Review Article

SEAFOOD PROCESSING AND QUALITY CONTROL

Abstract

To ensure food security and quality of seafoodproducts: As demand for quality food is increasing with the increase in population accurate identification of microorganismscausing spoilage of food becomes significant which is easily possible with the help of omics technology. Omics technology works at cellular and molecular levels. This technology can identify and detect low levels of contamination by pathogenic and bacteria spoilage and can be used to study the effect caused by processing and storage of seafood products.The collective use of Omics technologies that includegenomics, transcriptomics, epigenomics,epitranscriptomics, proteomics, metabolomics, immunomics, microbiomics etc, helps in maintaining food quality. On other side HACCP is also considered for quality control,it is systematic approach which includes conducting of hazard analysis, determining critical control points (CCPs), establishment of critical limits, monitoring of CCPs, establishment of corrective actions, verification of system,and record keeping. Its main objective is to identify and manage potential hazards throughout the food production process. Due to the highly perishable nature of seafood, it becomes important to have good processingtechniques which will enhance the storage life of seafood.Preservation techniques are classified into 3 categories:traditional processing methods,modern processing technologies and emerging technologies. All these practices at the end contribute to the quality and quantity of seafood products.

Keywords: Seafood, Preservation, Food Security, Quality Control, Omics technology

INTRODUCTION

Over the past 50 years the global population has increased and get wealthier, demand for seafood product per capita has increased from almost 10 kg in 1960 to over 20 kg in 2014 (Springmann et al., 2018). Countries where total protein intake are low, seafood protein become essential nutrient component because fish and seafood product supply readily available dietary source long chain omega –3 polyunsaturatedfatty acids for direct consumption (Food and Agriculture Organization, 2016). Land based production of plants and animals are primary component of food system, but on other side ocean and sea-based production are an important source of micronutrient rich foods (Seto and Fiorella, 2017). Fisheries and aquaculture contributed to food security as a direct source of protein, micronutrient and fatty acids (Koehn et al., 2022). There are many fish and shellfish which play a critical role in addressing deficiencies in other micronutrients such as vitamin A, calcium, vitamin B_{12},iron and zinc. These nutrients are often found in more bioavailable forms in fish and shellfish than in many vegetables, fortified staple and food supplements (Bogard et al., 2015). Nutrient deficiency is faced by many countries, individually finfish provide all dietary micronutrient for people which live within 100 Km of the coast in countries (Hicks et al., 2019). Fish and other aquatic animals'benefits are not limited to coastal communities: inland capture fisheries production has increased each year. In 2018 about 11.6 million metric tonnes (mt) is indicated, and inland aquaculture is much larger than marine aquaculture (30.8 mmt) or freshwater capture fisheries (12mmt), producing about 51.3 mmt in the same year (Action, 2020). According to Food and Agriculture organization (2024) , global fisheries and aquaculture production in 2022, sudden increase of 223.2 million tonnes, the increase from the year 2020 was 4.4 % production consist of 185.4 million tonnes and 37.8 million tonnes of aquatic animalsand algae. Environmental sustainability of food production is growing interest, and due to known seafood nutrient richness, key question arises that whether seafood provides an environmentally efficient way to micronutrient supply (Willet et al., 2019). Today's world population according to the UN will rise from 7 billion to approximately 9 billion by 2030 and to 10 billion by 2050 (Gerland et al., 2014). Such an increase in the growth of population will increase the global demand for additional food (Bene et al., 2015). Aquaculture has replaced wild capture fisheries as the main source of seafood for human consumption.The seafood industry has become increasingly globalized, competitive and complex thus contributing to the economy worldwide (Kummu et al., 2020).

SEAFOODPROCESSING TECHNIQUES TO INCREASE THE SELFLIFE OFSEAFOOD PRODUCTS:

TRADITIONAL PROCESSING METHODS:

DRYING

Drying is the oldest method of food preservation technique. It involves slowing down the microbial activity or enzymatic degradation reaction and reducing water content which helps in extending the food shelf life and its deterioration (Moradi et al.,2020). The drying process helps to reduce food weight and volume, simple transportation and less expensive storage (Llavata et al.,2020). The quality of finished product is affected by physical and biochemical changes that occur during this process (Alaei et al.,2018). Drying time, temperature and the product water activity are the factors which impact the food matrix. Poor quality dried food and agricultural product will result from an inappropriate or incomplete drying procedure. There is not enough quality to be introduced in the market. Sometimes, an ineffective drying process results in the loss of food taste, dark color of the finished product or the moisture gradients in the dried food. Processes involving low temperature (such as freeze drying) require longer time for drying, so high temperature drying techniques are more widely used, although, it compromises the quality of food. So, the problems faced by the food industry is to achieve shorter drying durations under moderate temperature and reduce the product quality low during the drying process. All know that drying process limits the quality and energy efficiency of the finished product. There are new technologies also which are established for the improvement of this dying process, for example, electro based drying methods. Other processes that use electrical energy for pretreatment or drying are electrohydrodynamic (EHD), pulsed electric field (PEF), ultrasounds assisted and dielectric drying (microwave and radiofrequency) (Ganjeh et al.,2021). Combination drying technologies are said to differ from single drying techniques in a number of ways. Traditional natural drying and hot air drying have given way to alternative drying techniques, such as contemporary vacuum, the vacuum freeze drying (VFD), vacuum microwave drying (VMD) and vacuum drying (VD) method (Papoutsis et al.,2017). Hot air drying is the most popular dehydration technique because it is inexpensive and easy to use. However, HAD has constraints caused by nitrogen loss and longer drying durations. Convective drying, which uses HAD, is a very efficient and energy efficient technique for drying dehydration. Compared to alternative methods, HAD has the advantage of being easy to use, requires cheap equipment investment, adjustable drying parameters and rapid drying rate (Gang et al.,2019). As result, dried aquatic products have consistent, dependable and repeatable properties. Microwave drying provides rapid dehydration, low energy consumption, high efficiency and penetrability due to its dielectric heating. There is an unequal distribution of energy and difficulty in controlling the MD endpoint (Chandrasekaran et al.,2013). Sublimation is the process used in the VFD process to extract water from a frozen matrix, effectively preserving most of properties of the photochemical (Donno et al.,2016). However, VFD is also a slow drying method, and the cost of processing is generally much higher than VD (Horszwald et al.,2013). Using VFD is also problematic because of high production cost & unfeasible energy consumption.

SALTING

Salting is a popular, inexpensive and natural method used in the food industry. It has several uses, such as microbiological assurance, improving sensory attributes (namely colour,taste and texture) and acting as an emulsifier and binding agent (Estevez et al.,2021). The general census is that 1.5% - 2.0% NaCl ensures sensory pleasure, various seafood items, cooked or canned (Jiang et al.,2023). For example, quality differences in fillets of light salted Tilapia (Oreochromis niloticus) during frozen storage were examined for physicochemical and microstructural reasons. The quality of Tilapia fillets was found to be enhanced by the use of light salting method. Additionally, it was demonstrated that the condition can impact how stable frozen fillets are kept in storage. Additionally, fish-based dishes are frequently served as the main course of many social events and celebrations in Egypt. Fish that has been fermented andsalted, such as Freekeh, Moha, Renga are examples of this (FSH). Even though these foods are widely popular, they pose significant health risks, including chemicals and biological ones. The presence of these possible contaminants in fish tissues raises the risk of food borne disease transmission. Such as poisoning from botulism to customers. To ensure the safety of fish-based foods and protect consumers, applying a Critical Control Point for Hazard Analysis (HACCP) is a preventative measure (Farag et al.,2022). Sodium (Na) is naturally present in seafood, however in raw items, it rarely exceeds 0.1g per 100g. However, after going through processing stages like salting, which is commonly done to improve seafood appearance and safety, the salt concentration can increase dramatically-up to a hundredfold. The safety and aesthetic appeal of seafood (Rybicka et al.,2022). The World Health Organization (WHO) recommends against ingesting more than 5g (2g of Na) of NaCl per day. However, given that the current consumption is over twice as high, it has been found that reducing the quantity of NaCl consumed is among the most cost-effective strategies to improve population health worldwide (WHO,2020). The methods which are used for reducing the amount of salt in food that guarantee its quality, safety and seafood allure, they fall into four primary categories: i) lowering the NaCl content ii) using substitutes for NaCl ,such as KCl, MgCl2, CaCl2 iii) the use of flavor enhances (such amino acids) and, iv) the blending of various methods (Pedro et al.,2019).

SMOKING

Smoking is a popular fish processing technique, inEurope, Africa and far east,and smoked fish & meat are delicious food. This outdated preservation technique considers the effect of seafood using salting, drying, heating & smoking to enhance the shelf life of seafood. Fish are exposed to flames during the smoking process (Adeyeye et al.,2019). The processing temperature divides smoked fish seafood into 2 categories; either hot or cold smoking. Cold smoked products are processed at temperatures below 33-degreecelsius declaring them to be little treated (Lovdal,2015). The cold smoking technique originally involved drying,salting and then inhaling smoke. The main aim of salting is lowering the water activity (aw) to prevent the spoiling mechanism, and salting can be achieved by injection, brine or dry methods. During the drying and smoking processes, there is an additional drop in (aw). Cold smoked seafood is very prone to spoiling; sensory evaluations indicate that it can be stored for 3-5 weeks at 4-degreecelsius. The primary cause of deterioration of cold smoked items is the off flavor from microbial metabolism and development. It has been explained that smoking releases over 200 different compounds, not all of which are good (Arvanitoyannis et al.,2013). Chemicals known as polyaromatic hydrocarbons (PAH), such benzo (a), pyrene, are especially problematic because of their association with the emergence of cancer. One of the reason PCS was developed is the concern about PAH that comes from pyrolysis. Wood smoke from burning wood chips or sawdust is the most common source of smoke condensates, any unwanted material should be removed by rising and refining the mixture (Montazeri et al.,2013). 0ne method that is becoming more and more common these days is purified condensed smoke, or liquid smoke (PCS). It is very easy to apply and manage liquid smoke (Swastawati et al.,2012). Liquid smoke requires basic equipment to be utilized, and the quality of chemicals linked to smoke is controlled. Use between 1% - 5% is ideal. Fish meat contains very little connective tissues. Autolysis enzymes may be able to break down the cathepsin enzyme with ease because it is a highly natural substance. This gives the meat its texture and creates a perfect environment for the growth of pathogens, such as dangerous bacteria and microbes that create histamine. Liquid smoke creates both bacteriostatic and antibacterial qualities, which when combined functions as a synergistic preservative. All harmful bacteria, including Staphylococcus aureus, Listeria monocytogenes and Escherichia coli, can be restrained by it. The fish flesh of sprats contains naturally found histidine because they belong to the clupeidae family. The application of liquid smoke reduces ph (5.56-5.58), which is induced by organic acids that condensed during smoking (Dien et al.,2019). In addition, compared to traditionally smoked fish products, the use of liquid smoke results in better tasting smoked fish products with lower moisture content, less salt and better microbiological parameters. A study examined the effects of different liquid smoke concentration and vacuum packaging made with Capoeta trutta on fish balls. The study discovered that adding liquid smoke enhanced the products sensory flavor. However, the study investigated that the items chemical and microbiological quality were unaffected by the addition (Ozpolat, 2022). The condition in which liquid smoke is used in the production and application of fish preservation techniques were examined in one study. The solution that contains lemon extract (0.75%), acetic acid (0.5%), NaCl (2%) and liquid smoke (0.002%) proved effective in spraying sea bream and sea bass fillets. These treated fillets exhibited minimal levels of spoiling microbes throughout the storage period after being vacuum packed and kept at 4-degreeCelsius for at least two weeks. After 14 days, the pseudomonad ale count, psychoactive count, and total viable count of the smoked fillets were approximately 5 & 6 log CFU/g, CFU/g and during all loading, 2-3 log CFU/g of Enterobacteriaceae. Notably, no infection was discovered, and there was a deficiency in other microbial communities (Racioppo et al.,2023).

MODERN PEOCESSING TECHNOLOGIES

REFRIGRATION AND FREEZING

The current value chain dictates that freezing happens both on board and at the processing facility, where it typically takes the form of double freezing, which involves both thawing and processing, before fish is shipped to market. 62% of processed food are only created by freezing and, India is the world's fourth largest supplier of seafood, primarily frozen fish. Freezing has been shown to be an effective preservation technique in the contemporary food industry for increasing the shelf life of many food items (Dhanapal et al., 2023). Freezing reduces the quality of food (color, texture, lipid oxidation, and enzymatic activity) and slows down the biological, chemical, and physical aspects of food deterioration. Protein denaturation is strongly correlated with the loss of sensory quality and has been related to quality loss in frozen fish (Yu et al., 2020). The chemical and structural properties of muscle may be negatively impacted by freezing. Less ice crystals form, and the muscle fiber has less textural damage as the freezing process becomes more uniform and quicker (Sampels, 2015). Slow freezing can produce large ice crystals that can burst cell membranes, increasing the risk of oxidation, textural degradation, and loss of water-holding capacity. Maintaining a constant temperature while storing frozen fish is essential to prevent ice crystals from forming (Sikorski et al., 2020). Furthermore, it was observed by a number of investigations that polyunsaturated fat did not diminish after frozen storage, although meat fat (C16:1) did, PUFA (fats). The most recent methods for rapidly freezing muscle meals include liquid immersion freezing, cryogenic freezing, pressure shift freezing (sometimes called high-pressure freezing), and the more traditional air blast freezers and plate freezers. Plate freezers are ideal for the surface and food because they guarantee the best possible contact between common fish and commodities. The most economical and effective solution for a range of goods methods is to use air blast freezers. The goods are transported via a tunnel or chamber with a cool airflow that can be changed in speed (Fidalgo et al., 2021). There are two possible orientations for the air flow while the goods are traveling on a belt: horizontal and vertical. The product load, belt speed, and airflow parameters all affect how quickly the product freezes. When ethylene glycol, also known as propylene glycol, is packaged using immersion freezing, liquid freezing media, such as brine, is sprayed or dipped into the product (Gokoglu at al.,2015). These characteristics allow this freezing method to work at temperatures between -6 and -20 o C with greater efficiency and the same speed as plate and air blast freezers that touch the full surface of the product. The process for cryogenic freezing is the same as that for immersion freezing. freezing, except in cases where liquids include nitrogen or carbon dioxide instead of water (Tavares et al., 2021).

CANNING

Canning is an important and secure way to preserve food when done properly. To kill or destroy any leftover bacteria, this procedure involves preparing the food, sealing it in sterilized cans or jars, and boiling the containers. Considering that foods vary in their natural amount of protection to keep the final step from spoiling, it might be necessary to complete it in a pressure cooker. Food is reheated in cans or other receptacles made to get rid of bacteria that cause food to deteriorate. The air in the jar is driven out during the heating process, and when it cools, it forms a vacuum seal. Normally, air would allow bacteria to enter the product, but this vacuum seal keeps that from happening. Food can be processed safely using a boiling water bath or a pressure canner. Cooking, canning, and boiling the sterilization vessels are the procedures needed to sterilize food. Any bacterium that is still present under these conditions is either eliminated or becomes weaker. Food preserved in a bottle or can through canning or bottling is immediately vulnerable to deterioration once it is opened. Bacteria may enter the canning process through water or an insufficient quality control system. Due to gas created by the can's internal disintegration, the majority of these failures are discovered quickly (Ariyamuthu et al., 2022). However, sometimes, poor manufacturing and unclean circumstances have allowed for the required "anaerobe" Acute toxins produced by contaminated food containing Clostridium botulinum have the potential to cause deadly illnesses. Canned foods are a major source of sodium in food. Excessive salt consumption raises the risk of health issues, such as high blood pressure. Three canning techniques were used in an examination of the preservation of Undulate

Venus shellfish (Paphia undulate): raw canning, smoking canning, and canning after cooking. The goal was to produce a wholesome and health-improving product by these techniques for preservation. The findings revealed a noteworthy ($p < 0.05$) increase in the moisture content of canned uncooked in contrast to the two other treatments—smoked and cooked P. undulate—and there was a noteworthy decrease in protein content ($p < 0.05$) in both the canned smoked and canned cooked treatments. in contrast to the uncooked in a can. A significant difference ($p < 0.05$) was seen in the fat content of canned raw, canned smoked, and canned cooked food. The slight difference in lightness(L*) isobserved in all canned shellfish treatments (P. undulate). Both lightness (L*) and redness (a*) decreased simultaneously in every canned food treatment, waves its shellfish. The most effective treatment for both lightness and flushing was canned raw. The highest value for hardness was found in canned smoke, which was followed by canned raw, first canned, and then canned again. The results showed that all panelists preferred cooked canned food over raw or canned smoked food, and that canned cooking was excellent(Abd-el-aziz, 2021). There was a marginally significant difference ($p < 0.05$) in sensory qualities across the three treatments.

HIGH PRESSURE PROCESSING (HPP)

This process entails preparing the food, sealing it in sterilized cans or jars, and then boiling the containers to kill or degrade any remaining bacteria. Considering that foods vary in their natural amount of protection. To keep the final step from spoiling, it might be necessary to complete it in a pressure cooker. Meals are heated in cans or other receptacles made to get rid of bacteria that cause food to deteriorate. The air in the jar is driven out during the heating process, and when it cools, it forms a vacuum seal. Normally, air would allow microorganisms to infect the product, but this vacuum barrier keeps that from happening. Either a pressure canner or a boiling water bath can be used to securely process food. Food is sterilized by boiling the sterilization vessels, cooking it, and then sealing it in jars or cans at each stage of the procedure. In these settings, any remaining microbe is either destroyed or becomes weaker. Food preserved by canning or bottling in a bottle or can is immediately prone to deterioration when it has been opened. Water or an inadequate quality control system can allow bacteria to infiltrate the canning process. Most of these errors are quickly discovered because they can burst or bulge from the internal breakdown gas (Pedro et al., 2019). However, there have been case where inadequate sanitation and manufacturing practices have allowed the obligatory "anaerobe" Clostridium botulinum to contaminate canned food, resulting in the production of an acute toxin that can be fatal or cause major illness. Cans and canned products are a major source of salt in meals. There is a higher chance of health issues, such as high blood pressure, when excessive salt consumption occurs. Three distinct canning techniques were used in the inquiry of the preservation of Undulate Venus shellfish (Paphia undulate): raw canning, smoke canning, and process, as well as canning after cooking. The intention behind employing these preservation methods was to create a nutritious and healthful product. As compared to the other two treatments—candied smoked and canned cooked—the moisture content of canned raw P. undulate was substantially ($p < 0.05$) greater, according to the results. When compared to the uncooked in a can, there was a significant drop in protein content ($p < 0.05$) in thecanned cooked and smoked treatments. Canned raw fatcontent differed significantly ($p < 0.05$) from canned smoked fat content cooked in a can. There was a minor variation in lightness (L*) across all canned shellfish treatments (P. undulate). P. undulate canned shellfish showed a simultaneous decrease in lightness (L*) and redness (a*) in all treatments. The treatment that displayed the highest values for both lightness and blushing was canned raw. The highest value for hardness was found in canned smoked, which was followed by canned raw, first canned, and finally canned again. The sensory qualities of the three treatments showed a marginally significant difference ($p < 0.05$); the results showed that canned cooking was preferred by all panelists over raw or canned smoked food, and that canned cooking was excellent (Lorenzo et al., 2021).

IRRADIATION

Foods stay in the same physical state following radiation treatment, which is a cold pasteurization procedure (Shafia et al., 2019). It has been shown to be an excellent preservation technique due to its capacity to effectively inactivate bacteria and viruses without affecting the nutrition or quality of food. In addition to its main purpose, it can also control the growth of bulbs and tubers, such as potatoes and onions, eliminate pests from spices, and increase the shelf life of perishable items. As such, it can be used as a method of preservationfor sustenance. This process or technique is safe and approved for use with a variety of foods by the U.S. Food and Drug Administration (FDA) and more than sixty additional national food control organization (Joshua, 2020). Radiation sources that are used to preserve food include ultraviolet, gamma-rays, and accelerated e-beams. For most dietary categories, dosages between 0.1 and 10 kGy are suitable. Fisheries products can now preserve and have their shelf life extended with the use of radiation and useful alternative techniques. Several early studies about the effects of radiation on fish and seafood shelf life evaluated that the optimal dosages for fishery items were between 1 and 5 kGy. The microbiological shelf life of the irradiation items was 1-2 times greater than that of the control samples. According toMahmoud et al. (2016), it found that uncooked tuna fillets stored at 5, 10, and a maximum TVC reduction of >7 log CFU/g at 25_C were exposed to a low dose of x- rayradiation (0.6 KGy). The study also looked at how radiation affected the biogenic amines in chilled fish fillets. They found that the greater dose of 0 to 2 kGy reduced the accumulation of tyramine, cadaverine, and putrescine while preserving the organoleptic properties. However, higher TBARS demonstrate that lipid oxidation brought on by radiation treatments will result in the development of tastes and aromas during storage (Maltarstrmeeki et al.,2013).

EMERGING TECHNOLOGIES

MICROWAVE ASSISTED PROCESSING

Microwaves are a legitimate substitute for traditional heating methods because they are a type of electromagnetic radiation with wavelengths between one millimeter and 1 meter. Microwave heating is frequently referred to as dielectric heating in the literature on the subject because waves are absorbed by materials with dielectric characteristics attributes (Zia et al., 2019). These materials, also referred to as dielectrics, have a poor electrical conductivity and a relatively high specific resistance. Furthermore, the atoms or molecules that comprise the dielectric (such as agricultural food products) exhibit the motion of a dipole. Microwave technology is a frequently used equipment in the food industry. Most houses have a small radiofrequency, which is used for pasteurizing, freezing, cookingor sterilizing food items (Guzik et al., 2021). Additionally, fish and other products from fisheries can be microwave dried. The outcomes are better when microwave drying is combined with other drying methods like air drying, vacuum drying, or freeze drying than when microwave drying is done alone. The components created by microwave processing have a more uniform, axial, cellular, and homogenous structure than those made using traditional methods. Its application can be found in the food processing industry as well as several manufacturing industry sectors. The unique properties of microwaves, such as penetration radiation, controllable electric field distribution, improved product quality, time and energy savings, quick heating, selective heat application, self-limiting reactions, and a reduced environmental impact, have led to their widespread use in applications related to industry and material processing, even though there are alternatives like ohmic resistance heating and electric furnaces (Baghel, 2023; Nguyen et al.,2020) examined the heating of surimi products using steam and microwaves. An additive method involving steam heating, and 35 kW of microwave treatment greatly boosted the gel strength and created a denser network architecture, according to scanning electron microscope images. Furthermore, after frying, the innovative heating method with moderate microwave power received the highest grade in the comprehensive sensory analysis.

ULTRASOUND

Ultrasound uses sound waves at frequencies up to 16 kHz, which are inaudible to humans. Ultrasound is a non-thermal technique that can be used in place of thermal food preparation to improve quality while reducing processing time and costs (Murtaza et al., 2023). Ultrasound can be applied to many food processing methods, such as extraction, emulsification, freezing, thawing, texture tenderization, preservation, and microbiological deficiency (Troy et al., 2016). The breakdown of microbe cell walls by ultrasonic treatment results in cavitation bubbles, shear disruption, microstreaming, and free radicals, all of which accelerate the decomposition of the organisms(Liu et al., 2016). Enhancing the taste and microbiological qualities of fish products can be accomplished through alone application as well as other techniques (Betts et al., 2014). Furthermore, the use of ultrasound can reduce extraction times. Reduced particle size leads to increased productivity and efficiency because it facilitates the extraction of significant bioactive compounds from fish waste (Arvanitoyannis et al., 2016)

FISH SPOILAGE

Fish is a highly perishable food. Tropical and subtropical climate of India contribute to severe spoilage problem due to humidity and heat. Comparing fish and animal tissue,fish tissue is more perishable in nature even under refrigerated conditions.

Table 1:perishability duration of seafood products & Meat products

Product name	**Temperature (in Celsius)**	**Duration**	**References**
Finfish	0 degree	14 days (2week)	Salama &Chennaoui, 2024
Beef	1.7 degree	Several weeks	Furman et al.,2024
Freshly caught fish	16 degrees	A day	Gupta et al., 2024

Spoilage of fish is depended on 3 factors:

1. Chemical
2. Physiological
3. Microbiological

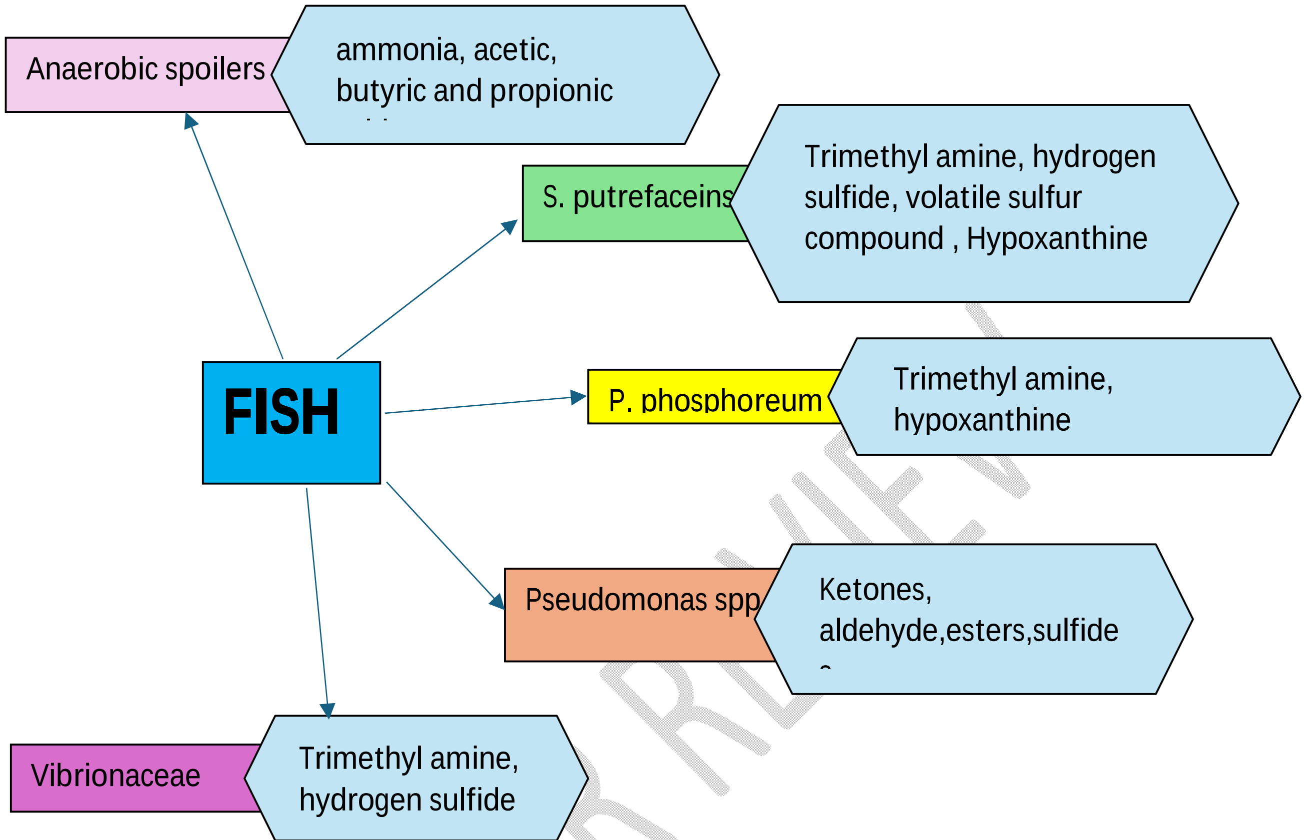

Figure 1: Spoilage compound and spoilage bacteria found during fish spoilage **(***Salama &Chennaoui 2024)*.

Chemical

Freshly caught fish have very little or no odour. Yet, all seafood that includes fish and fish products have fishy odour due to deterioration. Trimethyl amine is the chemical responsible for deterioration and fishy odour.Spoilage process includes the production of trimethyl amine due to action of bacteria on phospholipids and choline present in fish. In addition, the unsaturated fish fats went through oxidation and rancid which causes the smell of deteriorated fish. Sodium benzoate and ethylene oxide and the antibiotic aureomycin are responsible for the longer life of fish. In many countries use of these preservatives is restricted. Quality deterioration of fresh seafood products detection is important in supply chain. Synthetic preservatives are used for delay in deterioration but as chemicals are harmful people’s demand for safety increases. As synthetic preservative has many disadvantages like potential toxicity, carcinogenicity etc. More environmentally friendly techniques are being used. Modified atmosphere packaging (MAP) is used to pack fresh seafood and low temperature storage to prevent deterioration of food (Weiet al., 2024). Fish is a very perishable food that needs to be kept cold or frozen before it can be eaten or processed. The term "modified atmosphere packaging" (MAP) refers to the packing of food in an atmosphere whose initial composition is altered using fixed gases to achieve a desired profile. The primary cause of fishing product deterioration and subsequent quality loss is microbial deterioration (Alfaro et al., 2013). There are various advantages of Modified Atmospheric Packaging are that it preserved the natural color of the product, reduces the growth of microorganisms, extends the shelf-life of products, etc. Packaging methods have a crucial role in safeguarding products against deteriorating effects, such as microbiological, biochemical, and physical activities resulting from environmental factors. This entails preserving the quality of packaged food, extending its shelf life, and delaying spoiling. Concealment, marketing, communication, and confinement are some other uses for packaging (Restuccia et al., 2010). Active packaging, bio packaging, and bio coating are examples of recent advancements in MAP systems that maintain food items in an environment distinct from the typical composition of air(Lee, 2010). Another preservationtechnique is Vacuum packaging is the process of eliminating air from a pack before closing it is known as vacuum packing. Its main aim is to remove the oxygen by allowing the packing material to come into close contact with the product (Dewitt et al., 2016**).** The material used for vacuum packaging needs to be heat sealable and have a good gas and moisture barrier (Robertson et al., 2013**).** To prevent freezer, burn on fatty fishlike salmon, mackerel, sardines, and others, vacuum packaging is also a great option for frozen fish and fisheries goods. There are various advantages of vacuum packaging are, food in vacuum packs is easy to handle, vacuum packaging serves as a barrier for vapor and oxygen, oil, chemical, and translucent materials are all included in vacuum packaging (Kumaret al., 2014). Vacuum packaging minimizes financial loss from stored fish and fisheries products while guaranteeing product safety (Ochieng , 2015).

Chemical used to increase the shelf life of seafood

Sulfites serve as both antibacterial and antioxidant agents. They inhibit the growth of molds, yeasts, and bacteria that cause spoiling. Sulfites are frequently used in seafood to stop browning or discoloration, particularly in shrimp and other crustaceans. Sulfites inhibit oxidative reactions and microbial growth, which helps in maintaining the color and texture of seafood.The primary application of nitrates and nitrites is their antibacterial activity, especially against Clostridium botulinum, the causative agent of botulism. Commonly, they can be discovered in processed or preserved seafood, such as smoked fish. Nitrates inhibit the growth of harmful bacteria and contribute to the color preservation of processed seafood. Nitrites also contribute to flavor in order to keep seafood from drying out during freezing and thawing and to enhance texture, phosphates are employed. In seafood such as shrimp, scallops, and fish fillets, they are also utilized to preserve flavor and enhance water retention. Phosphates change the structure of proteins in seafood to increase its ability to retain moisture. Regulatory standard and safety concern.

Table 2: Shelf-life enhancement of seafoods by using chemicals

Chemical name	Role	Seafood example	References
Sulfites	-Serves as antibacterial and antioxidants agents. -Inhibits the growth of moulds, yeasts, and bacteria that causes spoilage. -Inhibits browning or discoloration	Shrimps and other crustaceans etc.	Baygar et al.,2024
Nitrates/nitrites	-Serves as antibacterial especially against Clostridium botulinum -Inhibits the growth of harmful bacteria and contributes to color preservation. -contribute to flavor	Preserved and processed seafood such as smoked fish	Zhong et al., 2022
Phosphate	-Keeps the seafood from drying out during freezing and thawing. - Enhances texture, flavor, water retention.	Shrimps, scallops, and fish fillets etc	Punvichai et al.,2024

Biological methods

-use of natural antimicrobial agents

Antimicrobial agents are substances that are used to kill or inhibit the growth of microorganisms, fungi, bacteria etc. Natural antimicrobial agents used in seafood preservation are essential oils, vinegar, chitosan, rosemary extracted. Antimicrobials can inactivate cells through lipids and the cell membrane by electrostatic contact, among other mechanisms of action that result in cell death (Olatunde &Benjakul, 2018). Antimicrobial activity of essential oils derived from various plant sources protects against various food spoilage and harmful microbes (Tongnuanchan&Benjakul, 2014). Thyme essential oils and their nano emulsion form were tested for their ability to inhibit fish spoiling microorganisms (Ozogul et al., 2020) Animal-derived substances like lactoperoxidase, lysozymes, chitosan, and so on have demonstrated superior antibacterial capabilities. Chitosan and its derivatives possess antioxidant and antibacterial qualities and are biodegradable, biocompatible, and nontoxic.

-Fermentation and probiotic applications

Fermentation is a food preservation technique used from ancient times for all types of food (Kong & Frohlich 2017**).**Since the Neolithic era, about 10,000 years B.C., food has been preserved through fermentation. This method is still in use today due to the improved sensory and nutritional qualities of the final products as well as their longer shelf life (Bourdichon et al., 2012). This is because, fresh fish have a limited shelf life, people have always tried to find better ways to preserve it. Fish sauce is one of the most popular fermented fish products. Probiotic applications enhance food safety by stopping the growth of infectious and rotting organisms. This lowers the occurrence of dangerous germs that are frequently found in seafood, such as Salmonella spp., Vibrio spp., and Listeria monocytogenes (Siroli et al.,2017). Probiotic application also improves the sensory quality and extends the shelf life of seafood.

Physical methods

Until the fish has gone through rigor mortis (that is stiffening of joints and muscles of a body after few hours of death). Stiffening of muscles and joints involves the conversion of glycogen present in fish muscle into lactic acid involving the decrease in phlevels. When fish is freshly caught it struggles for some time which involves the usage of glycogen which is present in the fish as energy form. Then the little glycogen left in the fish is converted to lactic acid to retard the growth of bacteria. As fish is highly perishable its rigor mortis is less when compared to other animals which are rested before slaughtering in slaughterhouse to build glycogen reserve.

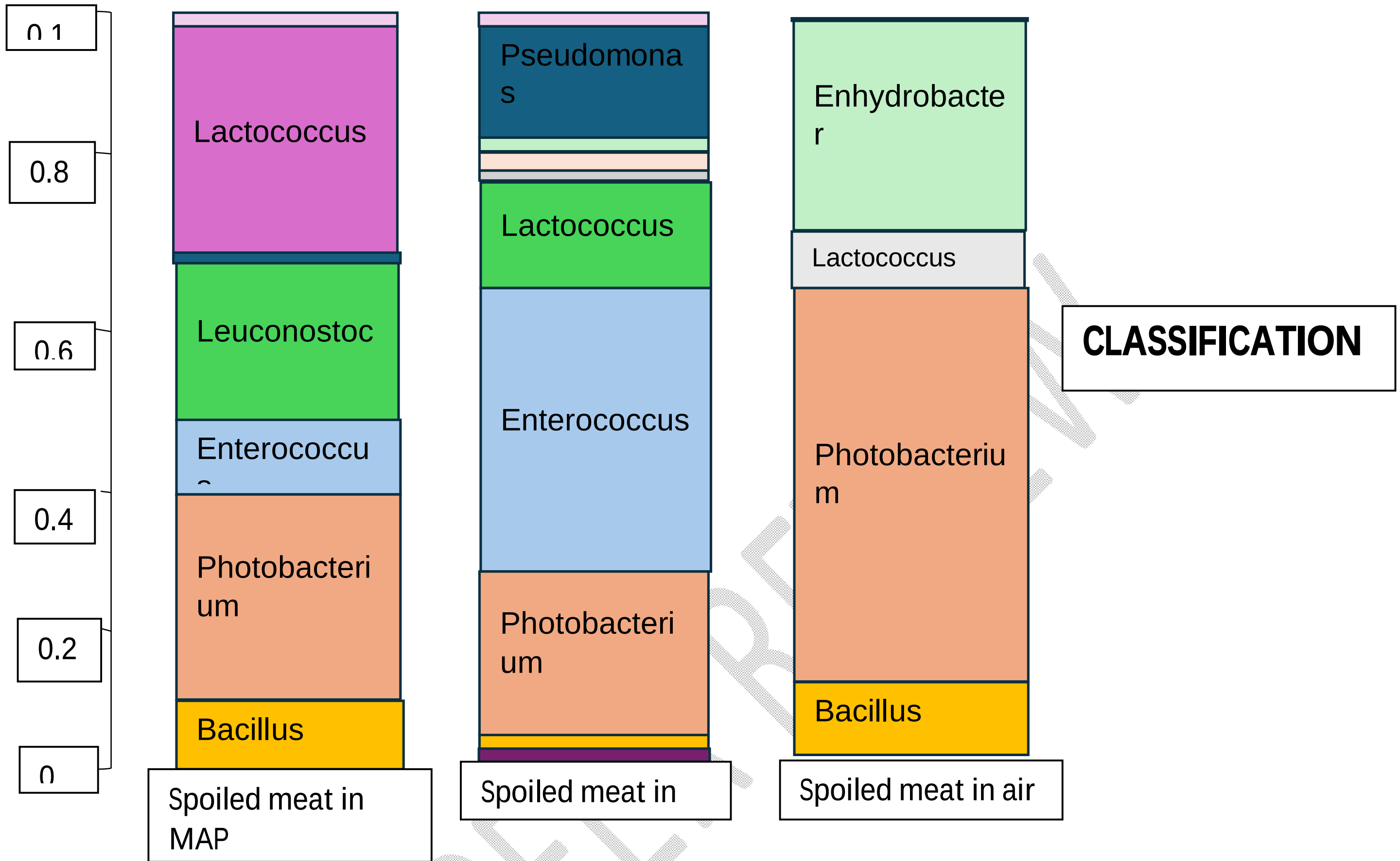

Figure 2: This histogram shows the availability of bacteria genera (>0.1%) in spoiled meat under various packing condition. **MAP:** Modified atmosphere packaging; **VP:** Vacuum packaging; **AIR**: Aerobic packaging (Cauchie et al., 2020)

QUALITY CONTROL IN SEAFOOD

OMICS TECHNOLOGY

It is defined as collective techniques that analyze molecules composed of cells, tissue, or organisms are defined as omics technology. It also involves the study of genomics, proteins, RNA and metabolites.Omics technology is used in checking microbial spoilage. Recentmethods for checking microbial contamination depend on culture dependent analyses(Sequino et al.,2022)where Omic technology is classified into 3 types i.e., sequencing based omics involves genomics, transcriptomics, etc. Epigenomics, epitranscriptomics, and MS based omics are proteomics, metabolomics. Knowledge based omics are immunomics,microbiomics.For maintaining safe, economically supportable food supply chainand prevention from microbial spoilage which will lead to quality control, omics technology is best suitedwhich leads to boosting of food security globally, where food quality and safety are main components (WHO, 2015).Food omics is technology that is used for improving food quality. Continuousboost in consumers awarenessabout food quality and safety increases the use and demand of food omics technology. Food authenticity and safety is a raising concern especially in case of imported food products. Which result in comprehensive labelling, detailed reports as per the recent laws and regulatory restrictions (Ferri at al., 2015). Current trend involves quality check by using more refined and biology-based techniques with traditionaltechniques, this is focused on recognition of novel markers whichare used for quality assessment and microbiological spoilage fingerprints using omics technology. Omics tools include genomics, transcriptomics, proteomics and metabolomics. They all develop in the recent technology revolution. (Den besten at al., 2018)life science has increased the use of omics technology which led to increase in the implementation and confirmation and reduction of cost have presented them into the light. Part of this led to development of tools which focused on the microbial communities in food supply chain and their application to human and animal health (Cook & nightingale, 2018). The first step in developing these omics techniquesis to offer a broader knowledge of the target system which includes utilization of concepts from the central biological dogma (1) DNA replication (2)transcription of mRNA (3) translation to protein. The making of molecular fingerprints and patterns related with food products with more thorough analysis of how traditional and innovative food processing technologies effect microorganisms, product structure, color, texture, and overall, which are related to food quality (Costello et al., 2020).

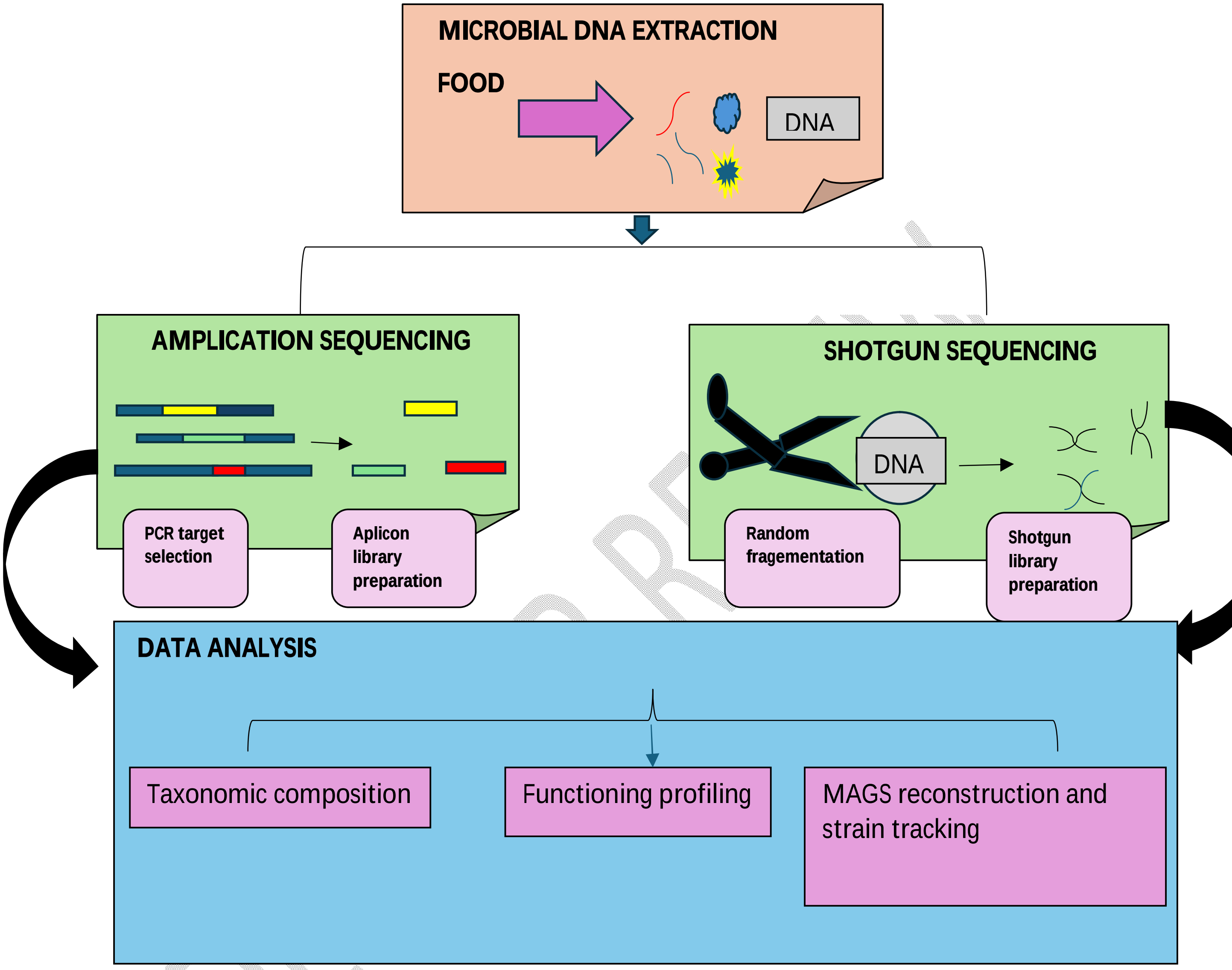

Figure 3:omics technologies-based systems in living cells (Ghamkhar et al., 2023)

Understanding omics technology will lead to improvedquality and safety controls of seafood. High throughput sequencing technologies (HTS) mentioned in above figure is a transforming food microbiology, the current higher sensitivity compared to culture dependent and other culture independent methods enables the detection of subdominant microbes that plays significant role in ecosystem study.According to the figure there are two common techniques which use NGS are amplicon sequencing and metabarcoding, it includes amplification and sequencing of specific marker genes and shotgun metagenomic of the whole genomic substance of microbial community. On other side metabarcoding is frequently used in food microbial ecology and is beneficial to offer a taxonomic picture of microbial community. And in shotgun-based method, entire DNA or RNA is fragmented by enzymatic or mechanical methods and sequencing. Other than offering taxonomic composition of entire microbial community (that includes bacteria, fungi, archaea, protozoa,etc) this evaluation involves the describing of its functional capability, determining the presence and availability of the specific genes of interest (genes involved in spoilage of food) and rebuilding of related metabolic pathways. Supplementing, reconstruction of the microbial genomes directly from metagenomics reads is an optimisticmethod to track specific microbial strains over the food chain. HTS supports product quality and safety management plans (Filippis et al., 2018).

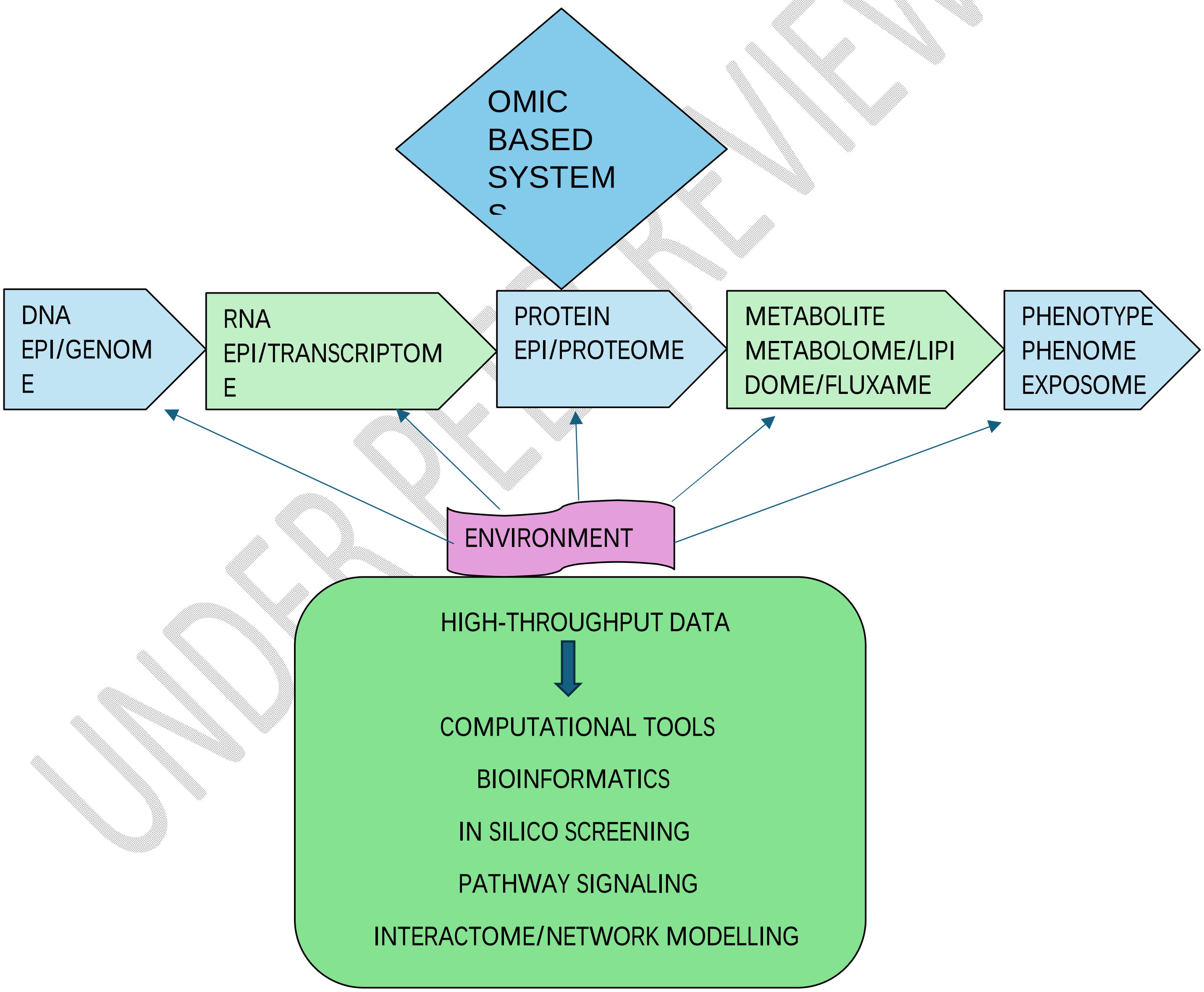

Figure4: Flow chart representing high throughput sequencing application to study food microbiome(Dai & Shen 2022)

Microorganism involved in deterioration in seafood:

Freshly catches fish from saltwater are very prominent to spoilage due to autolytic enzyme action, unsaturated fatty acids oxidation, and microbial growth (Gupta et al., 2024).Gutting (removal of internal organ in the abdominal part and preparing it for meal) of fish is post-catch practice which is important if it is not doneprotein hydrolysis is done by autolytic enzyme (autolysin: lysisis caused in the presence of microorganism which specifically hydrolyze mucopeptide polymers in the bacterial cell wall) is known as proteinases, becomes well-known issue. Factors influencing microbial spoilage are types and levels of microbes present and the fish ecology and type, harvesting methods, handling practices (Sanchez et al., 2024). Fish tissues are rich in non-protein nitrogenous compound, which also includes free amino acids like trimethylamine oxide and creatinine, as well as peptides and proteins, increases to 6.0 and carbohydrates are absent(Valimaa et al., 2019). The major culprits that are responsible for fish spoilage are gram negative aerobic rods such as Pseudomonas spp., Acinetobacter, Moraxella, and Flavobacterium, including facultative anaerobic rods like Shewanella, Alcaligenes, Vibrio and Coliforms (Odeyemi et al., 2020).

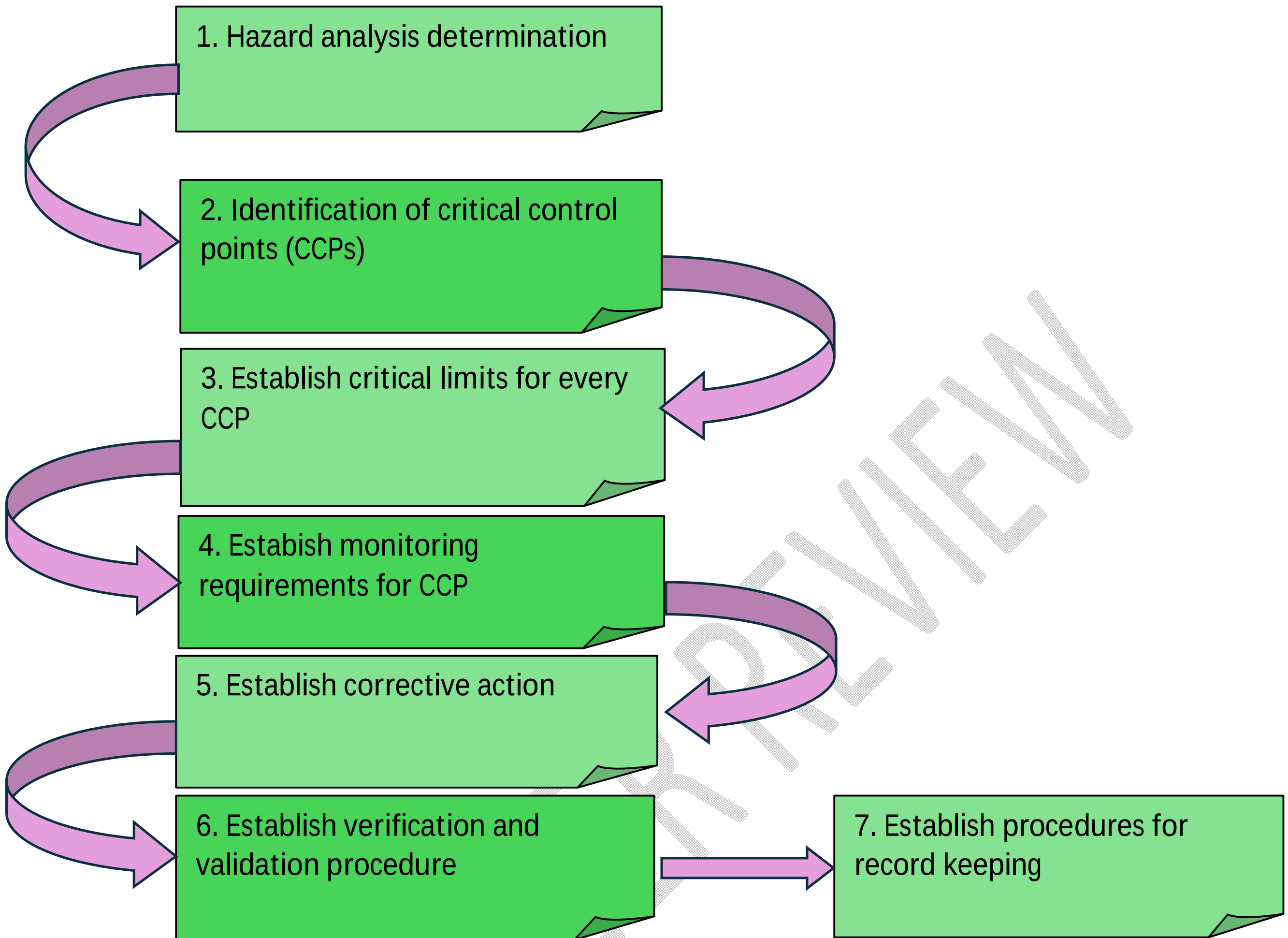

Figure 5: Principles of HACCP are applied as shown in this flowchart (Njunina, 2022)

As mentioned by the international commission on microbiological specifications for foods (ICMSF)(Steward at al., 2022).Government agencies and food processors worked on three main methods to manage microorganismsin foods. These three methods include education and training, facility and operation inspections, and microbiological testing(Mendonca et al., 2020).These methods' main objective is to create awareness of the causes and effects of microbial contamination and examine the strength of facilities, operations, and bonding to proper handling practices (Ngoc et al., 2020).These components are vital in food control strategy. Other than ICMSF guidelines prevention practices under hazard analysis critical control point (HACCP) is a key factor necessary for good quality and safety standards, particularly in managing seafood hazards (Hasani et al., 2024). Hazard analysis and critical control points (HACCP) is a food safety approach that is a preventive technique for food protection and consumers from chemical, physical, and biological contaminants. It is both post and pre-productiontechnique to ensure the absence of any type of contaminant that makes the output safe. HACCP is a preventive technique to make food safe. HACCP is done at every step to keep the quality of seafood up to date,i.e., from the initially from production process to food preparationand postproduction handling, including raw materials, production packaging, storage, distribution etc. Different countries have different regulatory bodies which includeHACCP specific programme applications for different foods like meat, fish, juice, dairy products, seafood canned foods etc,to satisfy the food safety standards to protect public health and prevent the outbreak of foodborne diseases (Njunina 2022).

CONCLUSION:

There are various food preservation techniques which are classified into three techniques:traditional methods (smoking, salting,drying), modern processing technologies (freezing, canning, HPP, irradiation), Emerging technology (microwave assisted processing and ultrasound). These are the techniques which help in preservation of seafood, as fish is highly perishable in nature it needs to be preserved quickly. In seafood microbes play a crucial role in deterioration of seafood to retard its growth and identification of the specific microorganism which is causing the spoilage of seafood. Omics technology is used at molecular level in living body that includes cell, tissue, organ. Omics technology'smain objective is to keep a check on microbial spoilage. On other side HACCP is a food safety approach which is common for all foods which includes the systematic preventive methods to protect foodand consumer from chemical, physical, and biological contaminantsand makes use of scientific methods for preparation, handling, and storage of foods to prevent food spoilage by maintaining food quality.

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