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Canned Fish: Creating HACCP Plan

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Abstract

The fish canning industry is significant in the world food supply chain; it provides adequately packaged, shelf-stable fish protein products consumers need. This paper examines the canning process, the all-important aspects of food safety involved in canned fish processing, and the use of HACCP in the bid to guarantee safety and quality. The dangers of microbial contamination, histamine poisoning, and botulism are described and the precautions needed during the entire canning process. The paper also further discusses the global regulatory environment of fish canning industries in compliance with legal requirements on food safety in industries such as the FDA and EU regulations. Moreover, spoilage concerns under processing and post-process contamination have been highlighted, clearly showing how they affect the safety and quality of canned fish products. The paper also considers industry trends such as advancing technologies, consumer trends of going natural or produced with minimal processing as adopted by the Dole Food Company, and measures towards environmental sustainability. The increasing attention to environmental issues means that new advancements, such as efficient power consumption in processing and reusable packaging, are becoming critical. However, HACCP remains at the center of food safety assurance, bearing in mind that the food industry was changing, as stated above, during the development of HACCP. This paper further asserts that HACCP will remain the industry benchmark because of the reliability, flexibility, and cost efficiency of attaining high food safety standards in such a dynamic environment as new technologies and customers' tastes. In this paper, the author emphasizes that HACCP plays a significant part in the future evolution of canned fish and their quality characteristics.

Keywords; Canned Fish, HACCP (Hazard Analysis and Critical Control Points), Food Safety, Quality Assurance, Canning Process, Technological Advancements, Sustainability, Minimally Processed Products, Spoilage Prevention, Global Regulations.

Introduction

The technique of preserving food by exposure to heat is commonly known as 'appertization,' and was invented by the Frenchman Nicholas Appert in the early nineteenth century. This process of preserving foods entails placing them in tubular can-like structures and then heating the contents to high temperatures to eliminate pathogenic microorganisms, which has become standard in the food processing industry. But this method was perfected and even trained for many decades without any science about how and why this must be done. It was not until the microbiology and heat transfer theories marked the end of the 1800s that this process was supported by even rudimentary and advanced science. The current canning process is a completely well-developed field that has been improved with the help of scientific discoveries and modern technologies. Canned fish has become popular, and billions of fish cans are produced and consumed annually. As the Food and Agriculture Organization estimated in 2000, more than 14 million tons of fish, or about 12. 5% of the total fishery production is utilized to produce canned fish for human consumption (Thomson 1982). Canning has developed to be part of the most efficient and even semi-manual process, especially in advanced countries. However, in developed nations, the canning industry enjoys the favorable conditions of large-scale mechanized production processes that increase the effectiveness of the market demands worldwide. However, Canning technology is still more labor-intensive in many developing countries, as illustrated by Thailand, the Philippines, Brazil, Morocco, and others. Nevertheless, canning industries in these regions are very important because they offer employment to many people. In countries where labor is an important factor in the canning process, the industry also supports the economy, guaranteeing thousands of employees who work in this field.

The canning industry operates in two ways in different countries: mechanized and labor-intensive industries. This makes the canning sector confront safety and quality requirements while carrying out its activities. These difficulties are further compounded by the possible impacts on health due to canned fish. Occasionally, poisoning outbreaks due to the consumption of canned fish poisoned by things such as arsenic are very rare, though their impact is always severe. For instance, in 1982, Belgium experienced an outbreak of botulism where a consumer was killed after consuming foodstuffs from a can of salmon. This led to an exhaustive examination of the production of Alaskan canned salmon in the years 1980 and 1981. It was established to affect most of the contaminated products, and the recall of over 50 million cans in different parts of the globe, as a result of the study, demonstrated the result of food safety blunders. Its consequences reach not only the direct participants but can also lead to substantial business losses and cause a loss of consumers' confidence in the whole industry. The canning industry does, therefore, exist between a rock and a hard place in having to ensure the safety and quality of the foods it produces while at the same time positioning itself to take on the risks presented by large-scale food production. Due to the large size and continuous growth of the industry, issues of food hygiene must be well addressed. Negligence in these standards may result in health dangers to the public and detrimental impacts on the image of the concerned firm and, in general, the total industry. This makes the canning industry especially vulnerable to any safety or quality assurance issue.

In the canning industry, food safety can be attained by adopting the principles of hazard analysis and critical control points (HACCP). HACCP, as a procedure separate from GMP, is a science-based contractual approach to food safety, focusing on food hazard analysis and controlling those hazards. According to HACCP guidelines, producers that handle the fish requiring the canning process can be assured that these products meet very high safety standards. Therefore, HACCP principles concentrate on possible points of contamination from handling raw materials to issuing the final product. For instance, in production, fish must be checked thoroughly to avoid contamination by bacteria, pathogens, or any sharp object. For example, critical control points such as the temperature at which the fish is processed or how the cans are sealed are effectively monitored to prevent the product from becoming a health hazard. As for the legal and safety aspects, applying HACCP in the fish canning industry meets risks intentionally and systematically at a challenge. Due to the rising demand for canned fish, the industry faces new challenges, like changes in consumer preference, food safety and quality standards, and new foodborne pathogens. It also implies the maintenance of using HACCP and the introduction of new approaches for improving the safety of canned fish products. The fish canning industry is vulnerable to many challenges in food safety and quality. Although the method of heat treatment of fish and meat has developed into a scientific approach, the sore point remains the danger of contamination. However, the risks associated with this business can be managed using HACCP principles that provide a systematic way of managing these risks, making canned fish safe for human consumption. Consequently, further development in the industry, with the perpetual invention and the emphasis on safe production processes, will remain critical for gaining consumer confidence and the public's health.

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2. The canning process, safety and spoilage

HACCP principles were implemented in the fish canning sector around 30 years ago when few other food sectors embraced the system. This event was significant because the HACCP is the cheapest, most comprehensive, and most effective approach to safe and quality canned fish products (Williams et al. 2020). The reasons that prompted the adoption of HACCP mainly stem from the growing necessity for a scientific approach to food protection, the demands from the market, and several scandals that threatened the canned fish industry. However, as this paper seeks to discuss the reasons for this transition in more detail, there exists a need to clarify some facts and misconceptions regarding food preservation by heat. Another common myth is that heat in processing disinfects and gives the canned food product an infinite shelf life (Gavin & Weddig 1995). Though the heat treatment is felt to be very important, it still cannot guarantee that canned fish is free from viable microorganisms.

Figure 1: Food Spoilage

In properly canned products, one can get workable microorganisms under certain circumstances. This is a very important indication since using end-product sampling or analysis as the only basis to validate a canning lot's safety is ineffective. It is sometimes impossible to observe the presence of microorganisms or the possibility of spoilage through sampling, so this technique gives very little guarantee that the final product is safe to consume or stable.From this realization, it is now possible to discover that there is more to food safety and quality assurance than just testing foods ready for consumption. The program must have a detailed plan covering each stage of putting up and processing food to be canned to be safe and wholesome. This approach must systematically integrate several key factors:

The Quality of Raw Material: Everyman determined that the quality of raw fish used is indeed the most important determinant of the safety of the final product. When fish starts as contaminated or spoilt as raw material, this implies that even the best canning process will yield bad products. Suppliers of necessary inputs must be credible, and among the crucial elements of the plans, a thorough check of the materials purchased must be conducted. This involves inspecting the lot for evidence of contamination, spoilage, and nonconformity to standards before they get to the canning factory. Raw fish handling, storage, and transportation should eliminate contamination chances of raw fish by maintaining the right temperature and avoiding cross-contamination control.

Hygiene and Sanitation: Sanitary measures and cleanliness go hand in hand in canning since most foods undergo processing that makes them acidic. There is always a high potential for microbial contamination throughout the production process, especially during the preparation phase, as fish is cleaned, gutted, and prepared for processing. Thus, parts of the production facility must be kept clean to avoid contamination, and the appropriate handling of equipment, tools, and personnel is required. This entails washing the equipment within the farms, proper conduct by the workers on the ways, and using sanitizers on the external parts of the fish. Ventilation, air conditioning, and relative humidity control also control the surrounding environment.

Proper Thermal Processing: The application of heat on the canned materials within the sealed cans is normally considered the key step of the canning process regarding the safety of the foods. This heat treatment is intended to eliminate pathogenic microorganisms and avoid decomposing food products. However, the overall scanning process must be controlled, optimized, and checked to make thermal processing successful (Datta, 1992). The parameters of time and temperature during the heat treatment are critical. Should one of them be lacking, it could be the eradication of harmfully hazardous bacteria, thus posing a high likelihood of having increased cases of food-borne diseases. It is very important to regulate both temperatures and time since overheating can negatively affect food's nutritional quality or taste.

Thermal processing involves pressure cookers, retorts, and autoclaves, highly controlled equipment requiring some attention. Temperature sensors and pressure gauges should be accurate, and the process must have a pass and new check to verify that it complies with safety measures frequently. In thermal processing, parameters such as the type of fish, size of the can, shape of the can, and other probable factors influencing heat penetration and heat transfer should also be considered. This is as important as controlling the initial temperature during the heat treatment. Indeed, the material's cooling rate after heat treatment is also an essential factor. To be safe from bacterial or microbial growth, the canned fish must be cooled immediately after the process is complete. Such types of cooling also have the disadvantage of causing the formation of specific spoilage organisms, which decrease the shelf life of the product.

Proper Can Seaming: Another important issue in fish canning is proper can seaming. The seam must also be airtight. In no way can microorganisms enter the can, and the process is in no way splashing any liquid on the can. The seaming machine requires programming and adjustment to enable it to run smoothly. Any defects along the edge of the can, such as the formation of crack lines, poor sealing, or alignment of the two ends of the seam, indicate an increased risk of the can fish being unsafe for use. Seamed cans must be checked for visible defects before processing, and any exhibiting defects should be condemned. They also pointed out the need to conduct quality control checks to ensure the seaming process is checked and the right quality results, as well as the whole product, are achieved. All these critical control points mentioned above still do not completely eliminate spoilage, even with the blame control measures in place. Canned fish are also perishable and can become spoilt if the canning process is not correctly processed or if the cans are not well stored or handled after processing.

2.1Classification of spoilage in canned fish

Most spoiling in canned fish may result from underprocessing, contamination during handling, and inadequate storage conditions. Underprocessing happens wherever the thermal treatment is insufficient to kill all dangerous microorganisms present. This is due to the dangers of spoilage bacteria or botulism, like Clostridium botulinum, which is likely to develop wherever there is low oxygen. It is also possible to find contamination when preparing food by not adhering to the right hygiene rules during the preparation processes. Microorganisms can penetrate the cans if they are not closed correctly or if the container touches a contaminated surface and spoils the food. Storing foods under the wrong conditions, like high temperatures or humidity, also threatens food spoilage.

Indicators of Spoiled Canned Fish

These steps or signs can be used to determine when canned fish are spoilt. The symptoms include cell swelling, which clearly indicates that there are microorganisms inside the cans that produce gas. Other symptoms of spoilage may include objectionable smells or textures and soft or slippery texture. All these indicators should be accorded the seriousness deserved, and any product displaying such signs should be promptly dumped to avoid concentrations of bacteria that may lead to food-borne diseases. Applying the HACCP concept and high standards of control throughout the canning process will help the fish canning industry minimize the possibilities of spoilage and contamination and provide the consumer with a product of very high quality and long shelf life.

Food safety considerations

Canning involves using an airtight container, often called occult, or a closure that makes the container airtight, as well as a heat treatment process that would effectively destroy microorganisms likely to grow under ordinary storage conditions. The outer cover or canning process guarantees the canned food alien particles, and the heat treatment kills all pathogens, making the food commercially sterile (Smelt & Mossel 1982, Larousse 1991). This process is crucial in canned fish to help eliminate pathogens, allowing the canned fish to go for rather long times on the shelf without refrigeration. The United States Food and Drug Administration, in Regulation 21CFR Part 113.3 (e), defines commercial sterility to entail the application of heat and control of the water activity (aw) as a means of destroying microorganisms that are capable of reproduction at a temperature that is characteristic of the storage and distribution temperature. However, 'commercial sterility' needs to be separated from 'absolute sterility'. The latter means that no microorganisms can grow in the food. In contrast, commercially sterile food may contain microorganisms capable of germination but cannot simultaneously multiply under normal storage conditions (Ababouch, 1999). Such organisms may be obligate thermophilic spore-forming bacteria, which are heat-resistant organisms but grow better at Higher storage temperatures (> 40ºC), and acid-tolerant organisms, which survive in low pH (< 4.6).

Three such constraints include the pH, temperature (T), and water activity (aw), all of which determine the thermal processing of canned fish. All these factors have a cumulative influence directly on the extent of the thermal processing required to achieve commercial sterility and stability of the product during shelf life. Specifically:

pH: Fish acidity is an indicator of the efficiency of heat processing, resulting in microorganisms being inactivated. Low-acid products (pH > 4.6) are more difficult to process thermally than high-acid products because of the increased risk of botulinum.

Temperature: The kind and degree of heat treatment required should be adequate to kill other undesirable organisms that have different heat resistance. This is an essential parameter in raw milk fermentation and retains its relation to the character of microorganisms and other processing factors.

Water Activity (aw): Water activity is the condition that represents the amount of water in a food that is available for microbial growth. Reducing water activity through drying or adding salt, plus heat processing of the canned fish product, can also kill microorganisms.

These three parameters, combined with the right thermal treatments, allow the destruction of pathogenic microorganisms and stabilize the product shelf. Further, they enhance the efficiency of a process that counteracts microbial growth after canning. For instance, microorganisms that are heat resistant may be present in the canned product, but they will be inhibited from growing by the low Aw or nondesirable pH of the canning medium. However, it is important to ensure these conditions are controlled throughout the canning process lest the food goes bad or leads to food poisoning. Thus, proper canning of fish Vorlage inhabits at a commercial sterility level with the help of applied heat treatment, pH level, and water activity. Observance of these parameters helps to provide for the quality and shelf stability of the product and eliminate the possibilities of product contamination and spoilage (Nyati, 2018).

Table 1: Probability of finding at least one non-sterile container in a sample of size N

% of non-sterile containers in lot	Number of units in random sample						
	10	20	50	100	500	1000	10,000
0.001	0.000100	0.000200	0.000500	0.001000	0.004988	0.009885	0.095164
0.002	0.000200	0.000400	0.001000	0.001998	0.009950	0.019802	0.181271
0.005	0.000500	0.001000	0.002497	0.004988	0.024691	0.048772	0.393477
0.01	0.001000	0.001998	0.004988	0.009951	0.048773	0.095167	0.632139
0.02	0.001998	0.003992	0.009951	0.019803	0.095172	0.181286	0.864692
0.05	0.004989	0.009953	0.024696	0.048782	0.221248	0.393545	0.993270
0.1	0.009955	0.019811	0.048794	0.095208	0.393621	0.632305	0.999955
0.2	0.018921	0.039249	0.095253	0.181433	0.632489	0.864935	1.000000
0.5	0.048890	0.095390	0.221687	0.394230	0.918428	0.993346	1.000000
1.0	0.095618	0.182093	0.394994	0.633968	0.993430	0.999957	1.000000
2.0	0.182927	0.332392	0.635830	0.867380	0.999959	1.000000	1.000000
5.0	0.401263	0.641514	0.923055	0.994079	1.000000	1.000000	1.000000
10.0	0.651322	0.878423	0.994846	0.999973	1.000000	1.000000	1.000000

2.2 Spoilage Considerations

The fish canning industry must set a maximum acceptable level of pathogenic bacteria. Still, also spoilage bacterial spores as their survival can be detrimental to the stability of the enterprise. A 5D process is generally considered adequate to sterilize mesophilic non-pathogenic spores, the most heat-resisting of which is Clostridium sporogenes PA 3679. That is why the term "5D" stands for a 10^5 multiple reductions in spore population, guaranteeing their elimination during processing. Canned seafood products are processed slightly above the minimum botulinum cook in practice because thermophilic spore formers are more resistant to heat than mesophilic spores. The probability of survival of non-pathogenic thermophilic spores is estimated to be between 10^{-2} to 10^{-3} per container, suggesting a 2D to 3D process. This high rate of spoilage attributed to thermophilic spores is still tolerable as these spores are nonpathogenic. Furthermore, the survivors are also protected from germination at normal storage temperatures (less than 35ºC), reducing the spoiling potential.

Thermal processing technology applied by the fish canning industry may comprise short heat treatment, ranging from $F_0 = 5$ to 20 min, depending on the fish type and canning technology. F_0 is the sterilization process equivalent time – the number of minutes at 121.1ºC a food container has been exposed to and is calculated by taking Z = 10ºC. The Z value is the degree of heat needed to decrease the D-value by a decimal 10 in the microorganisms' inactivation. In this way, through the variation of F_0 time, the process guarantees the microbial inactivation without influencing the end product's acceptability, texture, color, and nutritional quality. Results with F_0 values between 5 and 20 min help to achieve both microbicidal and shelf-stable effects in canned fish products with desirable quality characteristics retained. The major aim of the thermal process is to inactivate pathogenic microorganisms and spoilage bacteria so as to make the final product safe to consume for its shelf life. But it is equally important here to achieve the right balance between sterilisation and the ability to maintain the necessary quality of canned fish in order to meet both the quality requirements and acceptability by consumers.

3. The regulatory context

Markets for canned fish recognized food safety risks with the product's use, especially after the severe botulism incidents related to canned products that occurred in the 1960s & shut down procedures within the cannery industry. Traditionally, end-product sampling and analysis were regarded as the ineffaceable means for canned fish safety (Das et al. 2022). The eventual outbreaks made people understand that more than just post-production measures in testing are needed to protect consumers. In response, the food control authorities and the canning industry enforced additional safety procedures in the 1970s from the principles of the Code of Practice for GMP and HACCP.

Introduction of GMP and HACCP in the Canning Industry

The canning industry began introducing safety and quality in the early 1970s when the demand for food safety standards was heightened. The implementation of these new strategies came from the principles of the Code of Practice for GMP together with HACCP (Nyati, 2018). What remained not very safe was now addressed by these regulations to incorporate the element of safety regardless of the stages in the manufacturing cycle, right from procurement of raw fish through canning and packaging to the distribution of canned products.

Key aspects of the regulations required:

Certified Canneries: Canned fish and all other canned foods and beverages had to meet certain standards and be processed in a facility that met certain requirements. Certification depended on specific standards of the plant's layout and design and hygiene and sanitation standards applicable to personnel and employees. This certification system reduced the number of dangerous installations, as only those properly equipped, certified, and maintained were allowed to run.

HACCP-based In-Plant Quality Control Programs: It demanded that the canning industry take and establish HACCP-rooted quality control programs in every plant. These systems would alarm possible risks within the production process and specify key control points to reduce these risks.

Food Control Authority Oversight: A number of provincial and local food control authorities regulate the certification of canneries, the approval of HACCP plans, and the ongoing verification of HACCP implementation to ensure compliance with the international standard of food safety.

FDA Regulations and the Better Process Control (BPC) Plan:

The most significant event that led to the standardization of these safety practices was the U.S. Food and Drug Administration's FDA intervention (FDA, 1997). The BPC, owned by the FDA regulations, was based on the National Canners Association's FDA Better Process Control Plan and was developed into a GMP regulation in 1971. It was designed to regulate the processing of safe canned food, especially low-acidity foods such as canned fish, which are most susceptible to botulism. These regulations are 21 CFR Part 108 – Emergency Permit Control and 21 CFR Part 113 – Thermally Processed Low-Acid Foods; the regulations went into force in January 1973. The key premise of the BPC plan was to address the burden of food safety on food industry workers. It compelled the operators to maintain and regulate such essential parameters of heat treatment and packaging so that one remembers to take prerequisite actions to avoid polluting or spoiling food. For acidified foods, the FDA developed a specific GMP regulation (Part 114), issued in 1979, to cover the new hazards connected with changing the acidity of low-acid foods to decrease heat treatment requirements.

Key Features of the FDA's BPC Plan:

Thermal Processing: The BPC Plan focused on the thermal processing of canned fish, which required controlling temperature to remove pathogens like Clostridium botulinum. Operators had to follow a standard processing timetable to increase temperatures enough for the canned fish to kill pathogenic microorganisms.

Recordkeeping and Monitoring: The BPC plan also emphasized adequate documentation of processing time and temperature or any other key parameters. Such records would have been useful when it came to inspection, compliance, or audit exercises.

Employee Training and Accountability: The plan also maintained that employees required constant sensitization to adhere to workplace safety measures. Even the lower-ranking production workers and managers were responsible for ensuring that only safe production procedures were used in the workplace.

International Support and Codex Alimentarius Guidelines:

This process's Domestic stakeholders also included the energetic participation of international organizations like the FAO/WHO Codex Alimentarius Commission (CAC), which reciprocally synchronized their food safety regulations with the FDA and other authorities (FAO, 1997; FAO, 2000). Codex guidelines were instrumental in harmonizing food safety in the different countries regarding canned fish products' quality so that trade could check for standards and ensure that the quality of the products being traded was consistent. This paper finds that the canned fish industry has advanced from responding to food safety issues to developing new strategies for ensuring food safety. Implementing HACCP and GMP, accompanied by other strong surveillance by food control authorities, has significantly controlled foodborne hazards and enhanced the safety and quality of canned fish products. Looking at the history of these regulations, it is evident that everyone in the value chain has been working hard to achieve a more secure and reliable food supply system.

4. Hazards in Fish Canning

Canned fish o have a very good safety record. However, some biological hazards require a good HACCP plan to prevent them from happening. Biological risks of fish canning are botulism, histamine poisoning, and staphylococcus enterotoxin poisoning (Ababouch, 1995; Huss, 1994). Listeria monocytogenes is the second most dangerous pathogen, which could cause botulism due to toxicity produced by Clostridium botulinum in canned fish. Histamine food poisoning results from mishandled or spoiled fish before canning, especially tuna, mackerel, and sardines; due to microbial action, histidine is converted to histamine, a potent vasodilator (Ababouch, 1991). It shouldn't be ingested because it could lead to a food-borne disease famously known as scombroid poisoning.

Staphylococcus enterotoxin poisoning is another risk, which may result when fish carrying Staphylococcus aureus bacteria are processed, and the toxins produced by these bacteria can cause vomiting and diarrhea in human consumers (ICMSF,1981).. Besides biological risks, risks of chemical nature, while not exceedingly high in the fish canning industry, do exist. Some fish absorb heavy metals like mercury, lead, and cadmium in the pollution of water bodies where the fish are found. Nevertheless, these contaminants are mostly regulated by monitoring programs conducted by food control authorities. These programs protect against levels of heavy metals in fish that exceed the acceptable limits. Chemical contamination assessment in the aquatic environment and the safety of canned fish products can only be supported by legislation and national monitoring programs. These hazards, their causative agents, and ecological factors are described in detail in several encyclopedic works (Huss, 1994; FDA, 2001; Jouve, 1996). Knowledge of this kind is crucial in order to apply effective HACCP principles in the fish canning industry, which will increase the safety and quality of the products being produced.

4.1 Histamine poisoning

Histamine poisoning, also called scombrotoxin poisoning, is a chemical food-borne illness that occurs a few hours after consuming fish containing high histamine levels (Taylor, 1986). This condition's signs may manifest after taking between several minutes to several hours. Scombrotoxin results from the fish histamine accumulation, which occurs when the histidine amino acid of the fish muscle is converted to histamine acid following a decarboxylation process. This decarboxylation reaction is an enzyme known as histidine decarboxylase, which is synthesized by some bacteria, including species of Enterobacteriaceae, Clostridium, Vibrio, Photobacterium, and Lactobacillus. However, it is highly significant that strains of bacteria can produce histidine decarboxylase more often, and they are most likely to be found in fish that are not properly processed or stored.

Tuna, mackerel, sardines, and other (especially scombroid) fishes are most vulnerable since all muscles contain high free histidine. This histidine forms a substrate complex with the histidine decarboxylase enzyme of bacteria. Moreover, any proteolytic process, autolytic or bacterial, is likely to raise the concentration of histidine to a higher level and thus increase the prospect of histamine formation (Nikoo et al. 2022). This is especially so in canned fish because poor processing methods or lack of proper cold storage before canning offers the right environment where bacteria thrive to produce histamine. However, it is quite clear now that histamine poisoning results from the consumption of spoiled fish. In contrast, pure histamine, ingested in doses that match those found in spoiled fish, was not shown to cause disease in controlled challenge studies conducted on human volunteers. This raises the chances that other causes—often linked to the presence of different toxins, the affinity of histamine to other compounds in spoiled fish, or the body's reaction to fish spoilage—are indeed a factor in toxicity. However, the biggest issue is avoiding bacteria growth and histamine formation during the canning process. These include heat treatment, proper handling, and sanitation in the canning processes.

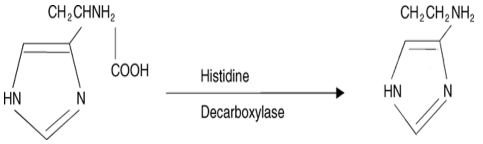

Figure 2: Formation of histamine.

Prevention and Control Measures for Histamine Poisoning:

Temperature Control: The best way to avoid the formation of histamine is to properly cool the fish immediately after harvest. Fish spoilage should also be controlled by storing the fish at a temperature not exceeding 4°C as early as possible to check bacterial growth and histamine formation.

Hygiene and Sanitation: The manufacturing plants must ensure that GMPs are followed and sanitation procedures are followed to prevent bacterial contamination. This comprises washing and disinfecting all utensils and structures that come into contact with fish and fish products.

Proper Canning Procedures: Such lethal processes should be able to cook the fish thoroughly to an extent where bacteria-producing histamine are neutralized. Cans should be tightly closed to avoid reaction with the surrounding environment.

Quality Control: Monitoring and checking histamine levels in fish before, during, or after processing can help identify any problem. Groups of up to 550 µg/g histamine-positive fish should be discarded.

Training and Education: Canning operators should learn about the dangers of histamine formation and how to process and preserve fish to minimize histamine formation. Such precautions greatly reduce the chances of histamine poisoning, which makes canned fish products palatable.

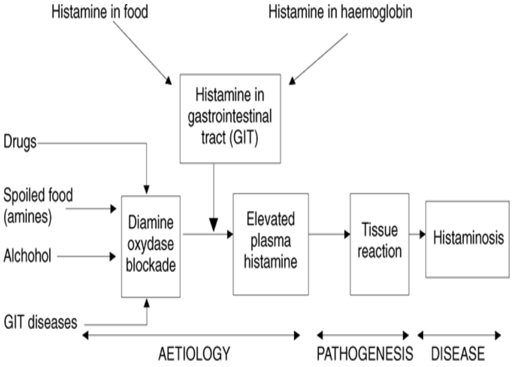

Figure 3:The disease concept of food-induced histaminosis.

4.2 Botulism

Neuroparalytic botulism is an often fatal illness that results from the ingestion of foods containing neurotoxins originating from toxigenic strains of Clostridium botulinum. 'Botulism involving fish was first reported in the Russian literature in 1818 and then in USA the disease was reported in 1899.' Type E botulism, particularly related to fish products, has been a recognized problem for quite some time. Before 1980, all other examples of type E botulism, with only three exceptions, were associated with fish and marine or freshwater mammals (Huss, 1981). However, fish can also contain other forms of botulinum toxin. In their survey, Huss (1981) found that type E botulism contributed between 20–70% of the marine food product-associated cases, while type A and type B in 21–44% and 9–80%, respectively. Although canned fish are not a common cause of botulism, they are still a worthy cause for concern. Of the 165 occurrences reported in the USA, Canada, Japan, USSR, and Scandinavia, only 5 (3%) were associated with canned fish (Huss, 1981). Two major forms of botulism in canned seafood have been attributed to underprocessing and post-process contamination (Stumbo, 1973;Pflug, 1980).

Underprocessing is a situation where sterilization is not properly done, which may result from the wrong design of the sterilization process or malfunctioning of sterilization equipment. Underprocessing can be avoided only when all factors that determine sterilization are clearly defined and strictly controlled. Most countries also allow only licensed seafood-canning firms to operate, and each firm has to notify the relevant authorities of its planned process (Bryan,1986). They include container dimensions, the intended value of F0, the process time and temperature, the product characteristics, and the sterilization methods suggested by Warne (1988). Process contamination, although uncommon, occurs when cool cans or infected cooling water results in toxin formation. Although this risk is small (3.8 × 10^−12), it cannot be eliminated and has to be maintained at a minimum. Seem integrity should be checked, cooling water treated, and cans sterilized and handled carefully to avoid such contamination. Therefore, controlling these factors may help to reduce the incidence of botulism in cannedfish.

4.3 Other hazards

Other common dangers associated with canned fish that are quite uncommon are microbial risks, food poisoning, and chemical poisoning. One of the food-borne diseases is staphylococcus enterotoxin poisoning (SEP), which may result from the consumption of canned fish. Most shockingly, cases of SEP in fish canning sectors were identified in France in the early 1960s, which led to the investigation of thermal treatments used in that industry. Analysis of the data obtained from the work of Thuillot et al. (1964, 1968) regarding thermal inactivation of Staphylococcus aureus proposed that the examined cocci failed to survive standard commercial heat treatments. However, these organisms were identified as entering post-process. Additional studies found that under-sorting may be the sole reason for low SEP, with fish being protected by the oil in which they were packed (Ababouch, 1992). Measuring against post-process contamination from other pathogens, such as S. aureus, is similar to safety measures previously outlined for botulism contamination.

Another umbrella threat associated with canned fish is chemical pollution. Many toxins can position themselves in fish parts through biomagnification and bioaccumulation, especially on predator fish. While biomagnification depicts the content in the food chain stacking up with the degrees in the food chain, bioaccumulation focuses on the buildup of chemicals in a specific organism's body, obviously accumulating over time. In particular, toxic compound levels are higher in older fish than in young, similar species (Huss, 1994). One of the most typical examples of the immediate adverse effects of this pollutant was the methyl mercury poisoning in Minamata, Japan, in 1953, affecting human health by causing illnesses as well as death and neurological disorders (Sainclivier, 1983). It, therefore, prompted attention to the levels of mercury within the sea and its surrounding organisms. According to different investigations, mercury content in the sea has not changed much from the natural amount. The permissible weekly rate of mercury intake with the recommendation of FAO/WHO is 0.2 milligrams per non-disabled man. The magnitude of mercury tolerance and durability limit in fish varies from 0.5 / 1 ppm (part per million, which totalizes mg/kg) (Sainclivier 1983, EEC 1991 & EEC, 1994). Other chemical risks are lead and tin, which may be present in canned fish. Lead can be in cans sealed through lateral soldering and may dissolve under conditions of high acidity. Tin is less dangerous, but it can pollute food through the deterioration of the tin can with modern canning processes, for example, canning tins, which are free of tin (Huss, 1988; Warne, 1988; Larousse, 1991).

5. Spoilage of Canned Fish

Paska indicates that spoilage of canned fish is pointed out by some features like leakage, swelling of the can, or unusual smell and texture of the fish. However, in some instances, the pathogenic microorganisms that cause food-borne disease may not show any sign of spoilage. There are four primary causes of spoilage in canned fish:

- Pre-spoilage or incipient spoilage before thermal processing.
- Underprocessing or under-sterilization.
- Thermophilic spoilage.
- Post-process contamination.

5.1 Pre-Spoilage

Incipient spoilage, also referred to as pre-spoilage, happens before thermal processing of the food product. It could be due to microbial or enzymatic action, which causes the production of gases, unpleasant smells, and high levels of dead cells in the finished product. A few pathogens, S. aureus and histamine-producing bacteria can synthesize thermostable toxins during pre-spoilage that can remain intact after the thermal processing and thus lead to foodborne illnesses. Fish at the processing plant contains 10^7 microbes per gram and may increase. The types of microorganisms present on or growing within raw fish used in canning include those from the fish's aquatic environment, the fish's food source, and the soil where vegetable adjuncts (such as spices and sugar) are grown. Contact surfaces can obtain more dirt exposure during the harvesting, transportation, washing, and handling processes. Washing fish can cause a reduction in microbial number in fish by up to 90%, and hence, it is important that the water used in washing fish is of a good microbial level. Washing water should be treated with chlorine (1-4 ppm) because it can help to decrease bacterial count. Fish handling activity like beheading and evisceration, opens up the fish body, which is a good target for microbial growth, and spoilage is more so if there is a delay in processing and if temperature encourages bacterial growth. During the thermal cooking of fish, vegetative bacteria and spores of Clostridium botulinum type E, yeasts, and molds are destroyed. However, spores of C. botulinum types A and B and thermophilic spore formers are heat resistant and can remain alive despite cooking. This is why meticulous cleanliness and prompt treatment to avoid contamination with such bacteria as S. aureus, which may form thermostable exotoxins, are critically significant.

5.2 Underprocessing

Underprocessing means that heat treatment has not been enough, and commercial sterilization has not been reached on the product. This element is usually present when bacterial spores remain alive since they are more heat resistant than vegetative bacteria, yeasts, and mold, which are generally destroyed during processing. The failure to adequately process the destruction of these spores could lead to germination and multiplication of the spores, leading to spoilage and or food-borne illness. The main reasons involving under-processing relate to time-temperature control deviation during the canning process, while the measures against under-processing involve temperature control and adequate retort, among others.

5.3 Thermophilic Spoilage

Thermophilic spoilage is observed if the time-temperature relationships within the scope of canning promote the growth of the thermophilic bacteria (Owusu-Apenten & Vieira 2022). While these bacteria are not pathogenic, they are spoilage bacteria owing to their tolerance to warm conditions. Soil and sediments are natural habitats of thermophiles, and spores of thermophiles can be found in food commodities. It has been noted that using food with ingredients such as starch, sugars, or spices enhances the germ count of thermophilic spores in the food. The development of thermophilic spoilage is favored where the cooling of the retorted containers is done slowly or where the final product is cooled to storage temperatures above 40 °C. This is due to a lack of sufficient cooling, which permits the temperature of cans to lie in the thermophilic range of 40°C to 75°C for a long time. However, this is no longer the case since new retorts used in the processing can cool cans rapidly. Some precautions taken to minimize thermophilic spoilage are adequate air cooling of the cans immediately after retorting to reduce their temperature to below 40°C as a matter of principle. Another way to store finished products is by storing them below 35°C, which prevents the growth of thermophilic bacteria that are lethal to the products. Moreover, washing raw materials, screening out sediments, and avoiding contamination of materials during preparation are particularly vital in mitigation. Particular attention should be devoted to ingredients such as starch and sugar because they contain thermophilic spores if improperly controlled (Gill, 2018).

5.4 Post-process contamination.

Post-process contamination, called leaker spoilage, is when microorganisms penetrate the can system after heat sterilization and sealing. This form of spoilage is economically important, contributing to 60 – 80% of canned products' spoilage. Leaker spoilage is due to microorganisms comprising bacteria, yeasts, mold, and aerobic spore formers originating from the can handling equipment, cooling water, or handlers. Leaker spoilage is directly connected with the condition of can seams. Cracks or improper can handling, such as mishandling or dropping the can, can allow some contaminants into the can through the seams. Another source is the cooling water, which is likely to cause microbial pollution due to improper chlorination. Defective tin plates or manufacturing errors in the canning practices themselves may cause the can's integrity to be violated and spoil the product. Some typical manufacturing problems are seam defects, undesired flanging, seam setting. Any normal abuse of the cans, such as dropping them, allowing them to roll over, or hitting other cans, also negatively affects the seam. In addition, the retorting process can lead to deformation if checked inadequately or not at all. For example, if cans expand significantly during processing and are not cooled properly, permanent seam distortion may occur, leading to leakage.

- Measures to control post-process contamination include:
- Close monitoring of the quality of the seams of the cans.
- Proper handling of the cans during the processing periods.
- Ensuring the water used to cool the cans is chlorinated (2–5 ppm).

The cans must otherwise be dried where access by other people or animals is limited to avoid contamination before being touched. Checking the seals and utensils used in canning and welding and properly maintaining these pieces of equipment is crucial to avoid leaker spoilage.

5.5 Other Causes of Spoilage

Non-microbial spoilage of canned fish products is also possible, including the following reasons: The first of these concerns is internal can corrosion; this not only creates a hydrogen gas but also makes the can swell (Evancho et al. 2009). Not only is the product completely unsellable by defining such characteristics, but it also points to a failure of the vacuum seal, which is a major concern for the product’s safety and quality. There is external corrosion, where small holes are created in the metal, allowing microorganisms to access the can and contaminate its contents. This has resulted in color spoilage – its non-microbial counterpart, for instance, in canned food salads containing fish and vegetables. Metals, including copper or iron, are used before the canning process, and the chemical interaction between the food and the can also leads to a change of unpleasant color. For instance, the interaction between sulfur-containing compounds in food with iron when blanching or cooking yields black iron sulfide, which is responsible for discoloration in commodities such as corn, peas, and fish meat. To avoid these color defects, processors utilize enamel-lined cans, where the problem does not exist, as enameled lining serves as a barrier to keep food from coming into contact with the metal can. Canned fish spoilage can result from microbial spoilage, under-processing, thermophilic bacteria, post-process contamination, and other causes that do not include bacteria. The following measures should be followed to reduce the chances of spoilage of canned fish products and make them safe for human consumption:

- Good manufacturing practices
- Stringer hygiene
- Proper temperature control.

6. The application of GMP in the fish canning industry

The use of good manufacturing quality practices

(GMP) in the fish canning industry is desirable and serves as a guideline for the production of quality fish that is safe for human consumption. Most countries have implemented GMP regulations that set down standards in aspects relating to the layout and construction of plants, equipment, staff cleanliness, and cleanliness of food-contact surfaces. The Common Features regulations applied below intend to mitigate such risks and guarantee the safety and quality of canned fish products. The regulations are contained in the Codex Alimentarius, a collection of global standards and codes of food practices. More specifically, the second edition of the Codex Alimentarius Code of Practice General Principles of Food Hygiene CAC/RCP 1-1969, Rev.3 (1997) serves as the mores document for the observation of GMP in food processing operations in the fish canning industry. The Codex also provides a guide to the recommendations for the best practices that most countries seek to follow to harmonize their food safety laws with international standards.

The Codex Alimentarius Commission's Codex Committee on Fish and Fishery Products (CCFFP) only elaborates on these GMP concepts for the fish industry. This adaptation process is done through a draft Code of Practice in the adoption procedure (Step 3) and seeks to provide direction on the GMPs that would be acceptable for the fish and fishery product sector. This draft Code of Practice details how to apply Hazard Analysis and Critical Control Points (HACCP). It gives directions on avoiding safety issues and quality issues likely to occur during fish processing. Regarding the quality of the final product, the document stresses the need to monitor the whole chain process right from the point where the raw materials are handled to the point where the final product is shipped out for use. Several critical GMP aspects underlined in the Code of Practice are especially significant to the fish canning industry. These include proper design and management of the facilities to reduce contamination, appropriate equipment to minimize chances of microbial contamination, the correct tools and equipment to handle fish, and adequate fish handling procedures.

GMP provides strict measures on personal cleanliness, protective clothing, equipment washing, and limitation of contact with the afflicted in production zones. Another important factor, which should also not be overlooked, is training because, during employees' work, they must know about hygiene measures, safety when handling food products, and necessary measures in case of emergencies that may occur during product processing. Another component of the GMP in the fish canning industry is the Sanita standards that should be adopted properly. This includes such basic aspects as cleaning and disinfecting equipment, facilities, and the plant environment. Sanitation prevents contamination and cross-contamination from raw fish to cooked fish products or different products with fish from other products. Further, adequate preservation methods and management of other inputs, especially the fish, must be followed before canning the product, meeting necessary conditions free from spoilt products or contamination. Besides the minimum requirement on safety measures, GMP also guarantees the quality of products. Consequently, when applied with close control of relevant factors, including temperature, time, and packaging, these standard operating procedures help the fish canning industry deliver the quality consumers expect. Additionally, before a product is actually withdrawn from circulation and a recall is made, successful implementation of GMP also eliminates such instances that could be costly to a company in terms of reputation. This is because compliance with GMP is not optional for fish canning companies (Hasnan et al. 2022). A mandatory requirement must be fulfilled if the organization wants to conduct its business within numerous national and international markets. To support the need for this research, the Codex Alimentarius and related national regulations form a sound groundwork for supporting the canning process and associated fish products, especially regarding safety and quality. At the same time, the work activity of the CCFFP goes on to exhibit control and influence in the constantly evolving industry.

7. The Application of HACCP in the Fish Canning Industry

The fish canning sector has used Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) principles since the early 1970s. In recent years, much experience has been accumulated in food safety & quality management in the industry & different generalized HACCP templates exist & are accessible in media & publications. However, to be effective, these models must be designed to provide client-specific canning handling and processing conditions for the canneries. The success of the customized HACCP plan implementation is a function of the level of understanding by company decision-makers, the capacity of the superiors in handling CCPs, and efficiency in monitoring and corrective action. All these factors define the possibility and efficiency of the HACCP program from the aspect of costs. This section presents a successful case of a safety and quality approach adopted in the fish canning industries in Morocco, which produces both sardines and mackerel, and Senegal, which produces tuna. The firms that applied this strategy have been able to export their products internationally and conform to the GMP standards of the EU and FDA. The staff of their enterprises received the HACCP and Basic Process Control (BPC) training in Morocco between 1994 and 1998, which would guarantee compliance with intergovernmental norms.

7.1 HACCP Team

In fish canning companies in Morocco and Senegal, the HACCP team comprises a QC manager, a production manager, a hygiene manager, and an external technical specialist where needed. Due to the extensive number of employees ranging from up to 600, many of them women, the hygiene manager is a woman. All the enactments of worker involvement are well stipulated in the HACCP plan. As a result, in addition to implementing measures to ensure hygiene and sanitation, the hygiene manager works under the supervision of the QC manager. If large movements or amounts are needed, the hygiene manager can talk to the company's GM and present opportunities and solutions without integrating safety. The technical advisor sometimes offers scientific and technical analysis as described. Team members are trained in the decisions and actions necessary to meet the specifications of the HACCP plan, hygiene, sanitation, laboratory methods, and retort and seaming control.

7.2 Description of the Products and Their Intended Use

The fish canning companies in Morocco and Senegal include a broad portfolio of canned fish products, including sardines, mackerel, and tuna. The varieties of this product segment range from 20-30, as stated in Table 7.3. These canned fish products are for human consumption and are best used as an appetizer or combined with other foods, including salads. They are usually taken with no further cooking required. It needs to be noted that the company exports a significant portion of its production to international markets, the two most significant consumers being Europe and the USA. All the products differ in component list and wrapping, but all the ones described above are created with the maximum possible carefulness and safety. For instance, sardines in cans come in a number of varieties, including those stored in vegetable oil, olive oil, and sauce tomato. Depending on the oil type, the shelf life of these products is three to five year at room temperature.

Table 2: Example of a description of canned fish products manufactured in Morocco

Product	Contents	Packing materials and format	Shelf life
1. Canned sardines in vegetable oil	Beheaded tail-off sardines: 75% soya oil: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	(1) Tin format 1/6 P 30 2 pieces, simple or easy open lid. (2) Aluminum alloy format 1/6 P 30 easy open lid. (3) ½ H 40. (4) 1/6 P 30 DAS R 26	5 years at ambient temperature
2. Canned sardines *au naturel*	Beheaded and tail-off sardines: 75% water: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 30 ES easy open lid. All cans are individually packed in paper holsters.	3 years at ambient temperature
3. Canned sardines in olive oil	Beheaded tail-off sardines: 75% Olive oil: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 30 2 pieces easy open lid. Some cans are individually packed in paper holsters.	5 years at ambient temperature
4. Skinless boneless canned sardines in olive oil	Skinless boneless sardines: 75% Olive oil: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 30 2 pieces easy open lid. (3) 1/6 P 22 2 pieces easy open lid. All cans are individually packed in paper holsters.	5 years at ambient temperature
5. Skinless boneless canned sardines *au naturel*	Skinless boneless sardines: 75% Water: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 30 2 pieces easy open lid. (3) 1/4 P 22, 2 pieces easy open lid. All cans are individually packed in paper holsters.	3 years at ambient temperature
6. Skinless boneless canned sardines in tomato sauce	Skinless boneless sardines: 75% Water + tomato paste: 22%; Soya oil: 2%; salt: 1% pH = 5.9-6.2. water activity a_w = 0.98	Tin (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 22 2 pieces easy open lid. All cans are individually packed in paper holsters.	3 years at ambient temperature
7. Mackerel fillets canned in soya oil	Mackerel filets: 75% soya oil: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin (1) format 1/6 P 30 2 pieces simple lid; (2) 1/6 P 30 2 pieces easy open lid. All cans are individually packed in paper holsters.	5 years at ambient temperature
8. Mackerel fillets canned *au naturel*	Mackerel filets: 75% Water: 24% salt: 1% pH = 6.2–6.5. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces easy open lid. All cans are individually packed in paper holsters.	3 years at ambient temperature
9. Mackerel fillets canned in tomato sauce	Mackerel filets: 75% Tomato paste: 22%; Soya oil: 2% salt: 1% pH = 5.8–6.1. water activity a_w = 0.98	Tin or aluminum alloy (1) format 1/6 P 30 2 pieces easy open lid. All cans are individually packed in paper holsters.	3 years at ambient temperature

7.4 Flow Diagrams

The work organization in these canneries, though different products, is generally similar in that the sets of organized activities are in a fixed sequence. This is illustrated in the flow diagram (Figure 4) and the layouts of the plant and personnel/work and product flow. The flow covers every process, from the raw fish intake through the processing and final sterilization and packing. Further, the details of sterilization technical parameters are also maintained in the GMP manual (Kumar, 2019). Table 2 displays thermal processing technical data for sterilization in a fish cannery in Morocco. Post slaughter, sterilization remains a way to eliminate dangers to canned fish products such as botulism, histamine poisoning, and other microbial dangers. The process of sterilization includes several types of retorts, such as Steriflow retorts utilizing overheated water, vertical steam retorts, which effectively destroys undesirable microorganisms and, at the same time, minimizes the negative influence on the quality of the products.

Figure 4: Example of a flow diagram for canning sardines or mackerel in Agadir, Morocco.

Table 3: Technical parameters of sterilization in a fish cannery in Morocco

Technical parameters of the Steriflow retorts	Thermal processing target values
Retort type	Steriflow using overheated water
Minimal F_0	7 to 14 minutes, generally > 10 minutes
Can format	¼ P22 (115 g), 1/6 P 25 (125 g); 1/6 P 30 (125 g); ½ P oval (375 g); ½ H 40 (365 g); ½ HL (425 g); ½ B (425 g).
Sterilization temperature	122.5ºC, with an overshooting at 123.5ºC. 23–
Heating duration	55 minutes at 122.5ºC
Minimal initial temperature	30ºC
Filling method	Manual fish packing and overfilling with liquid
Ratio solid/liquid	75% fish; 25% liquid (oil, water, tomato sauce)
Stacking of the cans in the retort basket	In bulk
Number of baskets per retort	4 Baskets
Sterilization system	Water is overheated to a pressure of 6 bars
Cooling method	The heating water is cooled through a heat exchanger and recycled to be used for cooling
Technical parameters of the vertical steam retorts	Thermal processing target values
Retort type	Vertical retorts using steam
Minimal F_0	7–14 minutes, generally > 10 minutes
Can format	1/6 P 30 DAS (125g); ½ HL (425g)
Sterilization temperature	115ºC.
Heating duration	55–85 minutes at 115ºC
Minimal initial temperature	30ºC
Filling method	Manual fish packing and overfilling with liquid
Ratio solid/liquid	75% fish; 25% liquid (oil, water, tomato sauce)
Stacking of the cans in the retort basket	In bulk
Number of baskets per retort	1 Basket
Sterilization system	Introduction of steam through the by-pass. Venting for at least 10 minutes at 105C. Close the by-pass. Open the regulating valve as temperature reaches 115ºC. This is start time.
Cooling method	Using cold water chlorinated at 2–5 ppm of active chlorine

7.5 Hazard Analysis

The HACCP plan is supposed to be developed after a thorough hazard analysis; therefore, in this study, the HACCP team examines all possible risks and the point at which they can enhance the product's safety. Contamination risks originate from raw fish and personnel, water and ice, equipment, and microbial resilience despite attempts at sterilizing equipment (EFSA, 2021). The team evaluates possible causes, seriousness, and probability for each of the hazards found. The methods in the analysis are based on scientific data, the experience of the organizing team, feedback from clients and regulator agencies, and the contribution of a technical adviser. Potential risks include contamination by the bacterium Clostridium botulinum, histamine formation, and heavy metals, including mercury. Table 4.4 gives details of the hazard analysis for canned fish production. Some of the most significant hazards include:

Botulism: This can happen through a lack of thermal processing or cross-contamination during final product cooling. Other causes include measures such as sterilization and chlorine treatment of cooling water.

Consuming contaminated raw fish or histamine-producing bacteria during fish preparation can cause histamine poisoning. Avoiding histamine formation includes appropriate fish icing refrigeration and histamine determination.

Heavy metal contamination: Large amounts of mercury were only found in a single canned fish company, but it is recommended that all such firms avoid processing fish sourced from areas that may contain high pollution levels.

Post-process contamination: is possible when container closures are separately manufactured, which might cause problems. Measures include effective training of the container closure supervisor and proper care and maintenance of seaming equipment.

Table 4: Hazard analysis applied to canned fish

Hazard	Severity	Risk	Preventative measure(s)
Botulism because of insufficient thermal processing or because of post-process contamination during cooling	+++++	+	• Proper sterilization • Proper training of personnel in charge of sterilization • Proper chlorinating of cooling water.
Histamine poisoning because of contaminated raw fish or histamine accumulation during preparation.	++	+++	• Training of purchase supervisor in proper freshness assessment • Proper icing and refrigeration • Control of histamine level at receiving when in doubt.
High levels of heavy metals in canned fish	++++	+	• Good knowledge of fishing zones • Ensure the purchase of fish caught only in pollution-free areas
Post-process contamination with pathogens or toxic materials because of bad container closure	++++	+	• Training of container closure supervisor • Maintenance of seaming equipment
Staphylococcal poisoning because of bad handling of wet and hot freshly sterilized cans	+++	+	• Air drying of wet cans • Storage of wet cans in restricted-access area
Spoiled canned fish because of spoiled (high TVN) raw fish or of spoilage during processing	+++*	+	• Refrigerated fish transportation • Trained staff on sensory evaluation • TVN analysis if in doubt • SSOP
Thermophilic spoilage because of slow cooling or long storage at $T > 40$ºC	++*	+	• Rapid cooling to reach $T < 40$ºC in less than 1 hour • Storage of finished products at $T < 40$ºC

+: Very low, ++: low, +++: average, ++++: high, +++++: very high.
*: The severity and risk here refer to economic impact of spoilage.

7.6 Record-Keeping

Documentation plays an important role in record keeping because it assists in passing information within the HACCP systems. The companies provide various forms for documenting the outcome of the monitoring practices and correctives associated with GMP, SSOP (Standard Sanitation Operating Procedures), and HACCP (De Oliveira et al. 2016). Such records assist in establishing all activities and their authenticity and checking the various team members' understanding of the current status of each corrective action. The forms, since they are drafted to provide the maximum clarity and economy of labor, are simple though adequate. This clearly defines the role of the individual performing a given action and defines or points out who needs to approve or be informed of the action's result. Of course, this might also be useful in demarcating a clear line of responsibility.

7.7 Verification Procedure

Verifying the HACCP plan is another process, realized by checking whether the system is effective and updated. First, the verification was conducted every six months, but after some time, it was enough to do it once a year. The verification process includes several key steps:

Evaluation of Inspection Data: The food control authority's laboratory analyses every lot of the finished product chemically. Some of these tests are the TVB (total volatile bases) test, the histamine test, and the mercury test, all of which are subjected to statistical tests in a bid to determine the quality of the production.

Monitoring Data Review: The information gathered during the HACCP plan is analyzed very carefully. If deviations are observed, the QC manager analyzes the cause of the failure and intends to correct it.

Client Feedback: The Company also analyzes customer feedback to determine if there is anything wrong with the product.

Annual Audits: The technical advisor performs the audit once a year to check the authenticity of the HACCP procedures. Examples include deploying records generated by HACCP, assessing equipment maintenance, and checking the calibration of other instruments used in monitoring. When some deficiencies are recognized, they can be corrected immediately, and relevant changes to the HACCP plan are made. This audit also becomes a time to add new technologies, regulations, or client requirements.

7.8 Example of HACCP Plan for Canned Fish

Table 4:5 illustrates an example of a HACCP plan for canned sardines and mackerel in Morocco. Here, key process areas involved in the reception of raw fish, closure of fish containers, sterilization of containers, cooling, and storage have been designated CCPs. Every CCP has its own risk, control factors, control parameters, and how they will be monitored. For example, during the receiving stage, the temperature of fish and histamine content are observed not to use spoiled and contaminated fish (Khan et al. 2015). During sterilization, heat penetration and temperature distribution on the materials are controlled so that the correct sterilization is done correctly. Corrections are described for each CCP, for instance, rejecting off-grade cans or holding lots that do not meet the desired quality. Frequencies are clearly defined, and the responsible personnel can monitor them; for every new frequency, a record has to be made daily to ensure that all procedures are followed correctly.

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Table 4.5 Example of HACCP plan for the production of canned sardines and mackerel in Morocco

Critical control point	Significant hazard	Preventative (measure(s)	Critical limit	What to monitor	How to monitor	Monitoring frequency	Who monitors	Corrective action(s)	Records	Verification
1. Receiving raw fish	Spoiled fish or fish with high histamine levels	Proper Fish icing and handling after landing, refrigerated transportation	Fish $T < 6$ºC TVB <250 ppm Histamine < 50 ppm	Fish temperature TVB Histamine	Temperature measurement Chemical method Spectro-fluorimetry	Every received lot If freshness doubtful Every received lot	Reception supervisor QC manager QC manager	Fish sorting according to freshness. If needed, determination of TVB Reject if TVB > 250 ppm Reject if histamine > 50 ppm	Fish receiving (form 1+ 4) used for freshness, TVB and histamine	Daily record review Daily record review
2. Container closure	Post-process contamination	Training of the container closure supervisor Maintenance of closure equipment	No leaking containers	Visible defects	Visual inspection	Every 30 minutes	Container closure inspector	Isolate cans closed since last control and discard any leaking ones.	Container integrity records (forms 2+4)	Daily record review
				Integrity defects	Double seam analysis	Every 2 hours	Inspector	Isolate cans closed since last control and discard any leaking ones	Container integrity records (forms 2+4)	Daily record review
3. Sterilization	Survival of spores, especially those of *Cl. Botulinum*	Regular maintenance of the retorts. Training of the retort operating supervisor	F_0 = 7–14 minutes Sterilization parameters (Table 4.2)	Heat penetration & temp. distribution T, time, P	Ellab logging data equipment Recording	Twice a year and as needed Every retort cycle	QC manager Retort operator	Identify cause of deficiency and repair the retort Repair retort	Automatic recordings Sterilization (forms 3+4)	Review at every run Daily record review
4. Cooling sterile cans	Microbial contamination Thermophilic spoilage	Chlorination of cooling water. Cooling time < 1 hour	Residual free chlorine 1 ppm Duration of cooling < 1 hour	Chlorine level Duration of cooling	Chemical analysis Timing	Every day Every retort cycle	QC manager Retort operator	Identify lot and resterilize Isolate lot and check for thermophilic spoilage	Cooling water record Sterilization (forms 3+4)	Review at every run Review at every run
5. Storage of the finished product	Thermophilic spoilage	Storage at $T <$ 40ºC	$T <$ 40ºC	Record temperature	Calibrated Thermometer	Daily	Storage supervisor	Isolate lot and check for thermophilic spoilage	Storage temp. form (5 + 4)	Daily in the summer

8. Future trends

The fish canning industry is relatively young and adapts to the changing buyers' preferences, technologies, and global considerations of environmental preservation. Several trends have been identified, one of which requires further discussion: increased demand for convenient, minimally processed, and nutrient-dense canned fish (Augustin et al. 2016). The raw consumer is looking for improved quality fish products with natural flavors and nutrients that are easy to process and have a longer shelf life. Consequently, advancements in canning methods implemented practices like a steam process, natural chemicals, and vacuum packaging to include fish quality while avoiding using chemicals. The other emerging trend is that candy companies have introduced a wide range of products to appeal to many customers and diet preferences. In particular, fish canning companies offer choice products, including gourmet fish cans, organic fish varieties, and fish brands, as well as specific niches, including low sodium, high protein, etc. These product innovations target chocolate-conscious individuals due to specialized diets that include paleo, keto, and gluten-free. Recent innovations in fish canning technology are, therefore, helping increase the productivity and food safety of fish. Moving with the trend, companies are using automation, artificial intelligence, and machine learning to increase efficiency and reduce human interference. Also, by improving sensory technologies, including digital taste sensors, the freshness and flavor tendencies of canned fish products are maintained.

Sustainability has become a core operation concept with the newer threats striking from the environment. Many companies are practicing or gradually embracing using biopsy or recyclable material in packaging. Other processing technologies and efficient use of energy and power used in the canning plants, like renewable energy sources, are also being applied. It also assists in easing the pressure on the environment by cutting down on the industry's massive emissions, and it matches the current trend of consumers' awareness of sustainable produce in the market. However, as it is seen the number of innovations and trends widening, the importance of HACCP in the context of the canned fish industry will remain paramount. Due to its reliability, cost, and flexibility, HACCP has become an essential tool in ensuring that food safety is not compromised by new technologies or processes. However, the versatility to incorporate new trends in technology into enhanced food safety does guarantee a more significant incorporation of HACCP in the future of the industry.

Conclusion

The canned fish industry holds tremendous importance for world food security and trade as it offers consumers and food processors a stable protein source that is not perishable. Owing to convenience, nutritional value, and shelf life, canned fish is one of the most sought-after products in the food market. The process of canning is considered standard, which, however, changes with progression in technology, consumer tastes, and norms and standards. The following innovations seek to increase product quality, safety, and sustainability in canned fish products. HACCP is a critical method that needs to be practiced in the fish canning industry with concern for food safety and quality. According to the authors, HACCP provides guidelines and allows an understanding of possible hazards connected with each stage of the canning process. It also sets critical control points that mean its ability to develop effective preventive measures and minimize the possibility of contamination.

HACCP is a versatile concept that has become one of the most significant conceptual platforms for food safety because it helps the industry to implement new technological solutions, emerging processes, and even product novelties and ensure food safety at the same time. The industry is under a lot of pressure to be more health conscious and to source products in environmentally friendly manners. Health-conscious consumption plays a significant role while adopting various energy-efficient manners and technologies that are becoming more crucial in the industry. The ways through which the global fish canning companies are trying to implement environmental changes are as follows:

- Packaging material should be recyclable.
- Energy should be produced from renewable resources.
- Fish should be sourced responsibly.

The shift toward less processed products, product differentiation, and the changes in processing technologies are also changing the canned fish market. Therefore, it is possible to conclude that the issue of regulation still belongs to the key components of the industry’s activity. Regulations concerning canned fish products confirm their safety and quality according to international standards. As globalization and the internationalization of markets continue and the standards become more refined, delivering on these fundamentals and continuing to build the consumers’ trust that products are safe to consume remains key to sustaining success. The canned fish industry is expected to be more determined by technology and use of innovations, continued changes in regulations, and lastly, emphasis on sustainability. HACCP will help facilitate these changes while simultaneously considering the necessary food safety measures to be adopted to uphold the growth of this industry and meet the challenges of the changing world markets. With the emerging difficulties, this practice will ensure further utilization of HACCP, which is fundamental for the stable future of the industry and constant provision of consumers with qualitative and safe food.

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