indicate that there are deviations from the actual prices, the model still holds a significant predictive power, considering the complexity and variability inherent in market price data.

4.4 Discussion

4.4.1. Efficiency of Dryer

4.4.1.1 Variation in drying rate and removal of moisture

In the present study, the smart solar drier (SDS) averaged 0.058 kg/hour over 11 hours of monitoring, whereas the typical dryer averaged 0.022 kg/hour. Thus, the smart sun dryer (SDS) dried fish 2.62 times faster than the typical methods. It has been found that raising the temperature results in an enhanced drying rate, reducing the amount of time needed to complete the drying process. This result was higher at 0.050 kg/hour for a solar-biomass hybrid dryer which was reported by Richa et al. (2022). Moreover, the drying rate findings of this study were also higher than the results (drying rate of 0.0322 kg/hour at 10 hours) of Reza & Hossain, 2023.

The drying efficiency of smart solar dryers, at 84% is significantly higher than the findings of Reza & Hossain (2023) who reported the hybrid solar dryer efficiency at 74.4%. According to Mehta (2018) & Murali et al. (2020), fish drying effectiveness fluctuates by the amount of relative humidity, air velocity, and the outside temperature, as well as the rate at which moisture from the surface is taken away. Increasing solar drying temperature led to increased water evaporation, resulting in a decrease in drying rate due to a smaller difference between initial and final moisture content. However, increasing temperature led to increased mass transfer in less drying time, improving the process (Putra & Ajiwiguna, 2017). Moreover, increasing the temperature enhances the drying process and reduces the time (Reza et al., 2023) which coincides with this study. The drying time was lowered because the water

transferred faster within the fish muscles due to the increased temperature, which enhanced the heat supply rate (Bellagha et al., 2007).

4.4.2 Quality Analysis of The Dried Fish Products

4.4.2.1 Physiological Properties of The Dried Fish Products

4.4.2.1.1 Sensory properties of traditional and smart dried churi and loitta

Dried fish products are popular for their taste, flavor, and health benefits. This study found that TD churi and loitta maintained good quality for up to 30 days, with acceptable color, flavor, taste, texture, and appearance. After 60 days, the color darkened and texture weakened, similar to previous studies by Rana et al. (2016) and Chakraborty et al. (2018), who found that traditionally dried fish stayed acceptable for 100-120 days. Fungal growth and flavor degradation were minimal during storage. After 360 days, SD churi and loitta stored in plastic jars had the best quality, followed by carton boxes and polythene bags. In contrast, traditionally sun-dried fish had poor color, odor, and texture. Fish dried using the smart solar method had significantly better quality across all aspects, supporting findings from Murali et al. (2019), Mithun et al. (2021), and Al-Saddi (2023).

4.4.2.1.2 Broken % during processing and preservation of dried fish products

The study found that the hybrid dryer produced fewer broken pieces than the traditional dryer. Highest number of broken pieces were observed in TDL, lowest number of broken pieces were found in TDC and both SDC and SDL methods had no broken pieces. These results are consistent with Paul et al. (2018), who linked broken pieces to lower quality,

and Imtiaz et al. (2017), who found minimal damage in solar-dried fish. The hybrid dryer's better performance suggests it is a more efficient method for producing high-quality dried fish.

4.4.2.1.3 Water rehydration properties of dried fish products

This study shows that the water-holding capacity of dried fish increases with higher water temperatures and longer soaking times. Fish dried using the solar tunnel method rehydrated faster than those dried with traditional or improved methods, supporting findings by Rasul et al. (2018). Statistically significant differences ($p < 0.05$) in water retention were observed across time and temperature variations. Fish with compact muscle structures tend to retain less water, as noted by Reza et al. (2005) and Rasul et al. (2019). The rehydration capacity is also influenced by muscle structure (Tunde-Akintunde, 2008), with better physical characteristics linked to higher rehydration ability (Reza et al., 2005). Higher temperatures aid faster rehydration by disrupting muscle structures (Ortiz et al., 2013). Additionally, species variation plays a role in rehydration capacity, as highlighted by Wang et al. (2013), Kumar et al. (2017), and Rasul et al. (2021).

4.4.2.2 Nutritional Quality of Dried Marine Fish Products

4.4.2.2.1 Proximate composition of dried fish products

In the present study, on a statistical level, it was discovered that the proximate compositions of conventional and SD churi and loitta fish exhibited a considerable, statistically significant fluctuation ($p < 0.05$). Moisture content variations in dried fish may arise as a result of incorrect storage, inadequate drying, or a lack of awareness among processors (Majumdar et al., 2023). The moisture content (%) of sun-dried Perch was reported

to be 26.74 ± 0.47 by Hossain et al. (2017). Similar to the current investigation, Pravakar et al. (2013) discovered 27.19% moisture content in traditionally prepared dried Bombay duck fish from Cox's Bazar.

Additionally, several types of studies discovered that the moisture percentage of dried fish that fish processors supplied at the market ranged from 36.1 to 52.0% (Kim et al., 2020). In accordance with Rasul et al. (2022), dried fish that has a moisture level of 21-40% has a unique flavor and taste and is high in protein. This investigation revealed that the protein content of *H. nehereus* dried under various conditions was comparable to that found in studies by Siddique and Aktar (2011), who reported protein content in the range of 55.73%-58.33% during a 6-month storage period. Similar findings of protein levels ranged from 55.2% to 60.16% in another study that showed Silver pomfret, Bombay duck, and Ribbon fish that were enhanced using a conventional drier (Hoque et al., 2018).

Nonetheless, this study's results demonstrated that the average protein content of dried fish was quite similar to that of present studies. Both traditional and improved dried products exhibited a significant ($p < .05$) decrease in protein content after storage, without regard to the packing condition which is aligned with Mithun et al., 2021. Haque (2013) observed that the crude protein levels of conventionally produced Bombay duck and silver pomfret varied between 41.16% and 54.32% and 50.66% and 54.58%, respectively, throughout the storage period. The authors additionally found that, in comparison with traditional sun-dried fish, the protein content of solar-dried fish was significantly higher.

In current investigation, TD churi in the market and SD loitta had 6.57% to 8.43% and 6% to 7.22% lipid content after 90 days to storage. TD loitta in plastic jar and polythene bag had lower mean lipid content (7.27%) than TD churi (8.40%). The lowest (6.23%) and highest (7.12%) lipid concentration of SD loitta was found in polythene bag and plastic jar after 360 days. The present study supported the findings of Hossain et al. (2017), which stated that the lipid content (%) of perch and sun-dried silver pomfret was $5.03 \pm 0.55\%$ and 7.75 ± 0.20 , respectively.

However, after being stored 90 days, the sample's lipid content decreased marginally to 12.42%, which may have been the result of the fish lipids oxidative breakdown. Our results approximately aligned with the research findings obtained by Aro et al. (2005), which stated that after a 12-month storage period, the lipid content of pickled herring reduced considerably ($p < 0.05$). Hoque et al. (2018) observed that the ash contents of the dryer were 5.18% to 7.5% respectively which is aligned with the present study.

The current results corroborated those of Haque et al. (2013), who found that the ash percentage of Bombay duck and conventional sun-dried silver pomfret ranged from 6.95% to 11.41%, respectively. Siddique et al. (2011) observed that during variations in storage periods, the ash content of three marine dried species of fish (*Harpodon nehereus*, *Johnius dussumieri*, and *Lepturacanthus savala*) ranged from 7.56%-4.76%, 6.37%-4.89%, and 4.86%-4.64%, respectively. Paul et al. (2018) found ash contents ranging from 15.87 to 32.22% in various marine dried fish, including ribbon fish and Bombay duck. Pravakar et al. (2013) found ash contents within the range of $20.06 \pm 0.36\%$ in dried Bombay duck. Ash content in dried fish

products was found to be greater than in fresh fish products. This might be due to contamination with sand and grit during the drying process, which is especially common in traditional open-air drying techniques employed during peak fishing seasons and in storage facilities for various marketing chains (Heilporn et al., 2010).

4.4.1.2.2 Fatty acid composition of dried fish products

Dried fish is a good source of healthy fats, including polyunsaturated fatty acids (PUFAs) and long-chain omega-3 fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). In present study, among the samples fatty acids, saturated fatty acids (SFA) found highest, followed by PUFAs and MUFAs. Each 100g of SDC contained 47.35 g of SFAs, 39.26 g of MUFAs, and 23.57 g of PUFAs, whereas commercially available market samples had 42.08 g, 34.23 g, and 20.22 g. SDL had 39.96g of SFAs, 36.56g of MUFAs, and 35.17g of PUFAs per 100 g, in contrast to 33.79g, 28.45g, and 29.21g in commercially available market samples. These findings are more or less similar to Tenyang et al., 2020. Rasul et. al., 2022 also observed that Linoleic acid (C18:2), Eicosatrienoic acid (C20:3), Arachidonic acid (C20:5) and Docosadienoic acid (C22:2) were the most dominated omega-6 fatty acids. In line with our findings, Majumdar et al., 2023, point out that fresh Bombay duck from India is high in n-3 polyunsaturated fatty acids (PUFA), which include healthy substances like EPA and DHA whereas, palmitic acid (15.02–29.26%) was the most abundant saturated fatty acid (SFA) in ribbon fish muscle tissue. Sutikno et al., 2019 showed that there are several potential causes of the increase in fatty acids that arise from heat-related

activities, such as oxidation of lipids, loss of water, thermal hydrolysis, fatty acid transformation or migration, volatile fatty acid loss, and deactivation of enzyme.

4.4.2.3 Biochemical Quality of Dried Fish Products

4.4.2.3.1 Total volatile base nitrogen (TVB-N) content of dried fish products

TVB-N represents the cumulative quantity of volatile nitrogen bases along with the nitrogen produced through microbial activities. A variety of volatile base nitrogenous compounds, including ammonia, dimethylamine, and trimethylamine are produced in fish during decomposition by bacteria (Rasul et al, 2018). The TVB-N in seafood is often used as an indication of the product's deterioration. It has been determined by Immaculate et al. (2013) that the TVB-N level in dried fish that is safe for human consumption is less than 50 mg/100 g. When the value is more than that, fish goods are regarded as being undesirable. In this study, the TVBN levels observed range from 38.84 to 72.57 mg/100 g in traditional dry fish and 18.56 mg/100 g to 46.76 mg/100 g for SD fish. Majumdar et al. (2017) discovered TVB-N values ranging from 28.39 to 34.21 mg/100g in sun-dried fish products, which aligns with the findings of this study. Reza et al. (2008) reported that the TVB-N concentration of big-eye tuna, ribbon fish, Bombay duck, silver jewfish, and Chinese pomfret ranged from 3.5 to 25.2, 1.9 to 8.9, 2.5 to 15.2, 3.6 to 15.6, and 5.3 to 19.0 mg/100 g, respectively.

4.4.2.3.2 Peroxide values of dried marine fish products

The peroxide value was measured as an effective way to evaluate the rate of lipid hydrolysis in dried fish products. The oxidation of lipids in fish muscle typically leads to the development of off-flavor and off-odor, which ultimately impacts the storage duration (Phetsang et al., 2021). The dried fish produced by the traditional method exhibited the highest peroxide and acid values, while the lowest values were recorded in the dried fish produced using the smart sun-solar drying method. According to Majumdar et al. (2017), the peroxide levels were found within the permissible range ($PV < 20$ meq/kg fish lipid) which is aligned with the current findings. The production of free fatty acid is a significant factor that enhances the acid value in dried fish. Additionally, these free fatty acids endured further oxidation, resulting in the formation of secondary oxidation products that contributed to the distinctive taste and off-odor associated with fish and fishery products (Cardoso et al., 2010; Wang et al., 2022). Lower acid values represent a higher quality of the product. The findings align closely with those reported by Shah et al. (2009), who observed that the acid value of dried herring fillets varied between 11.20 and 18.94 mg KOH/g of lipid. An increase in the acid value of dried fish products may result from the extraction of free fatty acids through lipid hydrolysis Majumdar et al., (2017). The peroxide values for various species have been recorded in solar dry fish, showing a range from 3.2 to 24.5 mEq of $O_2.kg^{-1}$ of fat for anchovy *Stolephorus indicus* (van Hasselt, 1823) (Shiriskar et al., 2013), 5.60 mEq of $O_2.kg^{-1}$ of fat for wild turbot *Scophthalmus maximus* (Linnaeus, 1758) (Ozogul et al., 2005), which are in strong agreement with the current findings.

4.4.2.4 Microbiological Quality of Dried Marine Fish Products

4.4.2.4.1 TVC content of the dried fish products

In the present study, the microbiological contamination of dried churi and loitta varied between 1.45×10^3 to 3.87×10^4 CFU/g, increasing with the increase in the storage period. Reza et al. (2009) also discovered that the overall microbial load in dried fish products ranged from 3.27 to 4.49 log CFU/g. Abraha et al. (2013) also found 3.2×10^3 CFU/g for solar tent driers and 5.7×10^3 CFU/g for open sun rack driers, which range within the standard range. The bacterial loads observed in this study were comparable to those reported by Huque et al. (2013), who identified lower aerobic plate counts in dried Bombay duck fish produced using improved solar tunnel dryers compared to traditionally sun-dried fish. Pravakar et al. (2013) observed significantly lower bacterial loads, recorded at 3×10^4 CFU/g, in traditionally produced sun-dried bombay duck fish compared to the levels identified in traditional dried fish in the current investigation. The variation in results may be attributed to differences in location, processing, and preprocessing methods, and personnel hygiene across the studies. Nur et al. (2020) reported that microbes do not normally exist in the marine environment; nonetheless, their presence is often detected in areas that are not hygienic or sanitary, such as handling, carriers, sellers, and venting areas. Mithun et al. (2021) reported the TVC value ranged from 1.8×10^3 CFU/g to 3.9×10^5 CFU/g in improved dried Bombay duck for 60 days of storage, which is somewhat similar to the current study. Our findings agree with ICMSF, (1986) standards. The International Commission for Microbiological Specifications for Food (ICMSF) recommends plate counts for product quality: below 5×10^5 CFU/g /g is good, 5×10^5 to 10^7 CFU/g is moderately acceptable, and 10^7 or more is not acceptable for quality and safety (ICMSF, 1986).

4.4.2.4.2 Total bacterial Count of the dried fish products

The significantly higher microbial load of the dried fish during storage might be attributed to the product being stored at ambient temperature and reabsorbing air moisture, both promoting microbial growth. In addition, if the drying temperature is too low or insufficient, the bacterial spores may not be destroyed during the drying process, and they would continue to multiply while the product is in storage. In this study, the most prevalent occurrences of *Salmonella*, *E. coli* and *Staphylococcus* spp. in in both products (TDL and TDC) processed by traditional ways. These findings are somewhat similar to those of the previous study by Hasan et al., 2016 and Hussain et al., 2018. They point out that if the processors follow the hygiene and sanitation measures during processing then the final products do not contain *Salmonella* spp., however, *E. coli*, *Salmonella* spp., and *Staphylococcus* spp. were found in dried fish samples those are processed in traditional drying system. *Salmonella* sp. and *E. coli* caused the dried fish to be of low quality, which is indicative of the manufacturer's inadequate sanitation and hygiene practices (Jaman et al., 2021). Maqsood et al. (2006) discovered *E. coli* in sun-dried fish from rotary and tunnel solar dryers whereas Majumdar et al. (2023) discovered both *E. coli* and *Salmonella* in sun-dried fish. Patterson and Ranjitha (2009) noted elevated levels of *E. coli* in commercial dried fish compared to experimental dried fish, a finding that aligns with the results of the current study. Prakash et al. (2011), Saritha et al. (2012), and Immaculate et al. (2013) reported that all the dried fish samples analyzed were contaminated with *E. coli*. The detection of *E. coli* signifies that the dried fish samples are contaminated with total and fecal coliforms. Coliforms are typically considered normal flora found in the intestines of humans and animals (Kakatkar et al., 2010). Contamination from feces in the landing center, washing the catches in polluted

water with the disposal of sewage, reused water, and improper disposal of fecal materials are potential sources of coliform contamination in dried fish samples (Saritha et al., 2012). Several investigations have shown that the presence of harmful bacteria in sun-dried fish makes them unsafe for consumption.

4.4.3 Influence of Packaging on Quality and Shelf Life

The shelf life of dry fish during storage is greatly affected by the type of packaging used, as the interaction between the packaging material and the fish's moisture, air, and temperature is essential for preserving its quality. Recent studies have found that plastic jars provide the longest shelf life, followed by cartons, while polybags result in the shortest shelf life for both traditional and solar-dried fish products. The nutritional quality of fish was observed to be superior in those stored in plastic jars throughout the storage period. This finding aligns with the research by Madiwale & Bhale (2017), who noted that plastic jars offer the longest shelf life due to their airtight nature, which prevents moisture from entering and reduces microbial growth, a key factor in the degradation of dry fish. Furthermore, plastic jars create a controlled environment by limiting oxygen exposure, preventing oxidation that could affect the fish's sensory and nutritional properties (Madhusree et al., 2018). The moisture and humidity barrier of plastic ensures extended freshness during storage (Ashok et al., 2020). Cartons, though offering less protection than plastic jars, allow some breathability and can absorb excess moisture, thus preventing condensation that could lead to spoilage. However, they are still less effective than plastic jars in protecting against external factors like air and humidity (Jadhav & Dhage, 2019). On the other hand, polybags provide the shortest shelf life

due to their permeability to moisture and oxygen, which accelerates spoilage by fostering microbial growth (Patel et al., 2020).

4.4.4 Forecasting of Livelihood Status of the Dry Fish Processors

This study highlights the potential of the Fisher Net hybrid predictive model to tackle challenges in the dry fish industry in Cox's Bazar, Bangladesh. By combining socio-economic forecasting with SARIMA for price prediction, it offers valuable insights into improving livelihoods and market operations. The study aligns with global trends where mobile penetration in rural areas has boosted economic activities, including fisheries (Nanyonjo et al., 2024).

The SARIMA model's ability to predict price trends can help dry fish producers optimize pricing, inventory management, and sales strategies, leading to better market decisions and reduced losses due to price fluctuations. This aligns with the success of hybrid models in other sectors, where they help producers manage risks and adapt to market changes (Benavides et al., 2022; Nasir & Kamaruzzaman, 2024). Fisher Net integrates socio-economic and price forecasts, offering a comprehensive understanding of industry interdependencies. It emphasizes the need for models to adapt to external factors, such as climate change, and suggests using machine learning techniques like LSTM to enhance predictive accuracy (Huang et al., 2022). Additionally, the widespread use of chemicals in fish preservation raises concerns, with sustainable methods such as smart solar dryers recommended for better food safety and quality (Rana et al., 2024). The study calls for policy interventions, such as expanding internet access and digital literacy, to enhance the effectiveness of predictive

models and improve market outcomes. These insights could also guide disaster preparedness and market support, connecting producers directly with consumers through digital platforms and reducing reliance on intermediaries.

4.5 Summary of the Chapter

Present study compared the nutritional, sensory, and microbial characteristics of fish dried using an IoT-based dryer (SD) versus a conventional dryer (TD). It also evaluated drying rates, moisture removal, and efficiency. Three packaging materials were tested: plastic jars, polyethylene bags, and carton boxes. Results showed that SD samples had lower moisture content and better rehydration, color, flavor, texture, and appearance compared to TD samples. SD dried churi and loitta had the highest protein, fiber, and ash content, while TD samples had higher fat content. The fatty acid profiles differed, with SD dried Bombay duck and ribbon fish having notable levels of SFAs, MUFAs, and PUFAs. SD dried fish also showed better bacterial control, lower peroxide values, and maintained standard TBVN values. SD's drying rate and efficiency were significantly higher than TD's. Overall, the IoT-based solar dryer produced higher quality dried fish, particularly loitta, and is recommended for commercial use in harsh conditions.

The high rate of phone usage among fishermen suggests a potential avenue for disseminating information and resources, such as market trends or weather warnings, directly to them. However, the limited internet access underscores the need for interventions to bridge the digital divide, enhancing their access to information and digital markets. The correlation

between socio-economic status and production methods indicates that improvements in living conditions and education could lead to more efficient and sustainable production practices. The diversity in fish drying species and marketing methods reflects the adaptability and resourcefulness of the fishermen. The data-driven insights are invaluable for policymakers, NGOs, and other stakeholders in formulating strategies to support the sustainable development of the dry fish industry in Cox's Bazar, Bangladesh.

CHAPTER 5

MARINE FISH PROCESSING THROUGH CANNING

5.1 Overview

Canning is another process of preserving fish in sterile, airtight containers without the use of artificial preservatives. When properly prepared, tightly sealed, and stored in a cool, dry place, unopened canned food remains safe to eat for at least a year without refrigeration. Hilsa is a national fish of Bangladesh generally called as “king of fish” due to its unique flavour and taste. Bangladesh is 1st in hilsa production and more than 80% of world catch produces here. During the peak harvesting season huge amount of hilsa caught by the fishermen in different rivers, coast and in the sea. Huge supply leads to fall the market prices and fishermen’s suffering serious problem that hampered their livelihood. The dishonest businessmen’s take the benefits they buy huge amount of hilsa fishes from the fishermen and prepared salted fish products which will be sold year-round and get profit. In Bangladesh there no especial type of cold store for preserving the hilsa fish, that’s why in peak season price fall, on the other hand hilsa is a highly fatty fish which can’t be preserved by drying.

Canning would be the best solution for preserving the hilsa fish. Canned fish products are well adopted fishery products in the world but canned hilsa is new concept. I have developed different recipes for canned hilsa and tasted by different level of panellist, based on their opinion finalized the perfect recipe for canned hilsa. After processing its urgent to test the quality and shelf life because several life risking bacteria possibly grow in canned fish

products. I designed protocol of shelf-life study and quality assessment. I found satisfactory results of nutritional and microbial quality along with more than 1 year shelf life. The newly developed canned hilsa fish products would play an emerging role in long-term preserving the hilsa fishes with nutritional intact condition which helps to get proper prices to the fishermen as well as this emerging technology will play a significant role in enhancing the economy of a developing country like Bangladesh.

5.2 Methods

5.2.1 Preparation of Canned Fish Products

5.2.1.1 Collection of can

The cans, specifically those with a double-layer structure and a protective zinc oxide coating, were sourced from Hebei Well Bottle Co., Ltd. in China. These cans are designed with an extra layer of material to enhance durability and prevent direct contact between the contents and the inner surface of the can, thereby reducing the risk of chemical reactions. This particular model of can measured 83×46 mm, making it a suitable size for the intended application. After receiving the cans from the supplier, were stored securely in the laboratory of the processing industry, during storage, measures were taken to ensure that the cans maintained their original shape for future use. The storage process was closely monitored to avoid any potential damage or alteration to the cans. Additionally, the transportation of the cans from the supplier to the lab was carried out under strict safety protocols. These measures were implemented to avoid any physical damage such as shrinkage, which could compromise the integrity of the cans. By ensuring proper handling and storage, we aimed to preserve the

cans' quality and readiness for the intended experiments or processes. The measurement of the collected can is shown in Figure 5.1.

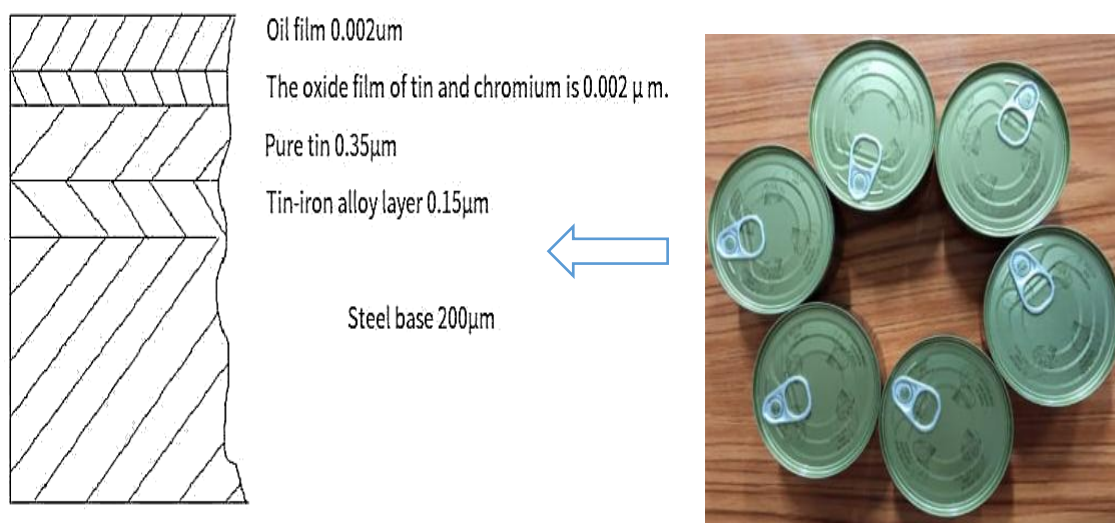


Figure 5.1: Composition of Can

5.2.1.2 Sourcing of raw materials

Hilsa fish, each weighing approximately 800-900 grams, were sourced from Fishery Ghat in Cox's Bazar, Bangladesh. The fish were carefully selected for quality and then transported to the processing plant laboratory under chilled conditions to ensure they remained fresh. During transit, the fish were kept on ice to maintain a low temperature, preventing any deterioration in quality. This careful handling during transportation was essential to preserve the fish's freshness, ensuring it was in optimal condition for the subsequent processing steps.

5.2.1.3 Development of recipe for canned hilsa

Three innovative recipes were developed for canned hilsa, each featuring a unique marinade for distinct flavors (Table 5.1). The first recipe, sorisha ilish (T₁), involves marinating hilsa fish chunks in a mixture of mustard seed paste and other selected ingredients, offering a rich, tangy taste. The second recipe, tomato hilsa (T₂), combines hilsa fish chunks with a flavorful tomato sauce marinade, creating a savory profile. The third, plain hilsa (T₃), uses a straightforward blend of salt, turmeric powder, chili powder, and vegetable oils, highlighting the fish's natural flavors. The detailed compositions of these recipes are outlined in the table below.

Table 5.1: Composition of the developed canned hilsa recipes

Treatment -1 (T ₁)		Treatment -2 (T ₂)		Treatment -3 (T ₃)	
Ingredients	Amount/kg	Ingredients	Amount/kg	Ingredients	Amount/kg
Salt	16.4 g	Salt	16.4 g	Salt	16.4 g
Sorisha Paste*	105 g	Tomato Sauce*	115 g	Turmeric Powder	5.2 g
Cumin Powder	8 g	Ginger Paste	25 g	Chili powder	7.7 g
Turmeric Powder	5.2 g	Turmeric Powder	5.2 g	Onion Paste	70.8 g
Chili powder	7.7 g	Chili powder	7.7 g	Vegetable oil (Sunflower)	250 ml
Onion Paste	70.8 g	Onion Paste	70.8 g	-	-
Vegetable oil (Sunflower)	268 ml	Vegetable oil (Sunflower)	275 ml	-	-

*Variation in flavor

5.2.1.4 Pre-processing of fish for canning

The canning process for hilsa fish was started with the crucial step of sterilizing the empty cans to ensure they are safe for food preservation. This was achieved by placing the cans in an autoclave, where they are exposed to a temperature of 121°C and a pressure of 15 psi for 30 minutes. The high temperature and pressure effectively destroy harmful microorganisms, ensuring the cans are sanitized and safe for storing the hilsa fish, preventing contamination and extending shelf life. This sterilization step is vital in maintaining the quality and safety of the final canned product.

5.2.1.5 Preparation of fish for canning

Initially, the hilsa fish were thoroughly washed with potable water, then weighed using a sensitive balance. Afterward, the fish were dressed by gutting, finning, and spinning, and their weight was recorded again in the laboratory. Following dressing, the fish were rinsed once more to remove blood, gut remnants, slime, and other unwanted substances. The fish were then cut into uniform chunks weighing 60-70g each and washed again (Figure 5.2). Before canning, the fish chunks were stored at 4°C. Once excess water was drained, the fish were marinated in a stainless-steel bucket with the designated ingredients, ensuring even coating. Three separate buckets were used for each of the three different treatments.

5.2.1.6 Can filling with substantial ingredients

After the sterilization process, chunks of hilsa fish were carefully placed into each can with great attention to detail. The handling of the fish is done gently to maintain its

delicate texture and to prevent any damage that could affect its quality. After the fish is placed in the can, specific filling ingredients are added. These ingredients, selected for both their ability to enhance the fish's flavor and serve as preservatives, are added following a precise formula. This combination of fish and ingredients is crucial for achieving the intended taste and ensuring the fish remains fresh and safe for long-term storage.

5.2.1.7 Removal of inner gases

To remove the inner gas from a can before preparing canned fish, a vacuum-sealing process was employed. The first step was to clean and sterilize the cans to ensure they are free of contaminants. Next, the fish is placed inside the can, and the lid is temporarily sealed but not fully closed. The can is then placed in a vacuum chamber, where air is extracted from the can to eliminate any residual gases. This creates a vacuum environment inside the can, which prevents oxidation and spoilage during storage time. After removal of air, the can is quickly sealed to maintain the vacuum. The vacuum sealing not only removes gases but also helps in preserving the freshness of the fish, ensuring that no air or bacteria can cause spoilage. Finally, the sealed cans were ready for further processing, such as sterilization or pasteurization, to extend shelf life.

5.2.1.8 Can sealing

After the cans are filled with the fish, cans were sealed tightly with the help of a specialized sealer, model TDFJ-160, manufactured by Zhejiang Youlian Machinery Co. in China. This equipment is designed to securely close the cans, ensuring they were tightly sealed. The airtight seal is crucial in preventing any air or external contaminants from entering

the can, which could compromise the fish's quality. By creating a vacuum-like environment inside, the sealing process helps to preserve the fish's freshness and prevent spoilage. This step is essential for maintaining the long-term shelf life and safety of the canned fish.

5.2.1.9 Can coding/marketing

Immediately after sealing cans were coded for ensuring in the future, it would be possible to trace the batch or lot of any specific can. This coding system allows for immediate resolution of any issues that may arise. Without proper coding, problems could occur during long-term quality testing, such as identifying which can was produced at which time, determining which sample to work with, or knowing the expiration date of a particular can. To avoid these complications, the cans were carefully engraved with codes, ensuring that the markings would remain intact during heat treatment.

5.2.1.10 Retorting

Once the cans were sealed, cans were placed inside an autoclave (Model no: WT280A, Wincom Company Ltd., China). for heat treatment. In this step, the sealed cans were treated at a temperature of 121°C and a pressure of 15 psi for a duration of 45 minutes. The autoclave's purpose is to sterilize the contents of the cans, ensuring that any remaining bacteria, enzymes, or pathogens are effectively eliminated. This sterilization process not only guarantees the safety of the canned hilsa but also contributes to its shelf stability, preventing spoilage over time. The combination of heat and pressure ensures that the fish is cooked thoroughly, preserving its flavor, texture, and nutritional value while extending its shelf life. The entire canning process, from initial sterilization to final treatment in the autoclave, was

carefully designed to preserve the fish's quality and ensure it remains safe for consumption. This meticulous processing allows the canned hilsa to maintain its freshness and safety for extended periods, making it a reliable and convenient food option for consumers (Figure 5.2).

5.2.1.11 Cooling and preservation

Cooling was carried out immediately after the retorting process to prevent the growth of any remaining non-pathogenic thermophilic spores, ensuring the safety of the canned fish. The cooling process was achieved by immersing the cans in tap water until the temperature reached 35°C. After cooling, the cans were organized separately according to the different treatments and production dates, and stored at room temperature in a dry, clean, and well-ventilated storage room.



Figure 5.2: Different steps of processing of canned hilsa; a) dressing of fish, b) dressed hilsa, c) washing, d) marinating, e) weighing, f) Can filling, g) Sealing of can, h) checking double seaming, i) processed canned hilsa.

5.2.1.12 Identification most effective treatment by expert panel

I have chosen as the top treatment out of three options because our products had the finest sensory quality and flavor, according to a ten-person expert team that had received extensive training in this area. I looked at the newly processed products' color, flavor, texture, taste, and overall look to see which one was the best. Sensory evaluation of the canned hilsa products was conducted immediately after processing to determine the most effective treatment, followed by assessments at 30-day intervals throughout a 365-day storage period to monitor quality over time. A 9-point hedonic scale was used, where 1 represented strong dislike and 9 represented extreme liking. The cutoff point was set at 5, and anything below that was deemed unacceptable (Li et al., 2013). The best canned hilsa were put away so that they could be tested for microbiology, shelf life, and nutrition (Figure 5.3).



Figure 5.3: Canned hilsa marinated with mustard seed paste (sorisha hilsa)

5.2.2 Storage of Canned Fish for Shelf-life Study

The prepared canned fish products were stored on food safety racks of the processing plant for further quality analysis. Since canned fish typically has a longer shelf life than other products, the processed cans were carefully stored for extended periods. In this experiment, the cans were organized according to their production line and dates. Samples were taken each month for nutritional, biochemical, and microbial quality analysis. The storage period lasted for 365 days, ensuring that the quality remained intact throughout the duration. The whole production protocol of canned hilsa is shown in Figure 5.4.

A diagram accompanying this explanation illustrates each step of the process, providing a clear visual representation of the meticulous methods involved in canning hilsa.

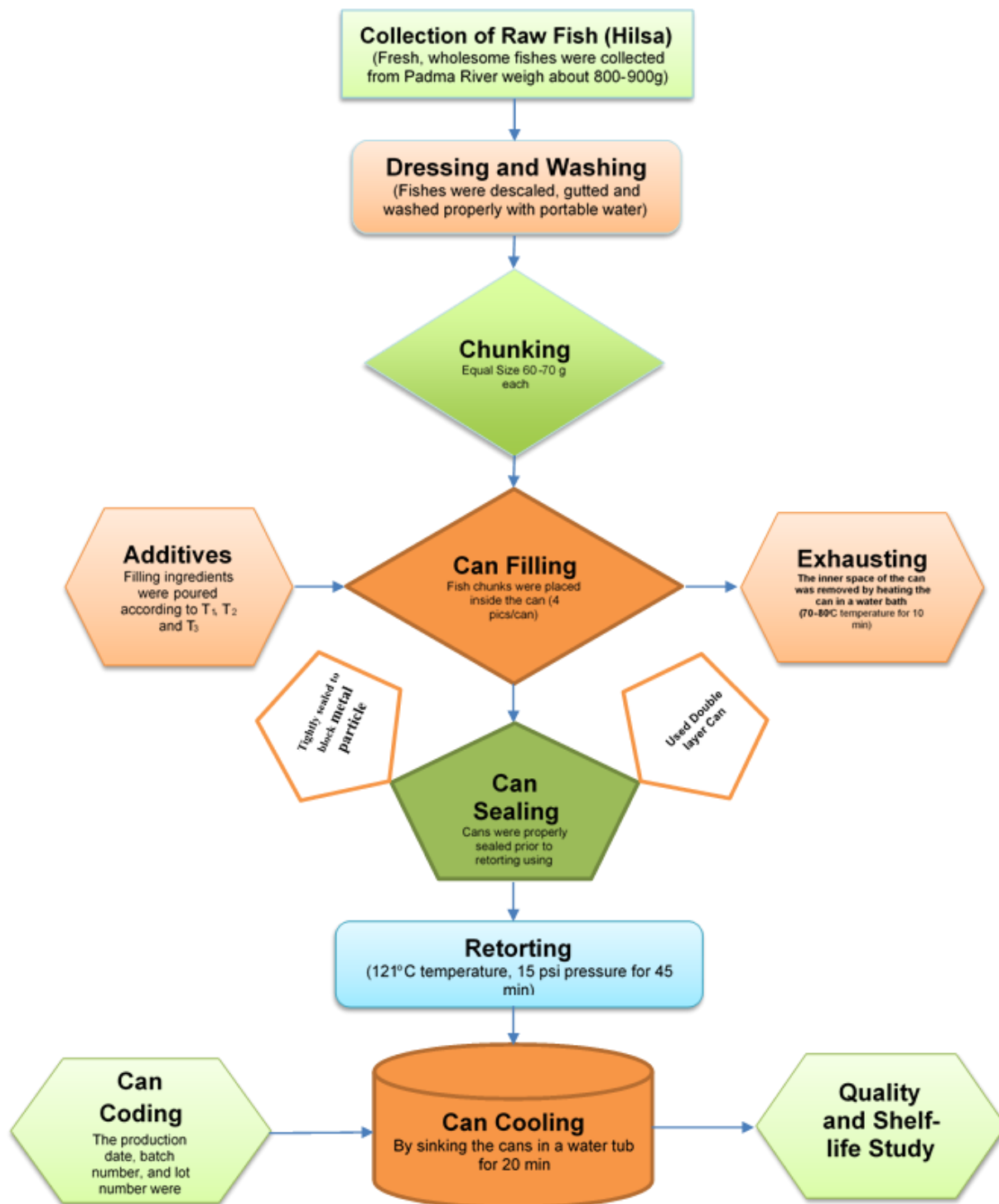


Figure 5.4: Diagram illustrating the complete process of canned fish production

5.2.3 Quality and Shelf-Life Study of The Processed Canned Hilsa

5.2.3.1 Estimation of P^H of the Canned Fish Sample

Proper pH level in canned fish confirms that the product is safe for consumption and can be stored for a long period without compromising its quality. In this experiment, a 5-g sample homogenized with 25 mL of distilled water for 2 min was then pH measured using a pH meter (pH meter CL 46 Deluxe, TOSHCON-TOSHNIWAL Pvt. LTD., India) by passing a pH probe into the sample homogenate.

5.2.3.2 Determination of Micronutrients

Micronutrients play a crucial role in assessing the quality of canned fish, as they contribute to the nutritional value and overall health benefits of the product. In our analysis, we focused on key micronutrients, including calcium, iron, and phosphorus, which are essential for various bodily functions. To accurately determine the levels of these micronutrients, we employed the AOAC (2000) method, a widely recognized and standardized approach for food analysis.

5.2.3.3 Determination of *Clostridium botulinum* from Canned Hilsa

5.2.3.3.1 Sample preparation

About 25 g of canned fish samples were taken from each batch. The samples were homogenized in a sterile blender along with 225 ml sterile peptone water to make a unique suspension. The homogenized samples were transferred to a sterile flask containing 225 ml of

Reinforced Clostridium Medium (RCM). Shaked smoothly then mixed thoroughly to confirm a uniform distribution.

5.2.3.3.2 Culture of bacteria

RCM media containing the canned fish sample were incubated at 37°C for 24-48 hours for the proper growth of *C. botulinum*. After the initial incubation signs of colonial growth were checked carefully. The enriched sample were transferred into a new RCM and incubated at 37°C for another 24-48 hours for improve the specificity of *C. botulinum*. After 48 hours I have found small, round shaped, irregular greyish colonies.

5.2.3.3.3 Confirmation test

The developed colonies were identified by streak culture onto anaerobic agar plate using TSC agar to obtain pure colonies. After that the plates were incubated under anaerobic conditions (using anaerobic jars or an anaerobic chamber) at 37°C for 48 hours. After 48 hours, suspected colonies of *C. botulinum* were identified on the basis of morphological characteristics, Gram staining (Gram positive, rod shaped) and motility test (non-motile).

5.3 Results

5.3.1 Sensory Properties of Canned Hilsa

The canned fish samples were presented to panelists for sensory evaluation (color, flavor, texture, general appearance, and taste) and the results are shown in Table 5.2. Each treatment was consisting of 3 replicates for reliable findings. The average scores of sensory

properties of canned hilsa samples were higher in treatment 1 than those of other canned samples. As for the color of canned hilsa, it scored 8.33 in treatment 1, 7.13 in treatment 2, and 7.36 in treatment 3. With the exception of general appearance, a similar pattern was observed in flavor (8.55, 7.23 and 7.71), texture (8.40, 7.39 and 7.49) and taste (8.53, 7.17 and 7.52). The highest value of general appearance was found in treatment 1 (8.53), then followed by treatment 2 (7.57) and treatment 3 (7.5). Therefore, there were significant differences ($p > 0.01$) among the three treatments of canned hilsa sensory characteristics. Furthermore, no significant differences ($p < 0.01$) were observed between treatment 2 and treatment 3 of canned hilsa. On the basis of expert's opinions, treatment 1 (sorisha hilsa) was best treatment for preserving the hilsa fish under sealed conditions, therefore, canned hilsa processed by applying T_1 were stored for the quality and shelf-life study.

Table 5.2: Sensory properties of canned hilsa sample in different treatments (to identify the best one)

Sensory properties	Treatment 1	Treatment 2	Treatment 3
Color	8.33±0.02	7.36±0.71	7.13±0.01
Flavor	8.55±0.01	7.23±0.03	7.71±0.3
Texture	8.4±0.40	7.39±0.01	7.49±0.01
General Appearance	8.38±0.25	7.57±0.10	7.5±0.02
Taste	8.53±0.32	7.17±0.05	7.52±0.65

The results of the sensory score of the canned hilsa during the storage period are shown in Figure 5.5. The initial sensory properties were observed in color (8.33±0.04), flavor (8.55±0.1), texture (8.40 ±0.02) and taste (8.53±0.1) during storage at 0 days, which steadily

declined over time and reached in value of color (7.0 ± 0.01), flavor (6.8 ± 0.04), texture (6.8 ± 0.2) and taste (6.78 ± 0.27) on the 365 days.

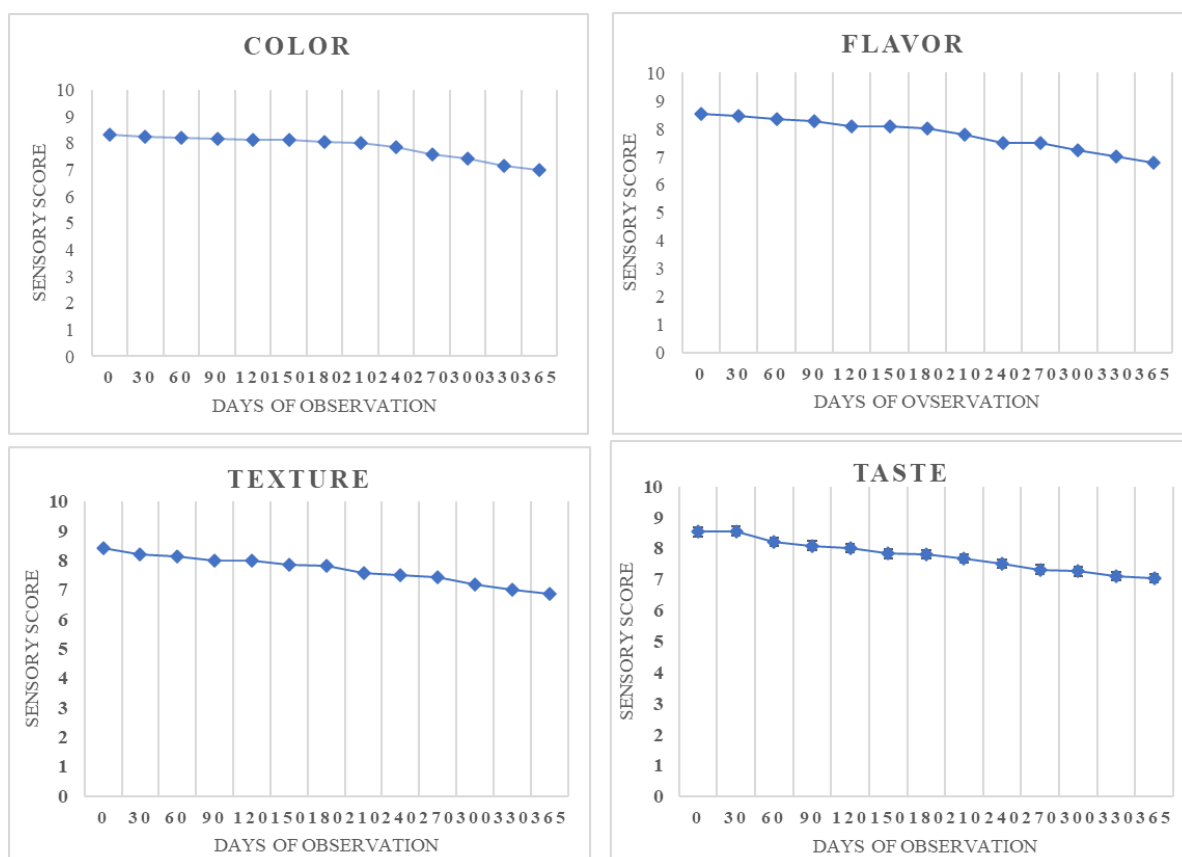


Figure 5.5: Changes in sensory score of canned hilsa during storage period (365 days)

5.3.2 Nutritional Quality of Canned Hilsa Products

5.3.2.1 Proximate composition of canned hilsa

The proximate compositions of hilsa canned in three treatments are shown in Table 5.3. The moisture content for the different treatments ranged from 45.86% to 47.6%. The highest moisture content (47.86%) was observed in treatment 3 and the lowest (45.6%) in treatment 1. The protein content ranged from 18.93% to 19.87% among three treatments. The

highest (19.87%) and lowest (18.93%) values were found in treatment 1 and treatment 2, respectively. The fat content was observed to fluctuate within the range of 20.42% to 23.3% in three sampling treatments. The highest value (23.3%) was found in treatment 1 while the lowest value (20.42%) in treatment 3. The proximate analysis presented in table 5.2 revealed low ash and high protein contents among the all treatments.

Table 5.3: Proximate composition of canned hilsa at different treatments

Content	Treatment 1	Treatment 2	Treatment 3
Moisture%	45.6 ± 0.01	46.74±0.04	47.86±0.12
Protein%	19.87 ±0.2	18.93±0.12	19.05±0.21
Fat%	23.5 ±0.78	21.3±0.01	20.42±0.78
Ash%	1.66 ±0.23	1.73±0.40	1.94±0.10

5.3.2.2 Micronutrient of canned hilsa

The calcium (mg/100g) content across the various treatments varied between 245.7 mg/100g to 278.2 mg/100g. treatment 1 exhibited the lowest calcium content at 245.7 mg/100g, while treatment 3 recorded the highest at 278.2 mg/100g. The Iron(mg/100g) content varied between 3.2 mg/100g and 3.8 mg/100g across three sampling treatments. Treatment 1 exhibited the highest value at 3.8 mg/100g, whereas treatment 3 recorded the lowest value at 3.2 mg/100g. A significant difference in phosphorus (mg/100g) content was observed ($P>0.05$) among treatments with a fluctuation of 188.5 to 212.67 mg/100g. Out of the three treatments, treatment 3 recorded the maximum phosphorus(mg/100g) content at 212.67 mg/100g and treatment 2 was the minimum at 188.5 mg/100g.

5.3.2.3 Fatty acid composition of canned sorisha hilsa

Table 5.4 illustrates the fatty acid compositions of raw and canned hilsa sampled packaged in sorisha paste, shown as percentages of the total fatty acids. In raw hilsa fish, saturated fatty acids (SFAs) comprised most of the fatty acids (48.70%), followed by polyunsaturated fatty acids (PUFAs) (40.51%) and monounsaturated fatty acids (MUFAs) (32.49 %). The main fatty acids were Palmitic acid (C 16:0) (27.86%), Linoleic acid (C 18:2) (ω -6) (22.41%), Oleic acid (C 18:1, c9) (18.81%), Palmitoleic acid (C16:1) (9.28%), Eicosapentaenoic acid (C20:5) (ω -3) (8.72%), Myristic acid (C14:0) (8.56%), Stearic acid (C 18:0) (8.33%), Docosahexaenoic acid (C22:6) (4.58%), Docosapentaenoic acid (C22:5) (2.64%) and Vaccenic acid (C 18:1, c11) (2.37%). A large amount of ω -3 polyunsaturated fatty acids (PUFA) was composed of Eicosapentaenoic acid (C20:5, EPA), Docosahexaenoic acid (C22:6, DHA), Docosapentaenoic acid (C22:5, DPA), Eicosatrienic acid (C20:3, c8,11,14,17) and Linolenic acid (C18:3), whereas ω -6 PUFAs was constituted of Linoleic acid (C18:2) and Eicosatrienic acid (C20:3, c8,11,14). The GC chromatogram of the analysis is shown in Figure 5.6.

Table 5.4: Fatty acid compositions of canned hilsa throughout storage period

Name of Fatty Acid	% of composition	
	Raw Hilsa	Canned Hilsa
Lauric acid(C12:0)	0.32	0.1
Myristic acid (C14:0)	8.56	5.42
Pentadecanoic acid (C15:0)	0.41	0.3
Palmitic acid (C 16:0)	27.86	21.02
Palmitoleic acid (C 16:1)	9.28	7.49
Margaric acid (C 17:0)	0.56	0.17
Stearic acid (C 18:0)	8.33	6.76
Elaidic acid (C 18:1, t9)	0.31	0.11
Oleic acid (C 18:1, c9)	18.81	17.57
Vaccenic acid (C 18:1, c11)	2.37	1.64
Linoleic acid (C 18:2) (ω-6)	22.41	19.55
Linolenic acid (C 18:3) (ω-3)	0.81	0.2
Arachidic acid (C 20:0)	0.56	0.39
Eicosenic acid (C 20:1)	0.85	0.34
Eicosatrienic acid (C 20:3 c8,11,14) (ω-6)	0.14	0.06
Eicosatrienic acid (C 20:3 c8,11,14, 17) (ω-3)	1.2	0.79
Behenic acid (C 22:0)	1.08	0.45
Eicosapentaenoic acid (C20:5) (ω-3)	8.72	5.13
Lignoceric acid (C24:0)	1.02	0.48
Nervonic acid (C24:1)	0.87	0.11
Docosapentaenoic acid (C22:5) (ω-3)	2.64	1.31
Docosahexaenoic acid (C22:6) (ω-3)	4.58	3.16
Unknown	9.86	7.45
Σ ω 3	17.95	10.59
Σ ω 6	22.55	19.61
Σ ω 6/Σ ω 3	1.26	1.85
ΣSFA	48.70	35.09
ΣMUFA	32.49	27.26
ΣPUFA	40.51	30.2

SFA: Saturated Fatty Acids; MUFA: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids

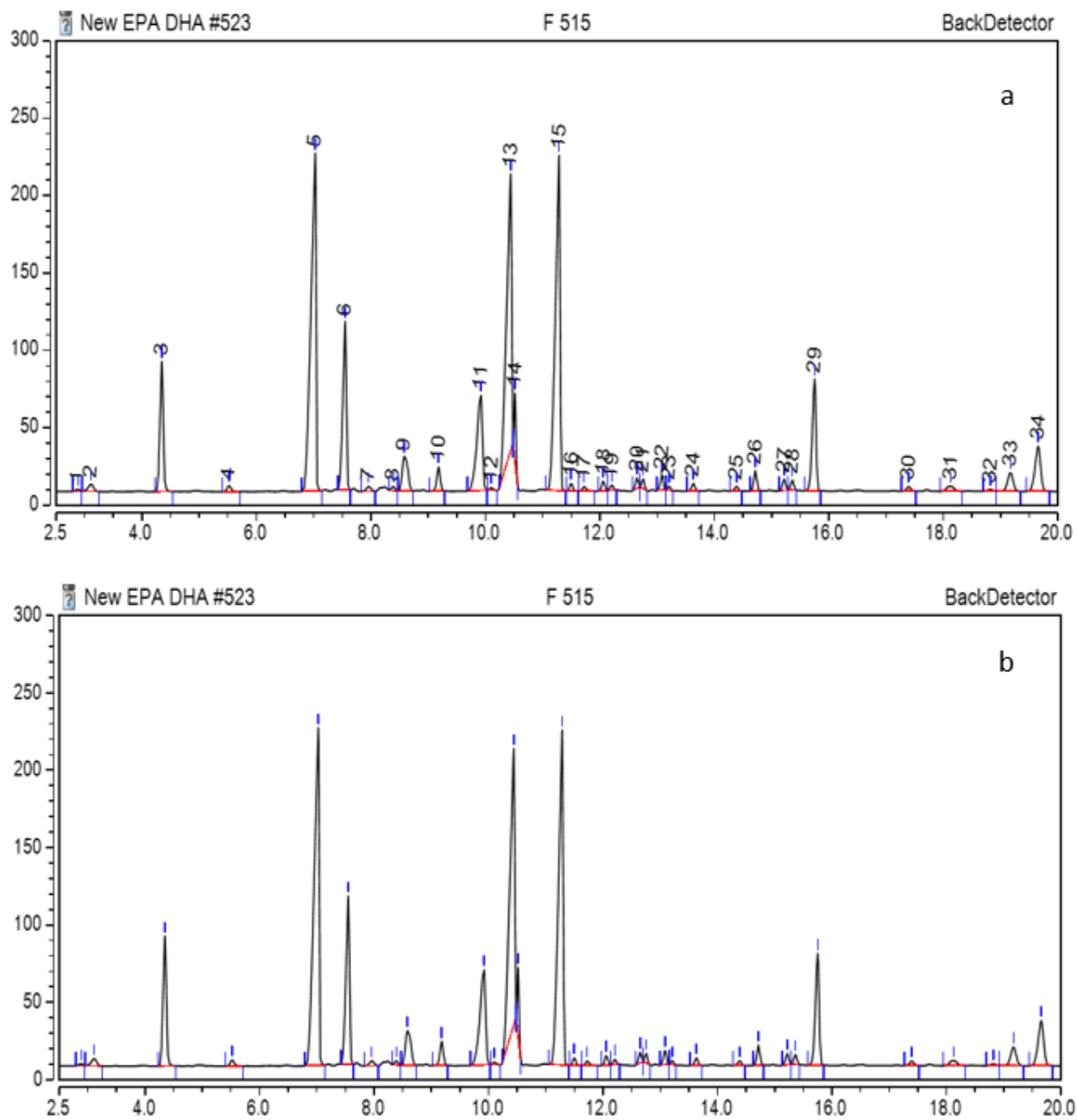


Figure 5.6: Chromatogram of fatty acid analysis by GC-MS; a) Canned Hilsa (Sorisha Ilish) sample and b) Raw Hilsa sample.

In the present study, based on individual fatty acid composition, the following decreasing pattern was detected for FA groups in sorisha paste with sunflower oil: MUFA > PUFA > SFA. The values for FA groups detected significant differences ($p < 0.05$) between raw fish and canning with sorisha paste. The overall quantity of SFA decreased as a result of the process, especially owing to the decrease in C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C20:0, C22:0, and C24:0. EPA and DHA dramatically reduced ($p > 0.05$) in sorisha paste with sunflower oil throughout the canning process. The ω -3 and ω -6 fatty acid contents of the hilsa packed in sorisha paste decreased during processing attributed to the reductions in the C20:3, c8,11,14,17, C20:5, C22:5, C22:6 and C 18:2, C 20:3 c8,11,14 contents respectively.

5.3.2.4 Amino acid composition of canned hilsa

Table 5.5 shows the amino acid contents (mg/ g sample) of raw and canned hilsa packed with sorisha paste. The results showed that glutamic acid (30.19 mg/g) is the most abundant non-essential amino acid in raw fish, followed by aspartic acid (17.23 mg/g) and alanine (10.73 mg/g), which together represent 36.08% of the total amino acids. Lysine (13.62 mg/g) is the major essential amino acid in hilsa fish, followed by leucine (11.43 mg/g) and threonine (7.12 mg/g), which together represent 19.96 % of total amino acids.

Furthermore, significant amino acids found in the raw hilsa fish were Serine (8.61 mg/g), cystine (6.78 mg/g), phenylalanine (6.41mg/g), histidine (6.38 mg/g), proline (6.87mg/g) and isoleucine (5.17 mg/g). This amino acid constituted approximately 24.95 % of total amino acids. However, some amino acids, such as methionine, valine, and tyrosine were found at a lower range. Valine was the least abundant amino acid in raw samples, at 4.29 mg/g.

The ratio of essential amino acids to non-essential amino acids (EAA/NEAA) represents an indicator of protein quality, where higher ratios indicate higher protein quality. In the present study, the EAA/NEAA ratio was found at 0.62 in raw fish. Moreover, the total essential amino acids (58.75mg/g), total semi-essential amino acids (7.79 mg/g), and total non-essential amino acids (94.65 mg/g) contained 36.45%, 4.83%, and 58.72% respectively of total amino acids (161.19 mg/g).

Table 5.5: Total amino acid profiles (g/100 g) of raw and canned hilsa

Name of Amino Acid	Composition (mg/g)	
	Raw	Canned
EAA		
Threonine	7.12	6.03
Methionine	4.33	3.91
Valine	4.29	3.82
Isoleucine	5.17	5.12
Leucine	11.43	11.32
Phenylalanine	6.41	5.34
Histidine	6.38	6.25
Lysine	13.62	12.85
SEAA		
Arginine	7.79	7.57
NEAA		
Aspartic acid	17.23	16.15
Serine	8.61	8.48
Glutamic acid	30.19	29.08
Glycine	9.67	8.54
Alanine	10.73	10.61
Cystine	6.78	6.67
Tyrosine	4.57	4.48
Proline	6.87	6.98
Total EAA	58.75	54.64

Table 5.5: Continued

Total SEAA	7.79	7.57
Total NEAA	94.65	90.99
EAA/NEAA	0.621	0.60
Total AA	161.19	153.2

EAA: Essential amino acids; SEAA: Semi-essential amino acids; NEAA: Non-essential amino acids.

During processing, there were significant changes ($p < 0.05$) in the total amino acids, non-essential amino acids, and total essential amino acids of canned hilsa packed in sorisha paste with sunflower oil. In hilsa packed in sunflower oil with sorisha paste, the levels of threonine, methionine, valine, leucine, phenylalanine, lysine, aspartic acid, glutamic acid, and glycine decreased throughout the sterilization process. The essential/non-essential (EAA/NEAA) ratio varies significantly during canning process.

5.3.3 Biochemical Quality of canned fish

5.3.3.1 Changes in pH value of canned Hilsa during the storage period

The pH values of the canned hilsa showed a decreasing pattern throughout the storage period (Figure 5.7). In the current study, the initial pH value of 5.30, recorded during storage at 0 days, remained relatively stable until day 90, with minimal variations. During the storage period, no significant ($p > 0.05$) differences were observed in pH values. This trend persisted throughout the following months, concluding in a pH value of 5.24 during storage at 365 days.

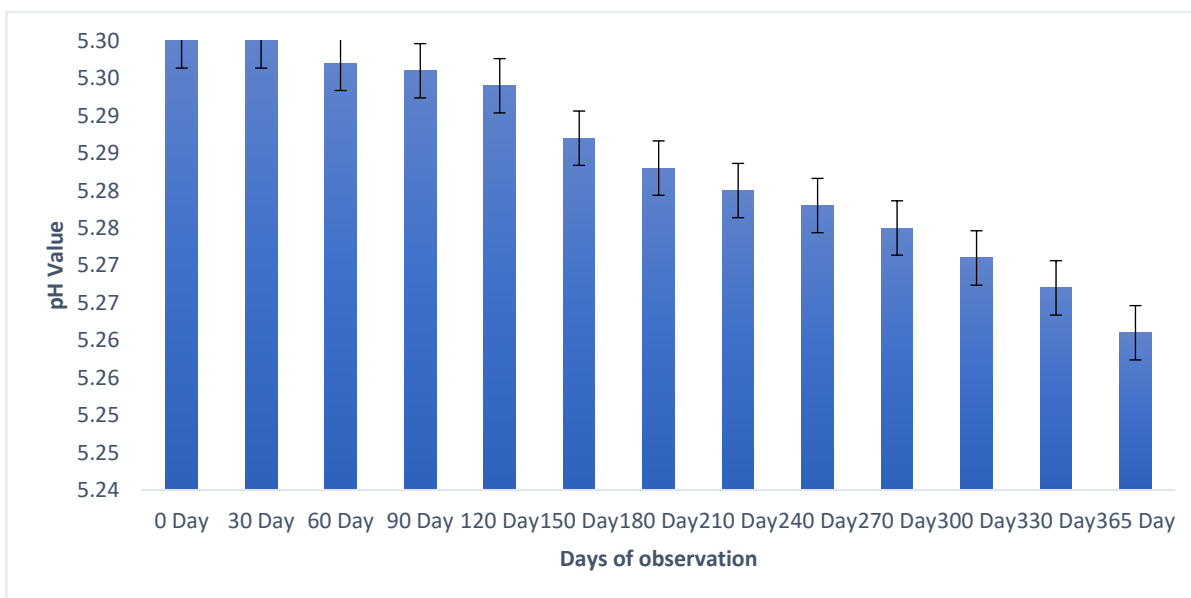


Figure 5.7: Changes in pH value of canned hilsa in different storage period

5.3.3.2 Changes in TVB-N and peroxide value of canned hilsa

The TVB-N values of the canned hilsa showed an increasing pattern throughout the storage period (Figure 5.8). The initial TVB-N value of canned hilsa was 13.76 ± 0.01 mg/100 g during storage at 0 days, which increased continuously throughout the time and reached 28.13 ± 0.06 mg/100g on the 365 days.

The peroxide value of canned hilsa was recorded at 6.97 ± 0.10 meq/kg of oil at the beginning of storage, which exhibited a gradual increase throughout the storage period. After a duration of 365 days stored at ambient temperature, the peroxide value exhibited an increase to 8.91 ± 0.10 meq/kg of oil.

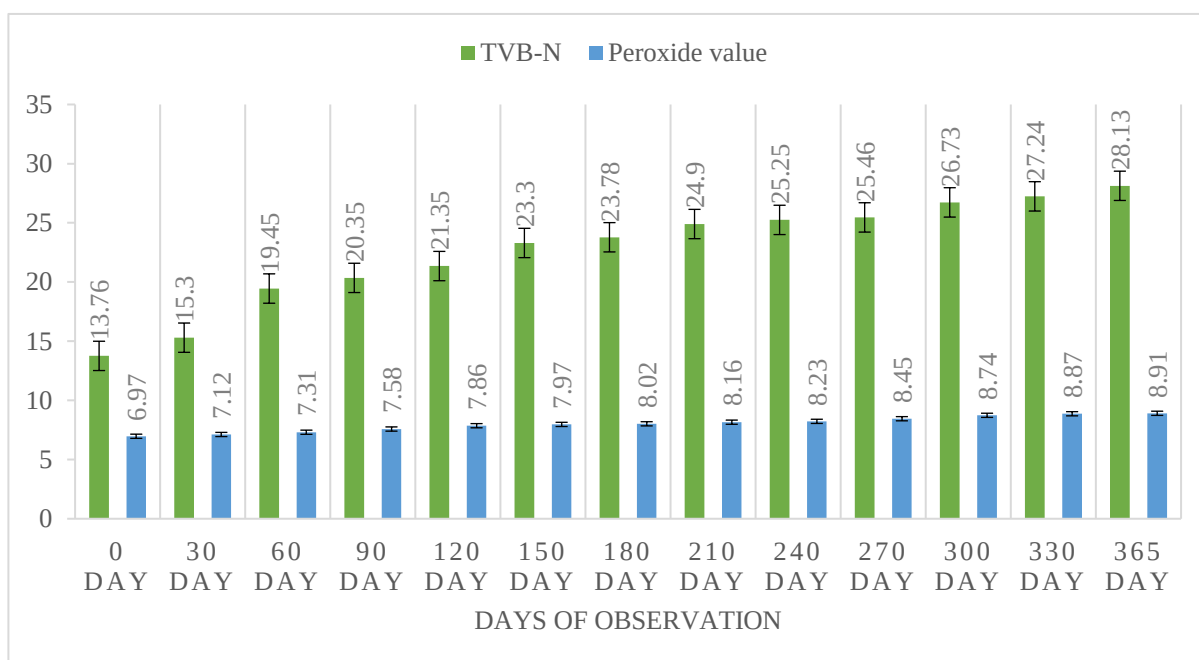


Figure 5.8: Changes in TVB-N and peroxide value of canned hilsa

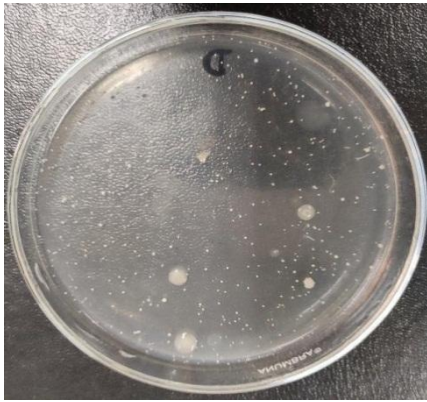
5.3.4 Microbiological Profile of Canned Hilsa

The changes observed in the microbiological profile during a 12-month storage period, focusing on Total Viable Count (TVC), total Coliform, *E. coli*, *Salmonella* spp., and *Clostridium* spp. of canned hilsa have been shown in Table 5.6. The results found significant differences in total viable count (TVC) during the storage period, with a significance level ($p < 0.05$). The TVC values were found to range from 1.9×10^2 CFU/g (at 180 days) to 7.2×10^2 CFU/g (at 330 days). The initial TVC for the 0-day canned was found to be 2.5×10^2 CFU/g and after storage of 360 days, it increased to 6.38×10^2 CFU/g. However, *Salmonella* spp. and *Clostridium* spp. were not identified, while total Coliform and *E. coli* frequently remained below detection limits (< 0.3 MPN/g) throughout the storage period (Figure 5.9).

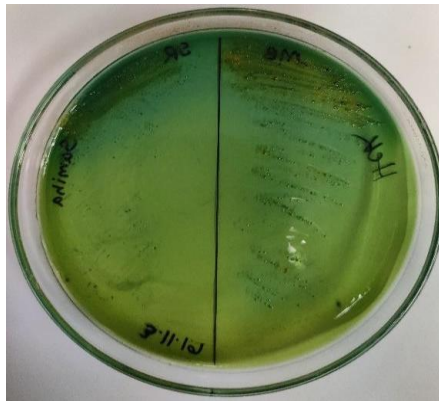
Table 5.6: Microbiological profile of canned hilsa

Storage Period	TVC (Total Viable Count) Cfu/g	Total coliform (MPN/g)	<i>E. coli</i> (MPN/g)	<i>Salmonella</i> sp. (Cfu/g)	<i>Clostridium</i> sp (Cfu/g)
0 Day	2.5×10^2	<0.3	<0.3	ND	ND
30 Day	4.7×10^2	<0.3	<0.3	ND	ND
60 Day	2.3×10^2	<0.3	<0.3	ND	ND
90 Day	6.8×10^2	<0.3	<0.3	ND	ND
120 Day	7.1×10^2	<0.3	<0.3	ND	ND
150 Day	3.7×10^2	<0.3	<0.3	ND	ND
180 Day	1.9×10^2	<0.3	<0.3	ND	ND
210 Day	5.4×10^2	<0.3	<0.3	ND	ND
240 Day	4.7×10^2	<0.3	<0.3	ND	ND
270 Day	2.86×10^2	<0.3	<0.3	ND	ND
300 Day	3.28×10^2	<0.3	<0.3	ND	ND
330 Day	7.2×10^2	<0.3	<0.3	ND	ND
365 Day	6.38×10^2	<0.3	<0.3	ND	ND

[As per the MPN (most probable number) chart, MPN <0.3 indicates an absence of test organism in 1 g; ND=Not Detected]



(a)



(b)



(c)

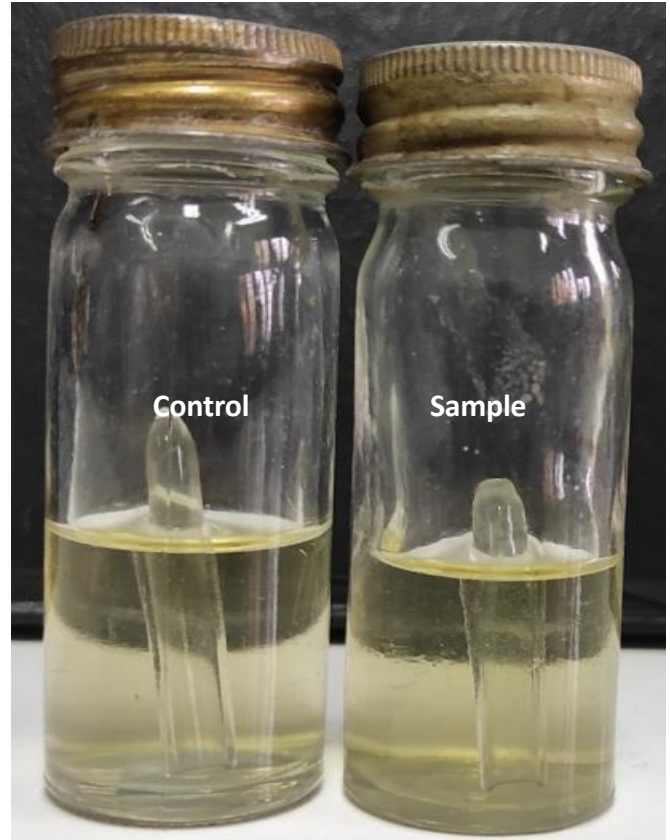
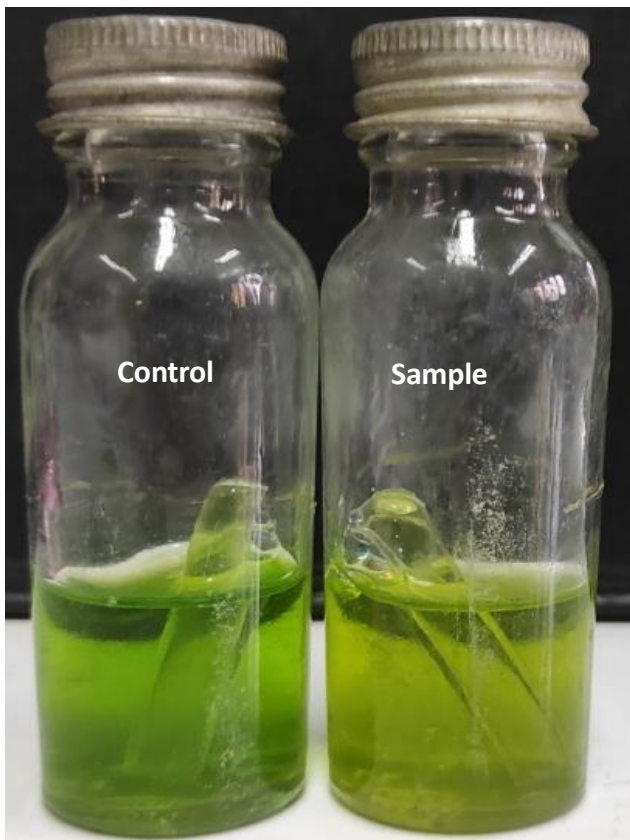


Figure 5.9: Microbial profile of canned hilsa; (a) TVC on plate count agar media; (b) Test of salmonella spp. on Hektoen agar; (c) Test of *clostridium* spp. on reinforced clostridium media; (d) Test of coliform occurrence in sample and (e) Test of *E. coli* occurrence in sample.

5.4 Discussion

5.4.1 Sensory Properties of canned Hilsa

The sensory quality of canned hilsa was assessed every 30 days interval throughout a 365-days of storage period. In this study, the samples were rated between very good and good for color, and between very good and acceptable for flavor and taste over the course of storage. These findings concurred with those of ElShehawy and Farag (2019). Sensory assessments indicate that canning increases hardness and decreases cohesivity as heat degrades connective tissue, causing cell blocks to split (Rodríguez et al., 2010). Research suggests that fish muscle texture is influenced by elements such as fibers density and fat concentration.

5.4.2 Nutritional Quality of Canned Products

5.4.2.1 Proximate composition of canned fish

The moisture content of canned hilsa ranged from 45.6% to 47.86%, aligning with the findings of Suresh Kumar (1984). The canning process reduces moisture in the final product due to the thermal treatment, which denatures muscle proteins and decreases their ability to retain water, thereby releasing a significant amount of moisture (Aubourg, 2001). The protein content across the three treatments ranged from 18.05% to 19.93%, meeting the WHO's (2007) criteria for high-quality animal products. The observed increase in protein content may be attributed to moisture loss during processing and storage, a trend also reported by Ramachandran et al. (2010). Fat content showed variability, which is largely influenced by the season in which the fish is harvested (Luzia et al., 2003). The high protein and fat levels in the canned samples may result from moisture reduction following sterilization (Aberoumand

and Baesi, 2024). Proximate analysis results (Table 5.2) indicated low ash and high protein content, supporting previous findings by Effiong and Mohammed (2008) and Mumba and Jose (2005).

It was discovered that heat processing caused the samples pH to drop (Biji et al., 2015). The TVB-N value varied across three sampling treatments. The TVB-N concentration indicates how much proteins in aquatic goods are degraded to amines and ammonia by microorganisms and endogenous enzymes (Luo et al., 2021). Reduced TVB-N content was linked to lower microbial population and putrefying metabolic activity, resulting in less ammonia nitrogen production (Kumar et al., 2019).

5.4.2.2 Fatty acid composition of canned sorisha hilsa

Each fatty acid group, SFA, MUFA, and PUFA, revealed values in the 32-48% range. Similar findings were reported by Gomez-Limia et al. (2020) for raw European eels (32.5–55.77%) and Prego et al. (2022) for mackerel fish muscle (30–36%). The main fatty acid content agrees with other studies conducted on fish species found in nature (Pirini et al., 2010; Prego et al., 2022). The n-3 and n-6 PUFAs are the most significant fatty acid sources for human nutrition and health (Zarate et al., 2017). The n-6/n-3 ratio has been suggested as a valuable measure in assessing the nutritional quality of dietary fat, which holds significant importance for humans. Various research has supported a low n-6/n-3 ratio and proposed an ideal n-6/n-3 ratio for enhancing human health (Simopoulos, 2016). In the present study, the mean n-6/n-3 ratio in raw hilsa was found at 1.26. The recommended range for the n-6:/n-3 ratio is 3:1 to 1:1 (Kim et al., 2007). Consequently, this species may be regarded as a source of

high-quality lipids. The findings from this study were somewhat similar to those of Selmi and Sadoc (2007). They reported that there were 27.58% saturated fatty acids (SFA), 23.15% monounsaturated fatty acids (MUFA), and 41.92% polyunsaturated fatty acids (PUFA).

The overall quantity of SFA decreased as a result of the canning process. Especially EPA and DHA reduction in sorisha paste with sunflower oil aligns with the findings of Stephen et al. (2010), who found that skipjack tuna exposed to various heat processing methods had lower levels of EPA and DHA. These reduced losses in the hilsa packed in sorisha paste with sunflower oil might be linked to the preventive action of spices (Chilli and sorisha paste) against lipid oxidation during sterilization (Sampels, 2013; Gomez-Limia et al., 2020). Spices can be incorporated into oil to enhance flavor and, in certain instances, inhibit oxidative degradation (Cardoso-Ugarte and Sosa-Morales, 2022). Numerous studies have examined the antioxidant properties of spices, which are linked to their chemical constituents, namely phenolic compounds and other physiologically active substances (Yashin et al., 2017).

The ω -3 and ω -6 fatty acid contents of the Hilsa packed in sorisha paste decreased during storage. This was noticeable in an increased n-6/n-3 ratio. These results align with earlier studies on canning (Naseri et al., 2011; Reblova et al., 2022). Previous research has explained that particular substances are gradually extracted by filling mediums during canning and storage (Aubourg, 2001; Naseri and Rezaei, 2012). The oxidation and lipid quality of canned fish may also be affected by the liquid media, according to the findings of Naseri et al. (2011). The filler medium could affect the final product's fatty acid composition in addition to transferring heat from the retort to the fish muscle. Additionally, it has been noted that during

storage, the pigments that are transferred from spices to oil can accelerate photosensitized oxidation (Damechki et al., 2001).

5.4.2.3 Amino acid composition of canned hilsa

Glutamic acid and aspartic acid are the main amino acids in several species of raw fish, including herring (Oluwaniyi et al., 2010) and Atlantic bonito (Ormanci and Colakoglu, 2015), cod (Teixeira and Mendes, 2020) and swordfish (Cobas et al., 2022). Lysine (13.62 mg/g) is the major essential amino acid in Hilsa fish, followed by Leucine (11.43 mg/g) and Threonine (7.12 mg/g), which together represent 19.96 % of total amino acids. Comparable results have been reported by Cobas et al. (2022) indicating that Leucine (around 8.7% of total amino acids) constitutes the predominant essential amino acid in the muscle of swordfish.

Mohanty et al. (2014) state that arginine is an amino acid that is conditionally essential, serving vital functions in hormone secretion, neurotransmission, regulation of blood pressure, cellular proliferation, and the healing of wounds. Glycine plays a pivotal role in the process of wound healing whereas Lysine plays a crucial role in development, and its deficiency can lead to immunodeficiency (Chen et al., 2003). Alanine is known to facilitate the metabolism of leucocytes and gluconeogenesis (Kudsk, 2006). The ratio of essential amino acids to non-essential amino acids (EAA/NEAA) was similar reported by Cobas et al. (2022), who observed the E/NE ratio in raw swordfish was 0.74.

In Hilsa packed in sunflower oil with sorisha paste, the levels of amino acids decreased throughout the sterilization process. A comparable decline was identified in

swordfish that were packed in sunflower oil in a study by Cobas et al. (2022) and these losses during sterilization may result from the leaching of particular amino acids into the filling medium. However, the amount of proline in canned Hilsa fish increased during sterilization, which suggests that other steps may also be responsible. The rising trend in proline levels might indicate that collagen was breaking down over time. It has been mentioned by Cobas et al. (2022) that they found aligned with results. A particular amino acid might have changed from one form to another via various reactions, including oxidation and the deamination process (Sikorski, 2001). The essential/non-essential (EAA/NEAA) changes were influenced by the amino acid and the filling medium, resulting from the different interactions between amino acids and filling oil (Aubourg, 2001), as well as the different amounts of protective components present in each oil (Gomez-Limia et al., 2021).

5.4.3 Microbiological profile of canned hilsa

The total Coliform and *E. coli* frequently remained below detection limits which is consistent with EOS (2005) and GCC Standardization Organization (2012, 2013, and 2016). El-Dengawy et al, 2012 reported that total Coliform and *Clostridium* spp. we're not detected in canned tuna, mackerel, and common carp. The results of the research aligned with the HACCP principle that fish products should not include any harmful microorganisms (Ababouch, 2002). This study's findings showing fish products do not contain salmonella germs in agreement with those of Mansour et al. (2023). It also agrees with the Egyptian General Authority for Standardization and Metrology's findings on the microbiology of canned tuna and sardines and the absence of *Escherichia coli* in brine-canned fish (EL-Dengawy et al., 2012; El Lahamy and Mohamed, 2020).

5.4.4 Biochemical Properties of Canned Hilsa

5.4.4.1 Changes in pH values of canned hilsa during the storage period

Metin et al. (2001) found that pH values remained within the permissible range (6.8~7.0) throughout the storage period which is aligned with the current study. Lower pH levels may be caused by lactacidogenic bacteria in canning, which mainly inhibit gram-negative aerobic bacteria (Islam et al., 2021). According to Jezek and Buchtová (2012), the pH reduction might be due to CO₂ solubility in muscle tissues.

5.4.4.2 Changes in TVB-N and peroxide value of canned hilsa

In the present study, TVB-N values were observed to increase progressively during the 365-day storage period. This trend is consistent with the findings of Ruiz-Capillas and Moral (2001) and Islami et al. (2015). Similar to earlier research, the results confirm a link between rising TVB-N levels and quality deterioration in seafood stored under modified atmosphere (MA) packaging, as reported by Ozogul et al. (2004) and Nayma et al. (2020).

The peroxide value exhibited an increase after 365 days of storage at ambient temperature. This finding is consistent with previous research, which indicated that the peroxide value of canned fish varied from 3.76 to 6.67 meqO₂/kg, with an average of 5.10 meqO₂/kg for *Scomberomorus guttatus* and *Scomber australasicus* over a six-month storage period (Anwar et al., 2020; Aberoumand and Baesi, 2024).

5.5 Summary of the Chapter

This chapter explores the development of canned hilsa fish products, focusing on preserving hilsa through canning, which ensures long shelf life without refrigeration. Hilsa, known as the "king of fish" in Bangladesh, is highly seasonal, with large harvests causing a price drop during peak seasons, harming fishermen's livelihoods. Canning offers a solution to preserve hilsa, avoiding the need for cold storage and drying, which is unsuitable for this fatty fish. The chapter details the canning process, from sourcing cans with protective zinc oxide coatings to the selection of high-quality hilsa fish from Cox's Bazar. Three unique recipes were developed for canned hilsa: sorisha Ilish (mustard paste marinade), tomato hilsa (tomato sauce marinade), and plain hilsa (salt, turmeric, chili). Fish chunks were marinated, packed into sterilized cans, and vacuum-sealed to prevent oxidation. The cans were then heat-treated in an autoclave to ensure sterility, with further cooling and storage for shelf-life study. Sensory evaluations by expert panels identified the best recipe based on flavor, texture, and overall quality. Shelf-life studies confirmed that canned hilsa could last over a year with satisfactory microbial and nutritional quality. Proximate analysis of the canned fish revealed good nutritional content, including high protein and fat, with minimal changes in fatty acid composition over 12 months. The development of canned hilsa provides a sustainable preservation method, benefiting both consumers and fishermen, while enhancing Bangladesh's economy by tapping into global fish product markets.

The fish processing industry in Cox's Bazar, Bangladesh, is a key contributor to the local economy but struggles with challenges such as inefficient drying techniques, significant

post-harvest losses, and limited access to advanced preservation methods. To tackle these issues and improve both productivity and sustainability, the implementation of hybrid solar dryers and small-scale canning methods offers a promising solution.

To successfully implement these technologies, both governmental and non-governmental organizations (GOs and NGOs) must play a crucial role in the following ways-

i. Funding Installation: GOs can provide funds through government or R&D initiatives to support the installation of hybrid solar dryers and small-scale canning technologies, ensuring that these technologies are accessible to fish processors.

ii. Loan or Profit-Sharing Models: NGOs can support the community by providing hybrid solar dryers and canning technology on a loan or profit-sharing basis, making the adoption of these technologies more feasible for smaller processors.

iii. Raising Awareness: GOs and NGOs can help raise awareness about the benefits of modern preservation techniques, such as improved product quality and safety, while also highlighting the negative impacts of current processing methods on product quality, public health, and the environment.

iv. Training and Financial Support: GOs and NGOs should offer comprehensive training programs for fish processors on the use of these technologies and provide financial assistance in the form of subsidies or low-interest loans to ease the initial investment burden.

v. Collaboration for Technological Improvement: Collaborating with research institutions will allow continuous improvements in these technologies, ensuring that fish processors have access to the most effective and user-friendly methods available.

In addition to hybrid solar dryers, small-scale canning techniques are also essential for preserving fish over longer periods. The adoption of modern preservation methods is crucial for the economic sustainability and growth of the fish processing industry. Not only do these methods improve the quality of the products, but they also meet health and safety standards, which enhance competitiveness in the market. This results in higher prices and better market access, should work to establish strong market linkages for processors to access broader markets. These efforts will help foster a more sustainable and profitable fish processing industry in Cox's Bazar, ensuring long-term economic stability and improved livelihoods for local communities.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study comprehensively explored the physiological, nutritional, biochemical, and microbiological characteristics of marine fish products processed through hybrid solar drying and small-scale canning, two innovative preservation methods.

- i. The findings affirm that hybrid solar drying is a sustainable and efficient approach, significantly reducing processing time while maintaining the nutritional and sensory qualities of dried marine fish compared to conventional drying, it enhances product safety, minimizes microbial contamination, and promotes hygienic practices through the use of renewable energy, making it ideal for coastal communities and dry fish processors aiming to meet export standards.
- ii. The Small-scale canning method demonstrated high efficacy in preserving hilsa fish, retaining essential nutrients and extending shelf life beyond one year under sealed conditions. The thermal treatment employed ensured food safety by eliminating harmful pathogens such as *Clostridium botulinum*, thus making canned hilsa a reliable, ready-to-eat product with great market potential.
- iii. Both preservation methods received favorable feedback in sensory evaluations, confirming their consumer acceptability in terms of taste, texture, and overall quality. Importantly, this research highlights the socio-economic benefits of these techniques, particularly for small-scale and artisanal processors in coastal

Bangladesh. Adoption of these methods could lead to improved livelihoods, enhanced food security, and greater participation in national economic growth.

- iv. Moreover, the study underscores the relevance of integrating sustainable technologies in marine fish processing to reduce environmental impact while increasing product safety and profitability. The data-driven insights offer valuable guidance for policymakers, development agencies, and stakeholders aiming to support a resilient and thriving marine fish industry.

Ultimately, this research contributes meaningfully to the advancement of sustainable fish processing practices and the empowerment of coastal communities.

6.2 Recommendations

There is a scope to undertake further research on this aspect to accurately determine the effect of hybrid solar drying and small-scale canning method on the quality and shelf-life of the marine fish product and to generate more information. Based on the results, the following recommendations are made to enhance the quality of the products-

- i. To enhance product quality and efficiency in industrial production, the optimization of drying parameters such as relative humidity, temperature, and drying rate should be prioritized to minimize nutritional loss and providing training to dry fish processors on the operational protocols and technical aspects of smart solar dryers to maximize their benefits.
- ii. Regular monitoring about the microbial communities (TVC, total Coliform, *Salmonella*, *Shigella*, *Staphylococcus* and *C. botulinum*) in both products processed

through hybrid solar drying and small-scale canning method should be implemented to maintain the food safety.

- iii. Use of preservatives like salt, spices or others ingredients can be considered further enhance the stability of the microbes for both dried and canned fish products, the use of salt during marination at the time of pre-processing of canning should be investigated to preserve the flavor and maintain the texture of hilsa fish.
- iv. The adoption of advanced packaging techniques (MAP, CAP, VP) should be explored to extend the shelf-life of the products, reduction of flavor loss and spoilage during storage period as well as increase the consumers attraction.
- v. Public awareness about the use of renewable energy should be raised by workshop or seminar at different fish processing zones. Hybrid solar drying system should be promoted among the dry fish processors with the help of technical team.
- vi. GOs and NGOs need to provide financial support to the small-scale fish processors in the establishment of hybrid solar dryer and canned hilsa processing plant as well as provide training on these technologies among the producers. Technical, financial and incentive support would encourage the adoption of hybrid solar drying and small-scale canning method.
- vii. Hygiene and sanitation should be maintained properly at every step of production, processing and storing of the products to meet the quality assurance official protocol which will help to meet national and international standard.
- viii. The trained producers should focus on creating branding of their processed safe dried and innovative canned hilsa products as nutritionally intact, high quality, safe and

exportable. Products should have to take certificate from BSTI and FIQC to promote the market nationally and internationally.

- ix. Consumer preference studies on sensory attributes (color, flavor, texture and taste) of both of the products at different levels of consumers should be studied to adjust the taste as well as meet the consumers expectations.

REFERENCES

- Abraha, B., Admassu, H., Mahmud, A., Tsighe, N., Shui, X. W., & Fang, Y. (2018). Effect of processing methods on nutritional and physico-chemical composition of fish: A review. *MOJ Food Processing & Technology*, 6(4), 376-382. <https://doi.org/10.15406/mojfpt.2018.06.00191>
- Al Banna, M. H., Hoque, M. S., Tamanna, F., Hasan, M. M., Mondal, P., Hossain, M. B., Chakma, S., Jaman, M. N., Tareq, M. A., & Khan, M. S. I. (2022). Nutritional, microbial and various quality aspects of common dried fish from commercial fish drying centers in Bangladesh. *Heliyon*, 8(10), e10830. <https://doi.org/10.1016/j.heliyon.2022.e10830>
- Alasalvar, C., Taylor, K. A., & Shahidi, F. (2002). Comparative quality assessment of cultured and wild sea bream (*Sparus aurata*) stored in ice. *Journal of Agricultural and Food Chemistry*, 50(7), 2039-2045. <https://doi.org/10.1021/jf010769a>
- Ali, A., Wei, S., Ali, A., Khan, I., Sun, Q., Xia, Q., Wang, Z., Han, Z., Liu, Y., & Liu, S. (2022). Research progress on nutritional value, preservation and processing of fish-A review. *Foods*, 11(22), 3669. <https://doi.org/10.3390/foods11223669>
- Al-Ismaili, A. (2021). A review on solar drying of fish. *Journal of Agricultural and Marine Sciences*, 26(2), 1-9. <https://doi.org/10.53541/jams.vol26iss2pp1-9>
- Al-Saddi, A., Pathare, P.B., Al-Rizeiqi, M., Al-Bulushi, I. and Al-Islam, A. (2023). Quality Improvement of Dried Anchovies at Three Solar Drying Methods. *Hindawi journal of Food Quality*, 23 (939468):11. <https://doi.org/10.1155/2023/4939468ss>

- Appiani, M., Cattaneo, C., & Laureati, M. (2024). Plant-based fish analogues vs. fish: Assessment of consumer perception, acceptance, and attitudes. *Food Quality and Preference*, 123, 105329. <https://doi.org/10.1016/j.foodqual.2024.105329>
- Aravindh, M. A., & Sreekumar, A. (2015). Solar drying-a sustainable way of food processing. In *Energy Sustainability Through Green Energy* (pp. 27-46). <https://doi.org/10.1007/978-81-322-2337-52>
- Arvanitoyannis, I. S., & Kassaveti, A. (2008). Fish industry waste: Treatments, environmental impacts, current and potential uses. *International Journal of Food Science & Technology*, 43(4), 726–745. <https://doi.org/10.1111/j.1365-2621.2006.01513.x>
- Ashok, A., Rajesh, R., & Kumar, M. (2020). The Role of Packaging in Extending the Shelf Life of Fish Products. *International Journal of Fisheries and Aquatic Studies*, 8(3), 25-31.
- Aubourg, S. P. (2001). Loss of quality during the manufacture of canned fish products. *Food Science and Technology International*, 7(3), 199-215. <https://doi.org/10.1106/4H8U-9GAD-VMG0-3GLR>
- Bahurmiz, O. M., Al-Saady, M., & Adzitey, F. (2018). Nutritional and sensory characteristics of locally produced canned tuna from Hadhramout, Yemen. *International Journal of Food Science and Nutrition*, 3(5), 13-18.
- Begum, M., Bhowmik, S., Juliana, F. M., & Hossain, M. S. (2016). Nutritional profile of hilsa fish [*Tenualosa ilisha* (Hamilton, 1822)] in six selected regions of Bangladesh. *Journal*

of Nutrition & Food Sciences, 6(2), 567–570. <https://doi.org/10.4172/2155-9600.1000567>

Bell, J. D., Sharp, M. K., Havice, E., Batty, M., Charlton, K. E., Russell, J., Adams, W., Azmi, K., Romeo, A., Wabnitz, C. C., & Andrew, N. L. (2019). Realizing the food security benefits of canned fish for Pacific Island countries. *Marine Policy*, 100, 183–191. <https://doi.org/10.1016/j.marpol.2018.10.034>

Belton, B., Johnson, D. S., Thrift, E., Olsen, J., Hossain, M. A. R., & Thilsted, S. H. (2022). Dried fish at the intersection of food science, economy, and culture: A global survey. *Fish and Fisheries*, 23(4), 941–962. <https://doi.org/10.1111/faf.12664>

Benavides, I. F., Romero-Leiton, J. P., Santacruz, M., Barreto, C., Puentes, V., & Selvaraj, J. (2022). Applying seasonal time series modeling to forecast marine fishery landings for six species in the Colombian Pacific Ocean. *Regional Studies in Marine Science*, 56, 102716. <https://doi.org/10.1016/j.rsma.2022.102716>

Bernardi, D. C., Mársico, E. T., & Freitas, M. Q. D. (2013). Quality index method (QIM) to assess the freshness and shelf life of fish. *Brazilian Archives of Biology and Technology*, 56, 587–598. <https://doi.org/10.1590/S1516-89132013000400009>

Bhattacharya, A., Chowdhury, S., Ikbali, A., Murmu, P., & Nath, S. (2022). Fish processing wastes: Environmental impacts and mitigation measures. *Indian Journal of Animal Health*, 61(2), 67–82. <https://doi.org/10.36062/ijah.2022.spl.02222>

- Birch, D., & Lawley, M. (2012). Buying seafood: Understanding barriers to purchase across consumption segments. *Food Quality and Preference*, 26(1), 12–21.
<https://doi.org/10.1016/j.foodqual.2012.03.004>
- Carabante, K. M., & Prinyawiwatkul, W. (2018). Data analyses of a multiple-samples sensory ranking test and its duplicated test: A review. *Journal of Sensory Studies*, 33(4), e12435. <https://doi.org/10.1111/joss.12435>
- Cardoso, C., Mendes, R., Pedro, S., Vaz-Pires, P., & Nunes, M.L. (2010). Quality changes during storage of minced fish products containing dietary fiber and fortified with $\omega 3$ fatty acids. *Food Science and Technology International*, 16(1), 31-42.
<https://doi.org/10.1177/1082013209352915>
- Carlucci, D., Nocella, G., De Devitiis, B., Viscecchia, R., Bimbo, F., & Nardone, G. (2015). Consumer purchasing behaviour towards fish and seafood products: Patterns and insights from a sample of international studies. *Appetite*, 84, 212–227.
<https://doi.org/10.1016/j.appet.2014.10.008>
- Chavan, B. R., Yakupitiyage, A., & Kumar, S. (2011). Drying performance, quality characteristics, and financial evaluation of Indian Mackerel (*Rastrelliger kanagurta*) dried by a solar tunnel dryer. *Science & Technology Asia*, 11-25.
- Chavan, B. R., Yakupitiyage, A., Kumar, S., & Rakshit, S. K. (2008). Experimental investigation on biochemical, microbial, and sensory properties of mackerel (*Rastrelliger kanagurta*) dried by solar-biomass hybrid cabinet dryer. *Journal of Food Agriculture and Environment*, 6(3&4), 167-171.

- Cheng, J. H., Sun, D. W., Zeng, X. A., & Liu, D. (2015). Recent advances in methods and techniques for freshness quality determination and evaluation of fish and fish fillets: A review. *Critical Reviews in Food Science and Nutrition*, 55(7), 1012–1225. <https://doi.org/10.1080/10408398.2013.769934>
- Colombo, F. M., Cattaneo, P., Confalonieri, E., & Bernardi, C. (2018). Histamine food poisonings: A systematic review and meta-analysis. *Critical Reviews in Food Science and Nutrition*, 58(7), 1131–1151. <https://doi.org/10.1080/10408398.2016.1242476>
- Debbarma, A., & Chinnadurai, A. S. (2023). Empowering women through digital literacy and access to ICT in Tripura. *Research Journal of Advanced Engineering and Science*, 9(1), 5-9.
- Deef, M., Samy Helal, H., El-Sebaee, I., Nadimi, M., Paliwal, J., & Ibrahim, A. (2023). Harnessing solar energy: A novel hybrid solar dryer for efficient fish waste processing. *Agri Engineering*, 5(4), 2439–2457. <https://doi.org/10.3390/agriengineering5040150>
- Delfiya, D. A., Mathai, L., Murali, S., Neethu, K. C., Nair, A. R., & Ninan, G. (2024). Comparison of clam drying in solar, solar-hybrid, and infrared dryer: Drying characteristics, quality aspects, and techno-economic analysis. *Solar Energy*, 274, 112554. <https://doi.org/10.1016/j.solener.2024.112554>
- Demissie, Y. A., Abreham, R. E., Wassie, H. M., & Getie, M. Z. (2024). Advancements in solar greenhouse dryers for crop drying. *Energy Reports*, 11, 5046–5058. <https://doi.org/10.1016/j.egyr.2024.04.058>

- Dhinesh, P., Harikrishnan, S., Kartick, A., Parivallal, M., Ramanathan, T., & Jayalakshmi, S. (2021). Microbial pathogens in canned fish collected from Tamil Nadu. *International Journal of Advanced Research in Biological Sciences*, 8(9), 23–29.
- Diseiye, O., Ukubeyinje, S. E., Oladokun, B. D., & Kakwagh, V. V. (2024). Emerging technologies: Leveraging digital literacy for self-sufficiency among library professionals. *Metaverse Basic and Applied Research*, 3, 59-59. doi: [10.56294/mr202459](https://doi.org/10.56294/mr202459)
- Elzubeir, A. O. (2014). Solar dehydration of sliced onion. *International Journal of Vegetable Science*, 20(3), 264–269. <https://doi.org/10.1080/19315260.2013.802754>
- Farmery, A. K., Alexander, K., Anderson, K., Blanchard, J. L., Carter, C. G., Evans, K., Fischer, M., Fleming, A., Frusher, S., Fulton, E. A., & Haas, B. (2022). Food for all: Designing sustainable and secure future seafood systems. *Reviews in Fish Biology and Fisheries*, 32(1), 101–121. <https://doi.org/10.1007/s11160-021-09663-x>
- Fernandes, L., & Tavares, P. B. (2024, January). A review on solar drying devices: Heat transfer, air movement and type of chambers. *Solar*, 4(1), 15–42. <https://doi.org/10.3390/solar4010002>
- Fernandes, L., Fernandes, J. R., & Tavares, P. B. (2022). Design of a friendly solar food dryer for domestic over-production. *Solar*, 2(4), 495–508. <https://doi.org/10.3390/solar2040029>
- Firfiris, V. K., Kaffe, Z. D., Kalamaras, S. D., Lithourgidis, A. A., Martzopoulou, A. G., & Kotsopoulos, T. A. (2022). A prototype passive solar drying system: Exploitation of

- the solar chimney effect for the drying of potato and banana. *Applied Sciences*, 12(22), 11784. <https://doi.org/10.3390/app122211784>
- Fitri, N., Chan, S. X. Y., Che Lah, N. H., Jam, F. A., Misnan, N. M., Kamal, N., Sarian, M. N., Mohd Lazaldin, M. A., Low, C. F., Hamezah, H. S., & Rohani, E. R. (2022). A comprehensive review of the processing of dried fish and the associated chemical and nutritional changes. *Foods*, 11(19), 2938. <https://doi.org/10.3390/foods11192938>
- Freitas, J., Vaz-Pires, P., & Camara, J. S. (2020). From aquaculture production to consumption: Freshness, safety, traceability and authentication, the four pillars of quality. *Aquaculture*, 518, 734857. <https://doi.org/10.1016/j.aquaculture.2019.734857>
- Freitas, J., Vaz-Pires, P., & Camara, J. S. (2021). Quality index method for fish quality control: Understanding the applications, the appointed limits and the upcoming trends. *Trends in Food Science & Technology*, 111, 333–345. <https://doi.org/10.1016/j.tifs.2021.03.011>
- Fudholi, A., Bakhtyar, B., Saleh, H., Ruslan, M. H., Othman, M. Y., & Sopian, K. (2016). Drying of salted silver jewfish in a hybrid solar drying system and under open sun: Modeling and performance analyses. *International Journal of Green Energy*, 13(11), 1135–1144. <https://doi.org/10.1080/15435075.2016.1175347>
- Galaviz-Silva, L., Gomez-Anduro, G., Molina-Garza, Z. J., & Ascencio-Valle, F. (2009). Food safety issues and the microbiology of fish and shellfish. In *Microbiologically Safe Foods* (pp. 227–254). <https://doi.org/10.1002/9780470439074>

- Ghaly, A. E., Dave, D., Budge, S., & Brooks, M. S. (2010). Fish spoilage mechanisms and preservation techniques. *American Journal of Applied Sciences*, 7(7), 859.
- Ginigaddarage, P. H., Surendra, I. H. W., Weththewa, W. K. S. R., Ariyawansa, K. W. S., Arachchi, G. G., Jinadasa, B. K. K. K., Hettiarachchi, K. S., & Edirisinghe, E. M. R. K. B. (2018). Microbial and chemical quality of selected dried fish varieties available in Sri Lankan market. *Sri Lanka Journal of Aquatic Sciences*, 23(1). <https://doi.org/10.4038/sljas.v23i1.7552>
- Gorjian, S., Hosseingholilou, B., Jathar, L. D., Samadi, H., Samanta, S., Sagade, A. A., Kant, K., & Sathyamurthy, R. (2021). Recent advancements in technical design and thermal performance enhancement of solar greenhouse dryers. *Sustainability*, 13(13), 7025. <https://doi.org/10.3390/su13137025>
- Hao, W., Zhang, H., Liu, S., & Lai, Y. (2021). Design and prediction method of dual working medium solar energy drying system. *Applied Thermal Engineering*, 195, 117153. <https://doi.org/10.1016/j.applthermaleng.2021.117153>
- Haque, E., Kamruzzaman, M., Islam, M. S., Sarwar, T., Rahman, S. S., & Karim, M. R. (2013). Assessment and comparison of quality of solar tunnel-dried Bombay duck and silver pomfret with traditional sun-dried samples. *International Journal of Nutrition and Food Sciences*, 2(4), 187–195. <https://doi.org/10.11648/j.ijnfs.20130204.15>
- Hassan, M. K., Poppy, M., Ahamed, T., Morsheda, F., Yadav, R., Hasan, A., & Siddique, M. P. (2021). Bacterial flora isolated from dried fishes sold at retail markets within Dhaka

- city corporation of Bangladesh. *Research in Agriculture Livestock and Fisheries*, 8(1), 109–115.
- Hassoun, A., Shumilina, E., Di Donato, F., Foschi, M., Simal-Gandara, J., & Biancolillo, A. (2020). Emerging techniques for differentiation of fresh and frozen-thawed seafoods: Highlighting the potential of spectroscopic techniques. *Molecules*, 25(19), 4472. <https://doi.org/10.3390/molecules25194472>
- Hassoun, A., Siddiqui, S. A., Smaoui, S., Ucak, I., Arshad, R. N., Garcia-Oliveira, P., Prieto, M. A., Ait-Kaddour, A., Perestrelo, R., Camara, J. S., & Bono, G. (2022). Seafood processing, preservation, and analytical techniques in the age of Industry 4.0. *Applied Sciences*, 12(3), 1703. <https://doi.org/10.3390/app12031703>
- Hin, L., Buntong, B., Mean, C. M., Chhoem, C., & Prasad, P. V. (2024). Impacts of using solar dryers on socio-economic conditions of dried fish processors in Cambodia. *Sustainability*, 16(5), 2130. <https://doi.org/10.3390/su16052130>
- Hixson, S. M. (2014). Fish nutrition and current issues in aquaculture: The balance in providing safe and nutritious seafood, in an environmentally sustainable manner. *Journal of Aquaculture Research and Development*, 5(3), 1–10. <http://dx.doi.org/10.4172/2155-9546.1000234>
- Howgate, P. (2015). A history of the development of sensory methods for the evaluation of freshness of fish. *Journal of Aquatic Food Product Technology*, 24(5), 516–532. <https://doi.org/10.1080/10498850.2013.783897>

- Huang, R., Wei, C., Wang, B., Yang, J., Xu, X., Wu, S., & Huang, S. (2022). Well-performance prediction based on Long Short-Term Memory (LSTM) neural network. *Journal of Petroleum Science and Engineering*, 208, 109686. <https://doi.org/10.1016/j.petrol.2021.109686>
- Hubackova, A., Kucerova, I., Chrun, R., Chaloupkova, P., & Banout, J. (2014). Development of solar drying model for selected Cambodian fish species. *The Scientific World Journal*, 2014(1), 439431. <https://doi.org/10.1155/2014/439431>
- Huque, R., Hossain, M. A., Pramanik, M. K., Hasan, M. Z., Islam, M., Khatun, A., & Munshi, M. K. (2013). Microbiological quality improvement of dried fish by gamma irradiation and assessment of food value upon irradiation with respect to biochemical aspect. *International Journal of Applied Pharmaceutics*, 3(2), 1–5.
- ICMSF. (1986). *Microorganisms in Foods: Sampling for Microbiological Analysis: Principles and Specific Applications* (2nd ed.). Blackwell Scientific Publications.
- Immaculate, K., Sinduja, P., Velammal, A., & Patterson, J. (2013). Quality and shelf-life status of salted and sun-dried fishes of Tuticorin fishing villages in different seasons. *International Food Research Journal*, 20(4), 1855–1859.
- Imtiaz, M.M., Haque, S.A., Sarker, M.R., Mufty, M.M., Ali, M.M., Parvez, M.S., Reza, M.S., Bhuyan, M.S., & Rahman, M.A. (2017). Quality assessment of improved sun-dried ribbon fish (*Trichiurus haumela*) by salt and turmeric powder treatment. *International Journal of Advanced Chemical Engineering and Biological Sciences*, 4(1), 162-167. <https://doi.org/10.15242/IJACEBS.R1>

- Islam, M. R., Akter, T., Hossain, A., Tora, A. T., Mely, S. S., Hossain, M. A., & Haque, M. M. (2024). Contribution and prospect of marine fisheries in the economy of Bangladesh and sustainable blue economy challenges: A review. *Marine Science and Technology Bulletin*, 13(1), 41–55. <https://doi.org/10.33714/masteb.1337034>
- Islam, M. S. (2003). Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. *Ocean & Coastal Management*, 46(8), 763–796. [https://doi.org/10.1016/S0964-5691\(03\)00064-4](https://doi.org/10.1016/S0964-5691(03)00064-4)
- Jadhav, M. S., & Dhage, S. R. (2019). Comparative Study of Packaging Materials for Dry Fish Products. *Food and Bioprocess Technology*, 12(11), 1537-1543.
- Jaman, M. N., Hoque, M. S., Yeasmin, F., Hasan, M. M., Ripon, M. A. S., Akter, A., & Jhumur, M. A. (2021). Comparative assessment of dried fish quality collected from market and drying centre at Kuakata in Patuakhali, Bangladesh. *Bangladesh Journal of Fisheries*, 33(1), 137–146. <https://doi.org/10.52168/bjf.2021.33.16>
- Jamil, M. G. M., Hossain, M. N., Mia, M. M., Mansur, M. A., & Uga, S. (2017). Studies on the proximate composition, quality, and heavy metal concentration of sun-dried Bombay duck and sun-dried Ribbon fish of Cox's Bazar District of Bangladesh. *Journal of Environmental Science and Natural Resources*, 10(1), 55-60. <https://doi.org/10.3329/jesnr.v10i1.34694>
- Jamioł-Milc, D., Biernawska, J., Liput, M., Stachowska, L., & Domiszewski, Z. (2021). Seafood intake as a method of non-communicable diseases (NCD) prevention in adults. *Nutrients*, 13(5), 1422. <https://doi.org/10.3390/nu13051422>

- Jianadasa, B. K. K. K., Ginigaddarage, P. H., & Ariyawansa, S. (2014). A comparative quality assessment of five types of selected fishes collected from retail market in Sri Lanka. *American Journal of Food Science and Technology*, 2(1), 21–27. <https://doi.org/10.12691/ajfst-2-1-4>
- Jimmy Jr, C. L., & Gente, J. M. D. (2024). A time series analysis of aquaculture milkfish production volume using the Box-Jenkins SARIMA Model: A case study from Davao Oriental, Philippines. *Davao Research Journal*, 15(3), 6-19. <https://doi.org/10.59120/drj.v15i3.222>
- Jimmy Jr, C. L., & Gente, J. M. D. (2024). A time series analysis of aquaculture milkfish production volume using the Box-Jenkins SARIMA Model: A case study from Davao Oriental, Philippines. *Davao Research Journal*, 15(3), 6-19. <https://doi.org/10.59120/drj.v15i3.222>
- Kakatkar, A.S., Gautam, R.K., Nagar, V., Karani, M., & Bandekar, J.R. (2010). Incidence of food-borne pathogens in freshwater fish from domestic market of Mumbai. *Fisheries Technology*, 47, 195–200.
- Karaca, A. C., & Capanoglu, E. (2022). Canned fish products: Current issues and future perspectives. *Mediterranean Journal of Nutrition and Metabolism*, 15(4), 575–579. <https://doi.org/10.3233/MNM-220082>
- Khalili Tilami, S., & Sampels, S. (2018). Nutritional value of fish: Lipids, proteins, vitamins, and minerals. *Reviews in Fisheries Science & Aquaculture*, 26(2), 243–253. <https://doi.org/10.1080/23308249.2017.1399104>

- Kose, S. (2010). Evaluation of seafood safety health hazards for traditional fish products: Preventive measures and monitoring issues. *Turkish Journal of Fisheries and Aquatic Sciences*, 10(1), 139-160.
- Kumar, M., Sahdev, R. K., Tiwari, S., Manchanda, H., Chhabra, D., Panchal, H., & Sadasivuni, K. K. (2021). Thermal performance and kinetic analysis of vermicelli drying inside a greenhouse for sustainable development. *Sustainable Energy Technologies and Assessments*, 44, 101082. <https://doi.org/10.1016/j.seta.2021.101082>
- Kundu, R., Pradhan, A., & Bandyopadhyay, N. (2016). Nutritional and microbial quality of major sun-dried fishes from EGRA Government-regulated dry fish market, West Bengal. *Journal of Environment and Sociobiology*, 23–34.
- Kwasek, K., Thorne-Lyman, A. L., & Phillips, M. (2020). Can human nutrition be improved through better fish feeding practices? A review paper. *Critical Reviews in Food Science and Nutrition*, 60(22), 3822–3835. <https://doi.org/10.1080/10408398.2019.1708698>
- Lawless, H. T., & Heymann, H. (2010). Qualitative consumer research methods. In *Principles and practices* (2nd ed., pp. 379–405). Springer. <https://doi.org/10.1007/978-1-4419-6488-516>
- Leek, S., Maddock, S., & Foxall, G. (2000). Situational determinants of fish consumption. *British Food Journal*, 102(1), 18–39. <https://doi.org/10.1108/00070700010310614>
- Liu, C., & Ralston, N. V. (2021). Seafood and health: What you need to know? In *Advances in Food and Nutrition Research*, 97 (1), 275–318.

- Liu, S., Fan, W., Zhong, S., Ma, C., Li, P., Zhou, K., Peng, Z., & Zhu, M. (2010). Quality evaluation of tray-packed tilapia fillets stored at 0°C based on sensory, microbiological, biochemical and physical attributes. *African Journal of Biotechnology*, 9(5), 692. <http://www.academicjournals.org/AJB>
- Lucci, P., Pacetti, D., Loizzo, M. R., & Frega, N. G. (2016). Canning: Impact on food products quality attributes. In *Food Processing Technologies* (pp. 41–60). CRC Press.
- Madhusree, K., Sharma, R., & Patel, S. (2018). Preservation of Dried Fish Products Using Various Packaging Materials. *Fish Processing & Preservation Review*, 25(2), 119-128.
- Madiwale, S. S., & Bhale, S. P. (2017). Effect of Packaging on Shelf Life and Quality of Dry Fish. *Journal of Food Science and Technology*, 54(7), 2052-2058.
- Mahmud, A., Abraha, B., Samuel, M., Mohammedidris, H., Abraham, W., & Mahmud, E. (2018). Fish preservation: A multi-dimensional approach. *MOJ Food Processing & Technology*, 6(1), 303–310. <https://doi.org/10.15406/mojfpt.2018.06.00180>
- Majumdar, B. C., Ahammad, B., Kabir, I. E., Mollik, J. R., Baidya, A., Hossain, M. F., Asadujjaman, M., Roy, T. K., & Paul, S. I. (2023). Sensorial, physicochemical and microbial quality evaluations of sun-dried marine fishes available in the Bay of Bengal of Bangladesh. *Applied Food Research*, 3(2), 100369. <https://doi.org/10.1016/j.afres.2023.100369>
- Majumdar, B.C., Afrin, F., Rasul, M.G., Khan, M., & Shah, A.K.M. (2017). Comparative study of physical, chemical, microbiological, and sensory aspects of some sun-dried

- fishes in Bangladesh. *Brazilian Journal of Biological Sciences*, 4(8), 323-331.
<https://dx.doi.org/10.21472/bjbs.040811>
- Manik, M. H. (2022). Current marine fisheries production status and opportunity in Bangladesh. *International Journal of Agriculture and Animal Production*, 2(3), 49–56.
<https://doi.org/10.55529/ijaap.23.49.56>
- Maqsood, S., Benjakul, S., & Kamal-Eldin, A. (2012). Haemoglobin-mediated lipid oxidation in the fish muscle: A review. *Trends in Food Science and Technology*, 28(1), 33–43.
<https://doi.org/10.1016/j.tifs.2012.06.009>
- Matos, E., Dias, J., Dinis, M. T., & Silva, T. S. (2017). Sustainability vs. quality in gilthead seabream (*Sparus aurata* L.) farming: Are trade-offs inevitable? *Reviews in Aquaculture*, 9(4), 388–409. <https://doi.org/10.1111/raq.12144>
- McManus, A., & Newton, W. (2011). Seafood, nutrition and human health: A synopsis of the nutritional benefits of consuming seafood (pp. 1–10). Centre of Excellence Science, Seafood and Health, Curtin Health Innovation Research Institute, Curtin University.
<http://hdl.handle.net/20.500.11937/32912>
- Mehta, P., Samaddar, S., Patel, P., Markam, B., & Maiti, S. (2018). Design and performance analysis of a mixed-mode tent-type solar dryer for fish-drying in coastal areas. *Solar Energy*, 170, 671–681. <https://doi.org/10.1016/j.solener.2018.05.095>
- Mishra, S., Verma, S., Chowdhury, S., & Dwivedi, G. (2020). Analysis of recent developments in greenhouse dryer on various parameters-a review. *Materials Today: Proceedings*, 38, 371–377. <https://doi.org/10.1016/j.matpr.2020.07.429>

- Mithun, B.D., Hoque, M.S., Van Brakel, M.L., Hasan, M.M., Akter, S., & Islam, M.R. (2021). Comparative quality assessment of traditional vs. improved dried Bombay duck (*Harpodon nehereus*) under different storage conditions: Solar chimney dryer a low-cost improved approach for nutritional dried fish. *Food Science & Nutrition*, 9(12), 6794–6805. <https://doi.org/10.1002/fsn3.2631>
- Mukilan, M., Harikrishnan, S., Jena, S., Parivallal, M., Sudarshan, S., & Jayalakshmi, S. (2022). Microbial quality of different dried fishes collected from fish market of Parangipettai, Tamil Nadu. *International Journal of Fisheries and Aquatic Research*, 7(1), 5–9.
- Murali, S., Alfiya, P. V., Delfiya, D. A., Samuel, M. P., & Ninan, G. (2023). Solar hybrid drying system for marine applications—A comprehensive review. *Journal of Aquatic Food Product Technology*, 32(1), 38–58. <https://doi.org/10.1080/10498850.2022.2155497>
- Murali, S., Amulya, P. R., Alfiya, P. V., Delfiya, D. A., & Samuel, M. P. (2020). Design and performance evaluation of solar-LPG hybrid dryer for drying of shrimps. *Renewable Energy*, 147, 2417–2428. <https://doi.org/10.1016/j.renene.2019.10.002>
- Mustapha, M. K., Ajibola, T. B., Salako, A. F., & Ademola, S. K. (2014). Solar drying and organoleptic characteristics of two tropical African fish species using improved low-cost solar driers. *Food Science & Nutrition*, 2(3), 244–250. <https://doi.org/10.1002/fsn3.101>

- Nagwekar, N., Tidke, V., & Thorat, B. N. (2017). Microbial and biochemical analysis of dried fish and comparative study using different drying methods. *Drying Technology*, 35(12), 1481–1491. <https://doi.org/10.1080/07373937.2016.1256889>
- Nanyonjo, G., Kwenza, Z., Nakamanya, S., Okello, E., Oketch, B., Bahemuka, U. M., ... & LVCHR study team. (2024). Finding women in fishing communities around Lake Victoria: "Feasibility and acceptability of using phones and tracking devices." *PLoS ONE*, 19(1), e0290634. <https://doi.org/10.1371/journal.pone.0290634>
- Nasir, A., & Kamaruzzaman, Y. N. (2024). Does future tuna landing stock meet the target? Forecasting tuna landing in Malaysia using seasonal ARIMA model. *International Journal of Social Economics*, 51(11), 1434-1449. <https://doi.org/10.1108/IJSE-03-2023-0233>
- Natarajan, S. K., Elangovan, E., Elavarasan, R. M., Balaraman, A., & Sundaram, S. (2022). Review on solar dryers for drying fish, fruits, and vegetables. *Environmental Science and Pollution Research*, 29(27), 40478–40506. <https://doi.org/10.1007/s11356-022-19714-w>
- Norton, B. (2017). Characteristics of different systems for the solar drying of crops. In O. Prakash & A. Kumar (Eds.), *Solar Drying Technology: Concept, Design, Testing, Modeling, Economics, and Environment*, pp. 69–88. <https://doi.org/10.1007/978-981-10-3833-43>

- Nukulwar, M. R., & Tungikar, V. B. (2021). A review on performance evaluation of solar dryer and its material for drying agricultural products. *Materials Today: Proceedings*, 46, 345–349. <https://doi.org/10.1016/j.matpr.2020.08.354>
- Nur, I.T., Ghosh, B.K., & Acharjee, M. (2020). Comparative microbiological analysis of raw fishes and sun-dried fishes collected from the Karwan bazar in Dhaka city, Bangladesh. *Food Research*, 4, 846–851.
- Ocano-Higuera, V. M., Maeda-Martínez, A. N., Marquez-Ríos, E., Canizales-Rodríguez, D. F., Castillo-Yáñez, F. J., Ruíz-Bustos, E., Graciano-Verdugo, A. Z., & Plascencia-Jatomea, M. (2011). Freshness assessment of ray fish stored in ice by biochemical, chemical and physical methods. *Food Chemistry*, 125(1), 49–54. <https://doi.org/10.1016/j.foodchem.2010.08.034>
- Oehlenschläger, J. (2012). Seafood: Nutritional benefits and risk aspects. *International Journal for Vitamin and Nutrition Research*, 82(3), 168–176. <https://doi.org/10.1024/0300-9831/a000108>
- Okoroigwe, E. C., Eke, M. N., & Ugwu, H. U. (2013). Design and evaluation of combined solar and biomass dryer for small and medium enterprises for developing countries. *International Journal of Physical Sciences*, 8(25), 1341-1349. <https://doi.org/10.5897/IJPS2013.3937>
- Olokor, J. O., & Ngwu, E. O. (2009). Study of the solar dried and traditional sun-dried fish products. pp. 75-79. <http://hdl.handle.net/1834/38020>

- Oparaku, N. F., Mgibenka, B. O., & Eyo, J. E. (2010). Proximate and organoleptic characteristics of sun and solar dried fish. *Animal Research International*, 7(2), 1169–1175.
- Ozogul, Y., Ozyurt, G., Ozogul, F., Kuley, E., & Polat, A. (2005). Freshness assessment of European eel (*Anguilla anguilla*) by sensory, chemical and microbiological methods. *Food Chemistry*, 92, 745–751. <https://doi.org/10.1016/j.foodchem.2004.08.035>
- Patel, S., Pillai, V., & George, S. (2020). Impact of Polybags on Shelf Life and Quality of Dry Fish. *Journal of Fisheries and Aquaculture*, 31(4), 423-429.
- Patterson, J., & Ranjitha, G. (2009). Qualities of commercially and experimentally sun-dried fin fish *Scomberoides tol*. *African Journal of Food Science*, 3, 299-302.
- Patterson, J., Kailasam, S., Giftson, H., & Immaculate, J. K. (2018). Effect of drying technologies on the biochemical properties of *Stolephorus commersonnii*. *Food Quality and Safety*, 2(3), 153–158. <https://doi.org/10.1093/fqsafe/fyy010>
- Paul, P. C., Reza, M. S., Islam, M. N., & Kamal, M. (2018). Quality assessment of traditionally dried marine fish of Bangladesh. *Asian Food Science Journal*, 5(1), 1–11. <https://doi.org/10.9734/AFSJ/2018/44406>
- Phetsang, H., Panpipat, W., Panya, A., Phonsatta, N., & Chaijan, M. (2021). Occurrence and development of off-odor compounds in farmed hybrid catfish (*Clarias macrocephalus* × *Clarias gariepinus*) muscle during refrigerated storage: Chemical and volatilomic analysis. *Foods*, 10(8), p.1841. <https://doi.org/10.3390/foods10081841>

- Prabhakar, P. K., Vatsa, S., Srivastav, P. P., & Pathak, S. S. (2020). A comprehensive review on freshness of fish and assessment: Analytical methods and recent innovations. *Food Research International*, 133, 109157. <https://doi.org/10.1016/j.foodres.2020.109157>
- Pradhan, N., Shrestha, M. K., Rai, S., Jha, D. K., & Sah, S. K. (2016). Biochemical assessment of dried fish products of Nepal. *Nepalese Journal of Aquaculture and Fisheries*, 3 & 4, 47–58.
- Prakash, S., Jeyasanta, I., Carol, R., & Patterson, J. (2011). Microbial quality of salted and sun-dried sea foods of Tuticorin Dry Fish Market, Southeast Coast of India. *International Journal of Microbiological Research*, 2(2), 188-195. [http://idosi.org/ijmr/ijmr2\(2\)11/16.pdf](http://idosi.org/ijmr/ijmr2(2)11/16.pdf)
- Pravakar, P., Mansur, M. A., & Asadujjaman, M. (2013). Quality and safety aspect of three sun-dried marine fish species: Chinese Pomfret (*Stromateus chinensis*), Bombay Duck (*Harpodon neherius*) and Ribbon Fish (*Trichiurus haumela*). *World Journal of Zoology*, 8(4), 381–387. <https://doi.org/10.5829/idosi.wjz.2013.8.4.7693>
- Preena, P. G., Swaminathan, T. R., Kumar, V. J. R., & Singh, I. S. B. (2020). Antimicrobial resistance in aquaculture: A crisis for concern. *Biologia*, 75, 1497–1517. <https://doi.org/10.2478/s11756-020-00456-4>
- Prego, R., Trigo, M., Martínez, B., & Aubourg, S. P. (2022). Effect of previous frozen storage, canning process, and packing medium on the fatty acid composition of canned mackerel. *Marine Drugs*, 20(11), 666. <https://doi.org/10.3390/md20110666>

- Purkait, S., Chattopadhyay, K., & Podili, V. (2024). Process of fish drying and marketing in coastal West Bengal: Prospect and challenges. In *Dry Fish: A Global Perspective on Nutritional Security and Economic Sustainability* (pp. 205-213). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-62462-9_14
- Rabiepour, A., Zahmatkesh, F., & Babakhani, A. (2024). Preservation techniques to increase the shelf life of seafood products: An overview. *Journal of Food Engineering and Technology*, 13(1), 1–24. <https://doi.org/10.32732/jfet.2024.13.1.1>
- Radhakrishnan, G., Breaz, T. O., Al Mahrouqi, A. W. A., Al Zakwani, N. A., Al Fahdi, M. H., Al Shuraiqi, A. S., Al Awamri, S. A., Al Aamri, R. S., & Karthikeyan, K. R. (2024). A comparative management analysis on the performance of different solar drying methods for drying vegetables and fruits. *Sustainability*, 16(2), 775. <https://doi.org/10.3390/su16020775>
- Rana, M. M., Asdaria, R., Mahmud, S., Irfan, A. F., Chowdhury, A. J. K., & Munir, M. B. (2023). Marine water aquaculture and an IoT-based smart fish dryer of the future: A sustainable environmental approach. *Desalination and Water Treatment*, 315, 515-522. <https://doi.org/10.5004/dwt.2023.30017>
- Rasul, M. G., Kabir, I. E., Yuan, C., & Azad Shah, A. K. M. (2021). Effects of drying methods on physico-chemical, microbiological, and sensory properties of torpedo scad (*Megalaspis cordyla*) (Doctoral dissertation, Iwate University).
- Rasul, M.G., Majumdar, B.C., Afrin, F., Bapary, M.A.J., & Shah, A.A. (2018). Biochemical, microbiological, and sensory properties of dried silver carp (*Hypophthalmichthys*

- molitrix*) influenced by various drying methods. *Fishes*, 3(3), p.25.
<https://doi.org/10.3390/fishes3030025>
- Relekar, S. S., Joshi, S. A., Gore, S. B., & Kulkarni, A. K. (2014). Effect of improved drying methods on biochemical and microbiological quality of dried small head ribbon fish, *Lepturacanthus savala*. *International Journal of Fisheries and Aquatic Studies*, 1(5), 60–66.
- Reza, M. S. (2024). Different types of dried fish products: A country's perspective. In *Dry Fish: A Global Perspective on Nutritional Security and Economic Sustainability* (pp. 45-58). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-62462-9_4
- Reza, M. S., Bapary, M. A. J., Islam, M. N., & Kamal, M. D. (2009). Optimization of marine fish drying using solar tunnel dryer. *Journal of Food Processing and Preservation*, 33(1), 47–59. <https://doi.org/10.1111/j.1745-4549.2008.00236.x>
- Rizal, T. A., & Muhammad, Z. (2018). Fabrication and testing of hybrid solar-biomass dryer for drying fish. *Case Studies in Thermal Engineering*, 12, 489–496.
<https://doi.org/10.1016/j.csite.2018.06.008>
- Rortveit, A. W., & Olsen, S. O. (2009). Combining the role of convenience and consideration set size in explaining fish consumption in Norway. *Appetite*, 52(2), 313–317.
<https://doi.org/10.1016/j.appet.2008.11.001>
- Rumape, O., Elveny, M., Suksatan, W., Hatmi, R. U., Voronkova, O. Y., Bokov, D. O., & Wanita, Y. P. (2022). Study on the quality of fish products based on different

- preservation techniques: A review. *Food Science and Technology*, 42, e78521.
<https://doi.org/10.1590/fst.78521>
- Rustad, T., Storro, I., & Slizyte, R. (2011). Possibilities for the utilization of marine by-products. *International Journal of Food Science & Technology*, 46(10), 2001–2014.
<https://doi.org/10.1111/j.1365-2621.2011.02736.x>
- Sablani, S. S., Rahman, M. S., Haffar, I., Mahgoub, O., Al-Marzouki, A. S., Al-Ruzeiqi, M. H., Al-Habsi, N. H., & Al-Belushi, R. H. (2003). Drying rates and quality parameters of fish sardines processed using solar dryers. *Agricultural and Marine Sciences*, 8(2), 79–86.
- Sahu, M., & Bala, S. (2017). Food processing, food spoilage and their prevention: An overview. *International Journal of Life-Sciences Scientific Research*, 3(1), 753–759.
<https://doi.org/10.21276/ijlssr.2017.3.1.1>
- Sampels, S. (2015). The effects of processing technologies and preparation on the final quality of fish products. *Trends in Food Science & Technology*, 44(2), 131–146.
<https://doi.org/10.1016/j.tifs.2015.04.003>
- Sanjee, S. A., & Karim, M. E. (2016). Microbiological quality assessment of frozen fish and fish processing materials from Bangladesh. *International Journal of Food Science*, 2016(1), 8605689. <https://doi.org/10.1155/2016/8605689>
- Saritha, K., Jayasantha, K.I., Aiyamperumal, V., & Patterson, J. (2012). Microbial and biochemical qualities of salted and sun-dried sea foods of Cuddalore, Southeast Coast

- of India. *International Journal of Microbiological Research*, 3(2), 138–143.
[http://idosi.org/ijmr/ijmr3\(2\)12/11.pdf](http://idosi.org/ijmr/ijmr3(2)12/11.pdf)
- Sarker, S., Bhuyan, M. A. H., Rahman, M. M., Islam, M. A., Hossain, M. S., Basak, S. C., & Islam, M. M. (2018). From science to action: Exploring the potentials of Blue Economy for enhancing economic sustainability in Bangladesh. *Ocean & Coastal Management*, 157, 180–192. <https://doi.org/10.1016/j.ocecoaman.2018.03.001>
- Scholderer, J., & Trondsen, T. (2008). The dynamics of consumer behaviour: On habit, discontent, and other fish to fry. *Appetite*, 51(3), 576–591.
<https://doi.org/10.1016/j.appet.2008.04.011>
- Secci, G., & Parisi, G. (2016). From farm to fork: Lipid oxidation in fish products. A review. *Italian Journal of Animal Science*, 15(1), 124–136.
<https://doi.org/10.1080/1828051X.2015.1128687>
- Selmi, S., Bouriga, N., Cherif, M., Toujani, M., & Trabelsi, M. (2010). Effects of drying process on biochemical and microbiological quality of silverside (fish) *Atherina lagunae*. *International Journal of Food Science & Technology*, 45(6), 1161–1168.
<https://doi.org/10.1111/j.1365-2621.2010.02249.x>
- Sengar, S. H., Khandetod, Y. P., & Mohod, A. G. (2009). Low-cost solar dryer for fish. *African Journal of Environmental Science and Technology*, 3(9), 265–271.
- Sevik, S. (2013). Design, experimental investigation and analysis of a solar drying system. *Energy Conversion and Management*, 68, 227–234.
<https://doi.org/10.1016/j.enconman.2013.01.013>

- Shah, A.K.M.A., Tokunaga, C., Kurihara, H., & Takahashi, K. (2009). Changes in lipids and their contribution to the taste of *Migaki-nishin* (dried herring fillet) during drying. *Food Chemistry*, 115(3), 1011-1018. <https://doi.org/10.1016/j.foodchem.2009.01.023>
- Shamsuzzaman, M. M., Mozumder, M. M. H., Mitu, S. J., Ahamad, A. F., & Bhyuian, M. S. (2020). The economic contribution of fish and fish trade in Bangladesh. *Aquaculture and Fisheries*, 5(4), 174–181. <https://doi.org/10.1016/j.aaf.2020.01.001>
- Sheng, L., & Wang, L. (2021). The microbial safety of fish and fish products: Recent advances in understanding its significance, contamination sources, and control strategies. *Comprehensive Reviews in Food Science and Food Safety*, 20(1), 738–786. <https://doi.org/10.1111/1541-4337.12671>
- Shiriskar, D.A., Khedkar, G.D., & David, L. (2013). Production of salted and pressed anchovies (*Stolephorus* sp.) and their quality evaluation during storage. *Journal of Food Science and Technology*, 50, 1172–1178. <https://doi.org/10.1007/s13197-011-0450-9>
- Siddhnath, Saklani, P., & Om, H. (2022). Examining the fungus in dried Bombay-duck (*Harpadon nehereus*). *National Academy Science Letters*, 45(3), 255–257. <https://doi.org/10.1007/s40009-022-01099-6>
- Siddiky, M. N. I., Bosu, A., Roy, B. C., Sarker, S. K., & Moniruzzaman, M. (2017). Proximate composition analysis of five important dried sea fish and evaluate their nutritive value. *International Journal of Natural and Social Sciences*, 4, 103–110.

- Siddiqui, S. A., Ucak, I., Jain, S., Elsheikh, W., Ali Redha, A., Kurt, A., & Toker, O. S. (2024). Impact of drying on techno-functional and nutritional properties of food proteins and carbohydrates: A comprehensive review. *Drying Technology*, 42(4), 592–611. <https://doi.org/10.1080/07373937.2024.2303580>
- Singh, P., Gaur, M. K., Kushwah, A., & Tiwari, G. N. (2019). Progress in hybrid greenhouse solar dryer (HGSD): A review. *Advances in Energy Research*, 6(2), 145–160. <https://doi.org/10.12989/eri.2019.6.2.145>
- Speranza, B., Racioppo, A., Bevilacqua, A., Buzzo, V., Marigliano, P., Mocerino, E., Scognamiglio, R., Corbo, M. R., Scognamiglio, G., & Sinigaglia, M. (2021). Innovative preservation methods improving the quality and safety of fish products: Beneficial effects and limits. *Foods*, 10(11), 2854. <https://doi.org/10.3390/foods10112854>
- Srinivasan, G., Rabha, D. K., & Muthukumar, P. J. S. E. (2021). A review on solar dryers integrated with thermal energy storage units for drying agricultural and food products. *Solar Energy*, 229, 22–38. <https://doi.org/10.1016/j.solener.2021.07.075>
- Sultana, N., Hossain, M. T., Siddique, M. P., Uddin, M. I., Dina, M. A., & Farhana, Z. (2010). Microbial quality of dried fish of different areas Chittagong and Mymensingh districts of Bangladesh. *International Journal of Bioresearch*, 2(8), 1–5.
- Tacon, A. G. (2023). Contribution of fish and seafood to global food and feed supply: An analysis of the FAO food balance sheet for 2019. *Reviews in Fisheries Science & Aquaculture*, 31(2), 274–283. <https://doi.org/10.1080/23308249.2022.2124364>

- Tamzi, N. N., Rozee, F. F., Sultana, T., Faisal, M., Khan, M. N. A., & Ghosh, S. K. (2024). Quality evaluation of improved and traditionally dried Bombay duck (*Harpodon nehereus*) through biochemical, microbiological, and organoleptic analysis. *Heliyon*, 10(5). e27315. <https://doi.org/10.1016/j.heliyon.2024.e27315>
- Tavares, J., Martins, A., Fidalgo, L. G., Lima, V., Amaral, R. A., Pinto, C. A., Silva, A. M., & Saraiva, J. A. (2021). Fresh fish degradation and advances in preservation using physical emerging technologies. *Foods*, 10(4), 780. <https://doi.org/10.3390/foods10040780>
- Thrane, M., Nielsen, E. H., & Christensen, P. (2009). Cleaner production in Danish fish processing—experiences, status and possible future strategies. *Journal of Cleaner Production*, 17(3), 380–390. <https://doi.org/10.1016/j.jclepro.2008.08.006>
- Tiwari, S., Tiwari, G. N., & Al-Helal, I. M. (2016). Development and recent trends in greenhouse dryer: A review. *Renewable and Sustainable Energy Reviews*, 65, 1048–1064. <https://doi.org/10.1016/j.rser.2016.07.070>
- Ullah, M. R., Rahman, M. A., Haque, M. N., Sharker, M. R., Islam, M. M., & Alam, M. A. (2022). Nutritional profiling of some selected commercially important freshwater and marine water fishes of Bangladesh. *Heliyon*, 8(10), 471-474. <https://doi.org/10.1016/j.heliyon.2022.e10825>
- Villagran, E., Espitia, J. J., Velázquez, F. A., & Rodriguez, J. (2024). Solar dryers: Technical insights and bibliometric trends in energy technologies. *AgriEngineering*, 6(4), 4041–4063. <https://doi.org/10.3390/agriengineering6040228>

- Wang, J., Zhang, M., Gao, Z., & Adhikari, B. (2017). Smart storage technologies applied to fresh foods: A review. *Critical Reviews in Food Science and Nutrition*, 58(16), 2689-2699. <https://doi.org/10.1080/10408398.2017.1323722>
- Wang, Y., Wang, H., Wu, Y., Xiang, H., Zhao, Y., Chen, S., Qi, B., & Li, L. (2022). Insights into lipid oxidation and free fatty acid profiles to the development of volatile organic compounds in traditional fermented golden pomfret based on multivariate analysis. *LWT*, 171, p.114112. <https://doi.org/10.1016/j.lwt.2022.114112>

APPENDICES

Appendix A: Questionnaire for livelihood assessment of the marine fish processors

Personal and Production Information of Dry Fish Producers at Nazira Tech, Coss bazar

1.PERSONAL INFORMATION

Name of the Respondent	:	
Mobile No:	:	
Address	:	
Age	:	

2.Education Status

Don't Sign	Can Sign Only	PSC	JSC	SSC	>HSC

3.Religious Status

Muslim	Hindu	Khristan	Buddhist	Others

4.Home Status

None	Kacha	Semi Building	Building	Rent

5.Marital Status

Unmarried	Married

Gender

Male	Female	Others

6.Family Size

Small (2-3)	Medium (4-5)	Joint (>5)

7.Drinking Water Facility

None	Self	Municipal	Others

8. Health Support

None	Village Doctor	Community Clinic	Govt. Hospital

9. Electricity Facility

None	<6 hrs. Support	6-12 hours Support	12-18 hours Support	Full time (24 hrs.)

10. Assets

None	Land Area	Fishing Boat with No. & Capacity	Fishing Trawler with No. & Capacity	Dry Fish Arot	Vehicles (Pickup/Truck/CNG/ Auto Rikshaw)	Others

11. Training Facilities

Duration	Organization	Topic	None

12. Drying Yard

None	Self	Work on Others

13. Annual Income

Fish Drying	Fishing	Others	Total Amount

14. Annual Expense

Family Consumption	Childrens Education	Health Support	Savings/Deficit

***If Deficit how to manage**

15. Loan

None	Amount/year	Source	Interest Rate	Duration

16. Earning Member

Only (he/she)	Both (H+W)	Monthly Income	Others

17. Education Facility (Childs)

None	Only PSC	PSC & SSC	>HSC

PRODUCTION INFORMATION**1.Species Drying**

Drying Season	Species Dried	Amount Dried	Market Price

2.Marketing Facilities

Locally Sell	Sell to the Arot	Sell to the Tourist	Others

3.Storage Facility

None	Cold Storage	Wooden Box	Plastic Bag

4.Drying Yard Workers Information

Worker's Type	Duration of Work	Daily Paid
Male		
Female		

5. Fish Dried

Collected from Boat (%)	Collected from Trawlers (%)	Collected from Market (%)	Local	Others (%)

--	--	--	--

6. Processing Information

Whole Dried Without Gutted	Dressing & Gutting Perform	Spitting	Properly Washed

7. Preservatives Used

None	Salt (%)	Turmeric Powder (%)	Others (%)

8. Chemicals Used

None	Used	Name	Amount @

9. Sun light Support

Season	Duration of Sun Light Support

10. Target Moisture

Species	Target Moisture	Drying Period

11. Production

Raw fish Name	Amount	Finally Harvested

12. Production Cost Calculation

Species	Production Cost/Kg

13. Support from Govt./NGOs

None	Govt. (UFO)	NGOs	Frequency

OTHERS INFORMATION**1.Use of Phone**

None	Button Phone	Smart Phone	Others

2.Network Facility

Low	Medium	Satisfactory	High

3.Internet Support

None	Low	Medium	Satisfactory

4.Internet Browsing Information

Able	Disable

5. Have Facebook Account

Yes	No

6. Learnning from Youtube

Yes	No

7. Disaster Information

None	Yes	Frequency

8. Govt. support during Banning Period

None	Yes	Frequency

9. Work During Banning Period

None	Type of Work	Income

10. Satisfaction Level in this work

Low	Medium	High

Any Others Opinion.....

Name of the Enumerator.....

Signature and Date.....

Appendix B: Sensory Quality Evaluation sheet

Sensory Evaluation of Dry Fish Product

Product type: Smart Dried Products/Traditional Dried Products (Give tick Mark)

Name of the Evaluator:

Designation:

Department:

Signature:

Date:

Day of Observation:

Product name	Flavor/ Odor	√	Color	√	Texture	√	General Appearance	√	Taste	√	Hedonic scale score (0-9)
Dried Churi	Excellent		Excellent		Excellent		Excellent		Excellent		
	Very good		Very good		Very good		Very good		Very good		
	Good		Good		Good		Good		Good		
	Moderately good		Moderately good		Moderately good		Moderately good		Moderately good		
	Slightly good		Slightly good		Slightly good		Slightly good		Slightly good		
	Acceptable		Acceptable		Acceptable		Acceptable		Acceptable		
	Rejected		Rejected		Rejected		Rejected		Rejected		
Dried Loitta	Excellent		Excellent		Excellent		Excellent		Excellent		
	Very good		Very good		Very good		Very good		Very good		
	Good		Good		Good		Good		Good		
	Moderately good		Moderately good		Moderately good		Moderately good		Moderately good		
	Slightly good		Slightly good		Slightly good		Slightly good		Slightly good		
	Acceptable		Acceptable		Acceptable		Acceptable		Acceptable		
	Rejected		Rejected		Rejected		Rejected		Rejected		

***Excellent and attractive: ≥ 7 to ≤ 9 , Acceptable: ≥ 5 to below 7, just satisfactory: ≥ 3 to below 4, Rejected: ≤ 3 .

Appendix C: Report of Laboratory Analysis (Out sourcing)



জীবনের জন্য বিজ্ঞান

শেখ হাসিনার মর্পন সব মানুষের উন্নয়ন

বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণা পরিষদ (বিসিএসআইআর)
BANGLADESH COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH (BCSIR)
INSTITUTE OF FOOD SCIENCE & TECHNOLOGY (IFST)

Analysis Report

Analytical Service Cell Ref No: F-515, 13/03/2024	Unit (Lab/Inst.) Ref No: ifst
Lab ID: IM-56	Sample Receiving Date: 13/03/2024
Sample ID: F-515	Submission Date: 13/03/2024
	Report Delivery Date: 20/03/2024
Sample Description: স্মারক নং: শেকুবি/এবিম্যাস/২৪/১৪৪, তারিখ: ০৭/০৩/২০২৪ইং	
Product Name: Fish Food	
Client's Details: মুহাম্মদ ফখরুল ইসলাম, রেজিস্ট্রেশন নং: ১৯-০৯৭১১, বিএসসি ইন এগ্রিকালচারাল ইকোনমিকস, শেরেবাংলা কৃষি বিশ্ববিদ্যালয়, ঢাকা-১২০৭। মোবাইল: ০১৬৩৯-৫৪৬৬২৬।	
Number of Sample: 01	

Report Details:

SI No.	Tests	Results
01	TVC (Total Viable Count), cfu/g	<10*
02	Total Coliform, MPN/g	<0.3*
03	<i>Escherichia coli</i> , MPN/g	<0.3**
04	<i>Salmonella sp.</i> cfu/25g	Not Detected
05	<i>Clostridium sp.</i> cfu/g	Not Detected

* <10 indicate absence of test organisms in 1 g of sample.

** As per MPN (most probable number) chart, MPN <0.3 indicates absence of test organism in 1g.

Comments: Based on the above microbiological test results, the sample is acceptable in quality.

Sadia 20.03.2024

Analyst
Dr. Sadia Afrin
Senior Scientific Officer
Industrial Microbiology Section
IFST, BCSIR, Dhaka-1205

Mohammad Nazrul Islam 20.03.2024

Section/Division In-Charge
Dr. Mohammad Nazrul Islam Bhuiyan
Principal Scientific Officer (PSO)
Industrial Microbiology Section
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BCSIR, Dhaka-1205

Mohammad Nazrul Islam 20.03.24

In-Charge /Director
Md. Habibur Rahman Bhuiyan
Director (Addl. Charge)
Institute of Food Science & Technology
BCSIR, Dhaka

Note:

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Analytical Service Cell

Dr. Qudrat-I-Khuda Road, Dhanmondi, Dhaka-1205, Bangladesh
Telephone: 9671108 FAX: 88-02-9671108 E-mail: asc@bcsir.gov.bd Website: www.bcsir.gov.bd

জীবনের জন্য বিজ্ঞান



"শেখ হাসিনার দর্শন, সব মানুষের উন্নয়ন"

বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণা পরিষদ (বিসিএসআইআর)
BANGLADESH COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH (BCSIR)

Institute of Technology Transfer and Innovation (ITTI)

ANALYSIS REPORT

ASC Ref. No.: IT-27, Date: 12.03.2024	Lab/Sample ID: IT-24030027
Name of Sample: Canned fish	Client's Details:
Sample Receiving Date: 12.03.24	Mohammad Fokrul Islam
Report Submission Date: 01.04.2024	Sher-e-Bangla Agricultural University, Dhaka-1207.
	Phone: +8801639-546626

Name of Test: Amino Acid Analysis
Method: Acid Hydrolysis Method (SYKAM S433 Amino Acid Analyzer)

Report Details

Sl. No.	Amino acid	Amount (mg/g)
01.	Aspartic acid	17.15
02.	Threonine	7.03
03.	Serine	8.48
04.	Glutamic acid	30.08
05.	Glycine	9.54
06.	Alanine	10.61
07.	Methionine	4.31
08.	Cystine	6.67
09.	Valine	4.22
10.	Isoleucine	5.12
11.	Leucine	11.32
12.	Tyrosine	4.48
13.	Phenylalanine	6.34
14.	Histidine	6.25
15.	Lysine	13.50
16.	Arginine	7.57
17.	Proline	6.68
Total Amino Acid		159.35 mg/g

.....01.04.2024.....
Analyst
S. M. Rashadul Islam
Scientific Officer
Centre for Research on Fish
Drying and Indoor Aquaculture, BCSIR

.....01.04.24.....
Supervisor
Dr. Md. Rakibul Hasan
Senior Scientific Officer
ITTI, BCSIR

.....01.04.2024.....
Officer-in-Charge
Md. Rezaul Karim
Officer in Charge
ITTI-BCSIR
Dhanmondi, Dhaka

Note: a. The results reported herein are based on the sample submitted to the laboratory.
b. Complaint and/or query regarding delivered test report should be lodged within one month of report delivery date.
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Analytical Service Cell
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বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণা পরিষদ (বিসিএসআইআর)
BANGLADESH COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH (BCSIR)
INSTITUTE OF FOOD SCIENCE & TECHNOLOGY (IFST)

Analysis Report

Analytical Service Cell Ref No: F-1356, 13/08/2024	Unit (Lab/Inst.) Ref No: ifst
Lab ID: IM-45	Sample Receiving Date: 13/08/2024
Sample ID: F-1356	Submission Date: 13/08/2024
	Report Delivery Date: 20/08/2024
Sample Description: Food, Production Date: 01.03.2024, Supplied in sealed jar. Product Name: Food	
Client's Details: মুহাম্মদ ফখরুল ইসলাম, রেজিস্ট্রেশন নং: ১৯-০৯৭১১, কিসসি ইন এগ্রিকালচারাল ইকোনমিকস, শেরেবাংলা কৃষি বিশ্ববিদ্যালয়, ঢাকা-১২০৭।	
Number of Sample: 01	

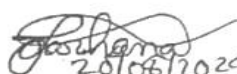
Report Details:

Sl No.	Tests	Results
01	TVC (Total Viable Count), cfu/g	6.38×10^3
02	Total Coliform, MPN/g	<0.3*
03	<i>Escherichia coli</i> , MPN/g	<0.3**
04	<i>Salmonella sp.</i> , cfu/25g	Not Detected
05	<i>Clostridium sp.</i> , cfu/25g	Not Detected

* <10 Indicate absence of test organisms in 1 g of sample

** As per MPN (most probable number) chart, MPN <0.3 indicates absence of test organism in 1g.

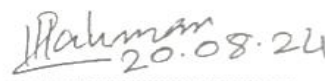
Comments: The above microbiological test results were found in the supplied sample.


20/08/2024

Analyst
Farhana Boby
Scientific Officer
Industrial Microbiology Section
IFST, ECSIR, Dhaka-1205


20.08.24

Section/Division In-Charge
Dr. Mohammad Nazrul Islam Bhuiyan
Principal Scientific Officer (PSO)
Industrial Microbiology Section
Institute of Food Science & Technology
BCSIR, Dhaka-1205


20.08.24

In-Charge /Director
Md. Habibur Rahman Bhuiyan
Director (Add. Charge)
Institute of Food Science & Technology
BCSIR, Dhaka

Note:

- The results reported here pertained to the sample received in this laboratory only.
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Analytical Service Cell

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Telephone: 9671108 FAX: 88-02-9671108 E-mail: asc@bcsir.gov.bd Website: www.bcsir.gov.bd



BCSIR CHATTOGRAM LABORATORIES

Bangladesh Council of Scientific and Industrial Research (BCSIR)



TEST REPORT

No. of Sample: 01 (One)	BCSIR Ctg. Ref.No.:39.02.1506.070.42.004.24
Sample ID: Mar/334	
Date of Sample Received: 21/03/2024	Referred by: আবদুল ইসলাম 01812025108, Real It Ltd., Agrabad, Chattogram.
Particulars of Samples: Dry Fish	Vide their Ref. No.: Date: 21/03/2024

Results:

Description of Sample	Parameter	Result
Dry Fish	Protein	65 %
	Moisture	10.15 %

S. H. Chakraborty
Signature of Scientist
Chemical Research Division
Sreebasri Chandra Bhattacharjee
Principal Scientific Officer
Chemical Research Division
BCSIR Chattogram Laboratories

Dr. Dipankar Chakraborty
Signature of Scientist-in Charge
Chemical Research Division
Dr. Dipankar Chakraborty
Principal Scientific Officer
Chemical Research Division
BCSIR Chattogram Laboratories.

Dr. Barun Kanti Saha
Countersigned by
the Director
Dr. Barun Kanti Saha
Director (Addl. Charge)
BCSIR Chattogram Laboratories
Chattogram-4220.

Note: The result reported above pertains only to the sample supplied in this laboratory. This report or any part of this should not be published without prior permission of the issuing authority. Any overwriting/erasing in the test result must have to be reported to the issuing authorities as early as possible. Any complain about test report will not be acceptable after one month from the date of issuing of the said report.

Analytical Service Cell (One Stop Service): +8801868-487524, +02333375138, email: pndbsircrg@gmail.com

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2025 03 06 09:25

 বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণা পরিষদ (বিসিএসআইআর)
 BANGLADESH COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH (BCSIR)
 Institute: Institute of Food Science & Technology (IFST)
 ANALYSIS REPORT

ASC Ref No.	: F- 515	Number of Sample	: One
Lab/ Sample ID	: OLT- 053/2024		
Sample Description	: Fish	Test Commencement Date	: 13.03.2024
Client's Details	: Muhammad Fakhru Islam Reg: 19-09711 B.Sc in Agricultural Economics Sher-E-Bangla Agricultural University	Test Completion Date	: 28.03.2024

Results

Sl. No.	Test Parameter	Results
1.	Fatty Acid Composition of the extracted fat (%)*	
	Lauric acid (C12:0)	0.10
	Myristic acid (C14:0)	5.42
	Pentadecanoic acid (C15:0)	0.30
	Palmitic acid (C16:0)	21.02
	Palmitoleic acid (C16:1)	7.49
	Margaric acid (C17:0)	0.17
	Stearic acid (C18:0)	6.76
	Elaidic acid (C18:1, <i>n</i> 9)	0.11
	Oleic acid (C18:1, <i>c</i> 9)	17.57
	Vaccenic acid (C18:1, <i>c</i> 11)	1.64
	Linoleic acid (C18:2)(<i>ω</i> -6)	19.55
	Linolenic acid (C18:3)(<i>ω</i> -3)	0.20
	Arachidic acid (C20:0)	0.39
	Eicosenoic acid (C20:1)	0.34
	Eicosatrienic acid (C20:3 <i>c</i> 8,11,14)(<i>ω</i> -6)	0.06
	Eicosatrienic acid (C20:3 <i>c</i> 11,14,17)(<i>ω</i> -3)	0.79
	Behenic acid (C22:0)	0.45
	Eicosapentaenoic acid (C20:5)(<i>ω</i> -3)	5.13
	Lignoceric acid (C24:0)	0.48
	Nervonic acid (C24:1)	0.11
	Docosapentaenoic acid (C22:5)(<i>ω</i> -3)	1.31
	Docosahexaenoic acid (C22:6) (<i>ω</i> -3)	3.16
	Unknown	7.45
2.	Peroxide Value (PV) of the extracted fat, meq O ₂ /kg	6.97

* Measured by Gas Chromatograph (GC)

Akter
28/3/24

Analyst
Jharmin Akter Lisa
Senior Scientific Officer
Institute of Food Science & Technology
BCSIR, Dhaka-1205

Akter
28-03-24

Supervisor
Md. Alamgir Kabir
Principal Scientific Officer
Institute of Food Science & Technology
BCSIR, Dhaka-1205

M. Rahman
28.03.24

Director (Addl. Charge)
Institute of Food Science & Technology
BCSIR, Dhaka

a. These results are based only on the samples submitted in this laboratory.

b. Any complaint about test report will not be acceptable after one month from the date of issuing of the said report.

c. This report/result shall not be reproduced/ published without prior approval of the authority.

Analytical Service Cell
Dr. Quadrat-i-Khuda Road, Dhanmondi, Dhaka-1205, Bangladesh



জীবনের জন্য বিজ্ঞান

শেখ হাসিনার দর্শন সব মানুষের উন্নয়ন

বাংলাদেশ বিজ্ঞান ও শিল্প গবেষণা পরিষদ (বিসিএসআইআর)

BANGLADESH COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH (BCSIR)

INSTITUTE OF FOOD SCIENCE & TECHNOLOGY (IFST)

Analysis Report

Analytical Service Cell Ref No: F-1164, 27/06/2024	Unit (Lab/Inst.) Ref No: ifst
Lab ID: IM-230	Sample Receiving Date: 27/06/2024
Sample ID: F-1164	Submission Date : 27/06/2024
	Report Delivery Date: 04/07/2024
Sample Description: Food, Production Date: 01.03.2024, Supplied in sealed jar.	
Product Name: Food	
Client's Details: মুহাম্মদ ফখরুল ইসলাম, রেজিস্ট্রেশন নং: ১৯-০৯৭১১, কিএসসি ইন এগ্রিকালচারাল ইকোনমিকস, শেরেবাংলা কৃষি বিশ্ববিদ্যালয়, ঢাকা-১২০৭।	
Number of Sample: 01	

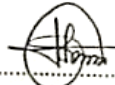
Report Details:

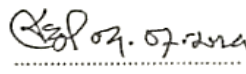
SI No.	Tests	Results
01	TVC (Total Viable Count), cfu/g	7.2×10^4
02	Total Coliform, MPN/g	<0.3*
03	<i>Escherichia coli</i> , MPN/g	<0.3**
04	<i>Salmonella sp.</i> , cfu/25g	Not Detected
05	<i>Clostridium sp.</i> , cfu/25g	Not Detected

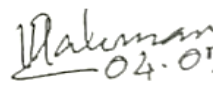
* <10 indicate absence of test organisms in 1 g of sample.

** As per MPN (most probable number) chart, MPN <0.3 indicates absence of test organism in 1g.

Comments: The above microbiological test results was found in the supplied sample.


04.07.24
Md Nurul Hossain, PhD
Senior Scientific Officer
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Bangladesh


04.07.24
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04.07.24
In-Charge /Director
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Director (Add. Charge)
Institute of Food Science & Technology
BCSIR, Dhaka

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Appendix D: Journal and Book Chapter Publications

#Journals

1. **Md. Masud Rana**, Roslianah Asdari, Ahmed Jalal Khan Chowdhury and Mohammad Bodrul Munir. (2023). Heavy metal contamination during processing of canned fish: a review on food health and food safety. *Desalination and Water Treatment*, 315: 492-499. <https://doi.org/10.5004/dwt.2023.30015>
2. **Md. Masud Rana**, Roslianah Asdari, Shakik Mahmud, Abrar Foysal Irfan, Ahmed Jalal Khan Chowdhury and Mohammad Bodrul Munir. (2023). Marine water aquaculture and an IoT-based smart fish dryer of the future: a sustainable environmental approach. *Desalination and Water Treatment*, 315 (2023) 515-522. <https://doi.org/10.5004/dwt.2023.30017>
3. **Rana, M.M.**, Saeid, A., Shakil, M., Adhikari, P. and Munir, M.B. (2025). Effects of varied drying on the proximate composition, sensory qualities, and rehydration characteristics of mud eel (*Monopterus albus*), *Food Research*, 9 (2): 130-140. DOI: [https://doi.org/10.26656/fr.2017.9\(2\).114](https://doi.org/10.26656/fr.2017.9(2).114)
4. Md. Masud Rana, Farjana Khanom, Sabikun Nahar Himi, Mst. Tasmim Sultana, Roslianah Asdari and Mohammad Bodrul Munir. (2025). Quality And Shelf-Life Analysis of Canned Hilsa (*Tenualosa ilisha*) Under Eco-Friendly Thermal Processing: A Sustainable Approach to Bangladesh's Blue Economy. *International Journal of Environmental Sciences*, 11 (235):3620-3633. DOI: <https://doi.org/10.64252/h10btk18>

#Book Chapters

1. Mohammad Bodrul Munir and **Md. Masud Rana**. (2024). Managing Natural Resources Through Innovation: The Importance of Sustainable IoT-Based Models-The Smart Solar Dryer. *IoT-Based Models for Sustainable Environmental management*. Vol.27, pp:81-94. <https://doi.org/10.1007/978-3-031-74374-0>

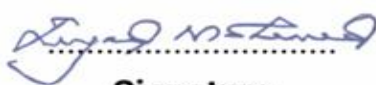
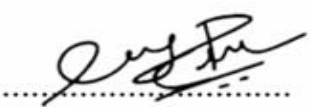
Appendix E: Attended Seminars and Publications

<u>Title of Presentation</u>	<u>Seminar/Conference</u>	<u>Venue and Date</u>
1. A Next Generation IoT-Based Eco-friendly Smart Fish Dryer: A Sustainable Solution for Ensuring Safe and High-Quality Processed Products	Insight International Research Conference-2024 (IIRC-2024)	Insight Institute of Management and Technology, Sri Lanka and 21 th January, 2024
2. Development of IoT Based Climate Smart Fish Dryer for Producing Premium and Exportable Dry Fish Products: Ensuring Food Health and Food Safety	4th World Summit on Obesity and Weight Management	Jointly Organized by Fisabio Foundation, Spain and Northern Caribbean University Jamaica and 9 th January, 2024
3. Development of Some Novel Recipes and Fillings for canned Hilsa to Enhance livelihood for small scale Entrepreneur in coastal areas: Revalorizing the canned fish industry in Bangladesh	International fisheries and aquaculture conference-2024	University of Rajshahi, Bangladesh and 8-9 th June, 2024
4. Revolutionizing the Dry Fish Industry: Fisher Net a Hybrid Predictive Model for Enhancing Livelihood and Market Price Forecasting in South East Coast, Bangladesh	9 th International Conference on Research in Intelligent Computing in Engineering (RICE-2024)	Stanley college of Engineering and Technology for Women, Hyderabad, India and 27-28 December, 2024

Appendix F: Certificates of Conference Participation (1)



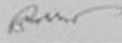
Appendix F: Certificates of Conference Participation (2)

Ref No: IIRC/2024/022		
		
INSIGHT		
INSIGHT INSTITUTE OF MANAGEMENT & TECHNOLOGY SRI LANKA		
CERTIFICATE OF PARTICIPATION		
<i>This is to certify that</i>		
Md. Masud Rana		
<i>has participated and presented a paper entitled</i>		
A Next Generation IoT-Based Eco-friendly Smart Fish Dryer: A Sustainable Solution for Ensuring Safe and High-Quality Processed Product		
<i>in the</i>		
Insight International Research Conference - 2024 (IIRC-2024)		
		
Signature Director - Insight Dr. Ziyad Thaha PhD	21st January 2024 Date	Signature Conference Chair Dr. Althaf Mohideen PhD

Appendix F: Certificates of Conference Participation (3)



Appendix G: Copy Right Certificates of the Innovation

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার Government of the People's Republic of Bangladesh									
Date of Publication						Date of Registration			
0	0	0	0	2	0	2	5	1	0
Copyright Registration No.				Validity of Registration					
CRA-29211				Life + 60 Years					
বাংলাদেশ কপিরাইট অফিস Bangladesh Copyright Office									
কপিরাইট রেজিস্ট্রেশন সনদ Certificate of Copyright Registration									
সৃজনশীল মেধা কর্মের শিরোনাম Title of Creative Intellectual Work									
<i>"Design and Development of SAU Smart Dryer: A Next-Generation Drying Solution"</i>									
সৃজনশীল কর্মের প্রণেতা (বড়ের অংশ) Author of the Creative Work (Type of Author & Proportion)									
<i>Md. Masud Rana</i>									
সৃজনশীল কর্মের স্বত্বাধিকারী (বড়ের অংশ) Owner of the Creative Work (Proportion)									
<i>Md. Masud Rana</i>									
স্বত্ব প্রাপ্তির মাধ্যম Mode of Ownership Gain					সৃজনশীল কর্মের ক্ষেত্র Field of the Creative Work				
Creator					Artistic Work (Graphics Design)				
The Registrar of Copyrights, Bangladesh Copyright Office is honored to issue this Intellectual Property Right Certificate Under the Bangladesh Copyright Act.									
Image of the Artistic Work					 Registrar of Copyrights www.copyrightoffice.gov.bd				
									
Attention: • Image of the Artistic Work will be treated as an integral part of this certificate. • Name of any work is not protected under the Bangladesh Copyright Act.									

Appendix H: Achieved “National Fisheries Award-2024” from the Ministry of Fisheries and Livestock for the Innovation

