Masteroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for naturvitenskap
Institutt for bioteknologi og matvitenskap

Tobias H. André

Investigating correlations between processing methods and quality parameters in fish; a semi-systematic review

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Investigating correlation between processing methods and quality parameters in fish; a semi-systematic review

By Tobias Harnes André

Innhold

Abstract

In this thesis, chilling and freezing was investigated to determine three things. Firstly, to determine what processing technologies were used. Secondly, to determine what quality parameters were measured. And thirdly, to determine if there were any correlations between the reported processing methods and measured quality parameters. To do this, 41 studies were chosen using a semi-systematic approach. Groups of processing methods were generalised into freezing, chilling and superchilling based on the technology used. Quality parameters were grouped by how they measured the parameters. Therefore, there was four groups of quality parameters; physiochemical (quality parameters measured by physical methods like water contents and pH), chemical (parameters measured by chemical methods like chemical composition and biogenic amines), sensory (quality measured by sensory/organoleptic methods like taste and smell) and microbial (quality parameters measured using microbiological methods usually showing presence of microorganisms). The included studies were first categorised by what processing method they used and what quality parameters were measured. Afterwards a synthesis of both processing methods and quality parameters was made to try to determine correlations. The results show that many cases used freezing as their processing method and mostly measured chemical quality parameters. The second most common processing method and quality parameter was freezing and physiochemical quality parameters respectively with only slightly fewer cases each. Superchilling, sensory and microbial quality parameters were all not often measured. Most of the included studies measured two quality parameters and one processing method. Also, there are three different ways to describe the results of processing methods; as a comparative study between two or more processing methods, comparative study of two or more types of processing methods (comparing cryogenic and air blast freezers) or a documentation of the effects of the processing methods on the product. Due to large internal variations, it seems like no correlation could be found outside of strictly general terms. As freezing and chemical were most common and chilling and physiochemical second most common, we can say that in the included study, the majority used freezing and/or chilling as their processing methods and physiochemical and/or chemical as the measured quality parameters. A method to narrow down could give more specific results, but the intention of a review needs to be taken into consideration so as to not compromise the review. Future studies following a similar method should attempt to narrow down to one quality parameter group and use different processing methods.

List of used acronyms	Full name
ISO	International Standard Organisation
ATP	Adenosine triphosphate
TMA	Trimethylamine
TMAO	Trimethylamine oxide
DMA	Dimethylamine
RSW	Refrigerated seawater
QIM	Quality index method
PUFA	Polyunsaturated fatty acids
WHC	Water holding capacity
CO2	Carbon dioxide
MAP	Modified atmosphere packaging
TVB-N	Total volatile base nitrogen
FFA	Free fatty acids
FAA	Free amino acids
TMA-N	Trimethylamine oxide

1.0 Introduction

The fish and seafood industry are a large part of Norway's economy. With the large amount of shoreline available to us, it has been a part of our country and culture for generations. With the industrialisation of the fisheries, problems that seemed minor like liquid loss and texture changes became larger problems due to scale (Mansfield, 2010). Exports and demands for fresh fish products are another part of these problems. As an example, 2% weight loss due to liquid leaving the product might seem irrelevant when applied to small-scale catches of fish. But when considering hundreds or thousands of tonnes of catch from the fishing fleet or from aquaculture installations, 2% loss is a significant loss of income. Another reason to be concerned about quality changes is food waste. Consumers tend to not buy products of low quality and if they do not, the products end up as waste. And throwing away food that is otherwise safe for consumption is a big waste of money and resources (Mason et al., 2011). Fish is also a sensitive and perishable food where a lot of important and significant changes can occur during storage and processing (Alasalvar et al., 2010; Jessen et al., 2014; Oehlenschläger, 2014).

This will be elaborated on in the Quality parameters (2.0) chapter below. But first, a small overview is in order. Firstly, the subject of quality will be shortly explained (and elaborated later as mentioned) followed by an overview of the freezing and chilling processes as well as a short introduction to the various methods of chilling and freezing.

Quality as a parameter can be difficult to define. According to International Standard Organisation, 9000:2015 (ISO), quality is defined as "degree to which a set of inherent characteristics of an object fulfils requirements." (ISO, 2015). They add that the term quality can be combined with an adjective like poor or excellent to signify how well the object fulfils the requirements and that quality needs to be inherent in the object (ISO, 2015). A generic definition of quality would be the characteristics of the product like colour, texture, taste, smell, safety, and stability of water and biochemical components like proteins, fatty acids and vitamins. In fish, and especially salmon, quality is highly influenced by pre-mortem handling as stress causes significant quality loss (Alasalvar et al., 2010; Fellows, 2022). However, in this thesis, I will focus on post-mortem processing specifically so little focus will be given to processes prior to the death of the fish. The easiest way to do this is to categorise quality parameters into sensory, chemical, microbial, and physiochemical quality parameters. In this case, sensory qualities are taste and smell together with colour and texture that fit in multiple categories, both being sensory qualities that can be measured by physical methods. Chemical quality are parameters retaining to the quality of the biochemical components in the fish. These qualities are central to the overall quality, as the contents of the fish muscle give the characteristics of the other qualities. Texture, colour, and taste all derive from the chemical content. Safety is twofold; safety can be a part of chemical, microbial and physical quality as well as being a prerequisite for production (Lawless & Heymann, 2010).

The changes occurring during long term storage are numerous, but the majority can generally be categorised into one of two types: autolytic changes and microbial changes. Additionally, there are two other types of changes that occur during storage but are not caused by enzymes or bacteria. These changes are physiochemical and can be changes during or caused by rigor mortis. Rigor is when there is insufficient adenosine triphosphate (ATP) to break down bindings between myosin and actin due to the loss of availability of oxygen making the metabolism going from aerobic to anaerobic, causing the muscles to become stiff (Alasalvar et al., 2010). Note that Rigor mortis is also an autolytic process, but the process will have direct consequences on the quality of the fish muscle. Rigor mortis can cause quality loss in fish muscle if the fish is processed during the rigor process. There are also other chemical changes happening during storage. These changes can be change caused by oxidation of components like fatty acids and proteins as well as cross linkages because of formaldehyde caused by the degradation of trimethylamine (TMA) (Alasalvar et al., 2010; Jessen et al., 2014; Oehlenschläger, 2014).

Autolytic changes are changes caused by enzymatic activity in the fish muscle. Enzymes are organic molecules that catalyse chemical reactions, and autolytic processes are enzymatic processes that specifically work with the breakdown of organic matter in biochemical processes. These changes will be discussed in detail in a later chapter (2.2) but can be summed up as lactic acid production, tissue softening, belly-bursting, gaping or induced toughening because of formations of cross linkages (Alasalvar et al., 2010; Jessen et al., 2014; Oehlenschläger, 2014).

Microbial activity is another group of change that occurs during storage. These changes are complex and will be elaborated on in a later chapter (2.3). Microorganisms typically cause changes by breaking down compounds while producing others. Compounds produced by bacteria include TMA, sulphuric acid, sulphides, ammonia, histamine, acetate, and other carbon-based compounds like aldehydes. All these changes are under the umbrella called spoilage mechanisms and are to be avoided when utilising preservation like chilling and freezing (Alasalvar et al., 2010; Jessen et al., 2014; Oehlenschläger, 2014).

Chilling and freezing are technologies where the effects of removing heat from the product is utilised. The main benefit is how removal of heat reduces the rate of autolytic and bacterial activity in the muscles. Not only does the lower temperature limit the growth of microorganisms, as many species of microorganisms cannot grow in colder temperatures, formation of ice-crystals in the fish during freezing will also prevent or even destroy some bacterial cells (Jessen et al., 2014). Chilling and freezing technologies are often used together with other methods like salting, heating, and smoking to provide even better shelf life by preventing spoilage through making it hard for microorganisms to grow. Spoilage causes significant negative impacts to all quality parameter groups and is therefore the primary objective with preservation. This is done through reducing and limiting activities of bacteria and enzymes that cause spoilage and quality loss (Fellows, 2022).

There are several technological methods to prevent spoilage and quality loss by reduction of temperature. In chilling, the general principle is that heat is removed from the product by the melting of ice, flowing cool air, water, or liquids (usually carbon dioxide or nitrogen) over the product or by storing the fish in refrigerated sea water (RSW) holding low temperature without freezing due to the salt in the water. Melting of ice requires heat and this heat is absorbed by the ice from the environment. With proper temperature control most of the heat needed to melt the ice will be removed from the fish and not taken from the environment. This will, over time, cool down the fish. The RSW-method follows a similar principle, but the water is usually in the liquid state rather than solid or in a slurry which is semi-solid ice. Depending on the catch size ice can be added to the slurry or RSW to make the chilling go faster. Another method that has become increasingly popular is super-chilling. This method is when the product is brought down to just below the initial freezing point and kept at that temperature. This can protect the product against temperature increases during distribution and storage, since the product itself functions as a freezing medium. In addition to that, superchilling saves significant amounts of energy as it requires less ice during storage depending on how low the cooling is intended to last (Fellows, 2022; Jessen et al., 2014; Kaale et al., 2011). A product cannot gain a higher temperature than its environment, and therefore with proper temperature control of the environment the product is in, a superchilled product does not require any ice during storage. It is also possible to store the fish at superchilled temperature during distribution to maintain the ice formation in the fish. However, this requires suitable, strict temperature control.

In freezing, there are typically three methods utilised; air, contact and cryogenic freezing. Air freezing is when cold air is “blasted” over the product to remove heat and induce freezing of the product. This method is often referred to as blast freezing. The air needs to have a low velocity to prevent freeze-burning of the surface due to the dryness of the air. Contact freezing is when the product is in direct contact with a cooled freezing medium. This is usually a metal plate that is cooled down by a refrigerant and is in contact with the product. In fisheries, contact freezing is usually for large catches that can be frozen in bulk. This is done by adding water to fill the gaps and then frozen in a block. Contact freezing is also utilised when freezing fillets. There, plate freezers are used in the same way as in whole fish, but usually without the addition of water to make a large block of ice. Cryogenic freezing is when a refrigerant is in direct contact with the product. A refrigerant is usually liquid nitrogen or carbon dioxide which evaporates, absorbing heat from the product (Fellows, 2022; Jessen et al., 2014).

2.0 Quality parameters

As previously mentioned, the term “quality” has several meanings depending on context and use. Professionally, common terms are like the one found in ISO 9000:2015 where how well a product manages to fulfil requirements (ISO, 2015).

2.1 Sensory methods

Sensory analysis is a scientific discipline where perceptions from senses are interpreted and analysed. Sensory analysis is based on qualitative measurements of objects. These types of analysis are not done with instruments but are usually measured by trained humans in a panel. Untrained panels can also be used in some cases, like large scale analyses. The panellists are trained to assess appearance, smell, taste, and texture in a specific way to allow for analysis. This is done by measuring the stimuli of sensory organs caused by products. There are several different methods for this measurement. These methods answer questions attaining to if there is a difference, what that difference is and how big the difference is (often called absolute value). These all have different functions and purposes which in turn decides what panel is needed. Sensory analyses of this kind are about differences between two or more products and are not necessarily helpful for this thesis, and therefore they will not be discussed in detail. However, profiling as a method will be used as an example of a more traditional sensory analysis that could be useful for the purposes of this thesis or future similar works (Sensorisk Studiegruppe, 2015). Preference varies between individuals and therefore the panel needs to be trained to give stable and reliable results. If a panel is incapable of producing results, they lose value as a panel (Guillerm-Regost et al., 2006; Lawless & Heymann, 2010).

A common way to assess sensory qualities of fish is the Quality Index Method (QIM), which gives a score from 0-4 for several parameters. This gives a double benefit of both giving an overall score of the fish and assessing the parameters individually. This rating system is based on the state the fish is in during inspection. Points are assigned to the product based on a standardised form. This form has a predetermined scheme which tells the assessor how many points to assign. 0 points signifies high quality or freshness, whereas higher points mean less fresh and lower quality. Table 1 shows a scheme for a QIM for halibut where the parameters are categorised as appearance, eyes, gills and flesh fillets. These parameters are mostly visual with the exceptions of the odour and texture sub-groups. QIM schemes are developed for multiple different types of fish (Guillerm-Regost et al., 2006; Lawless & Heymann, 2010).

In sensory analysis there is a method called profiling where points are attributed to a preselected number of characteristics. This can be any characteristic expected to have a presence in the product. Profiling functions in a similar way to QIM and can to an extent be utilised for the same purposes. Note that profiling is more limited, as one profiling test only tests one parameter at a time (Sensorisk Studiegruppe, 2015).

Table 1: An example of a quality index method scheme used for halibut.

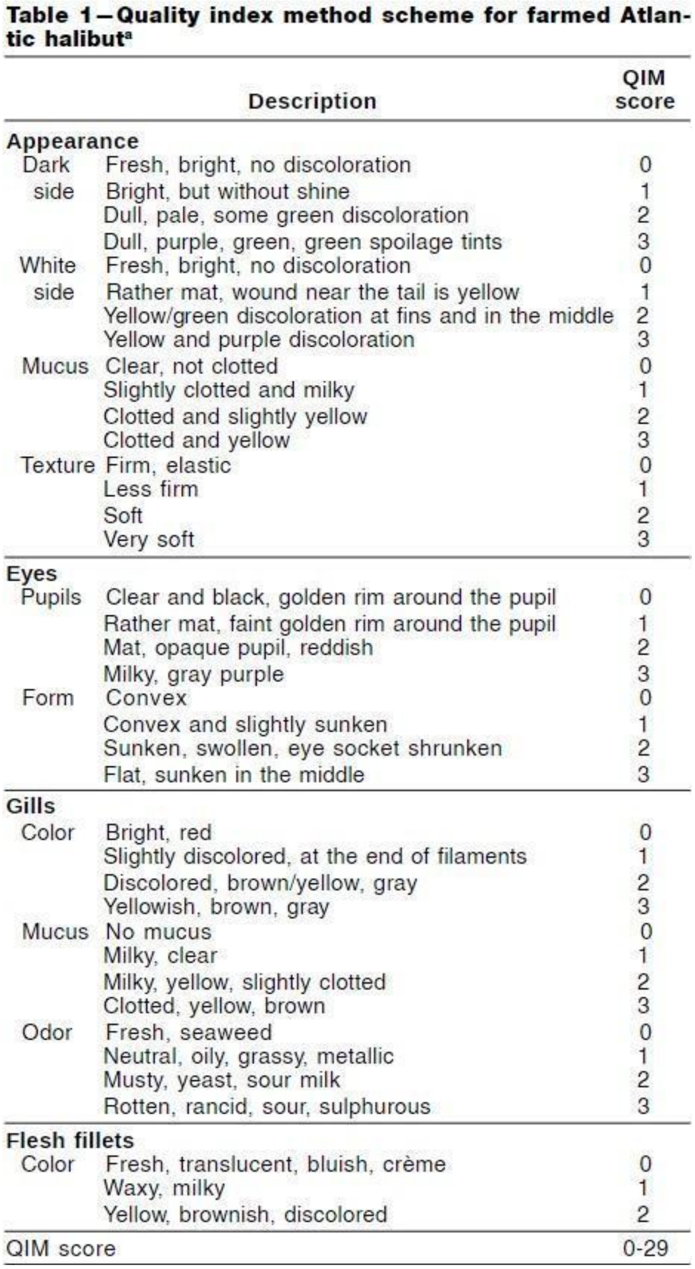


Table 1—Quality index method scheme for farmed Atlantic halibut[a]

	Description	QIM score
Appearance		
Dark side	Fresh, bright, no discoloration	0
	Bright, but without shine	1
	Dull, pale, some green discoloration	2
	Dull, purple, green, green spoilage tints	3
White side	Fresh, bright, no discoloration	0
	Rather mat, wound near the tail is yellow	1
	Yellow/green discoloration at fins and in the middle	2
	Yellow and purple discoloration	3
Mucus	Clear, not clotted	0
	Slightly clotted and milky	1
	Clotted and slightly yellow	2
	Clotted and yellow	3
Texture	Firm, elastic	0
	Less firm	1
	Soft	2
	Very soft	3
Eyes		
Pupils	Clear and black, golden rim around the pupil	0
	Rather mat, faint golden rim around the pupil	1
	Mat, opaque pupil, reddish	2
	Milky, gray purple	3
Form	Convex	0
	Convex and slightly sunken	1
	Sunken, swollen, eye socket shrunken	2
	Flat, sunken in the middle	3
Gills		
Color	Bright, red	0
	Slightly discolored, at the end of filaments	1
	Discolored, brown/yellow, gray	2
	Yellowish, brown, gray	3
Mucus	No mucus	0
	Milky, clear	1
	Milky, yellow, slightly clotted	2
	Clotted, yellow, brown	3
Odor	Fresh, seaweed	0
	Neutral, oily, grassy, metallic	1
	Musty, yeast, sour milk	2
	Rotten, rancid, sour, sulphurous	3
Flesh fillets		
Color	Fresh, translucent, bluish, crème	0
	Waxy, milky	1
	Yellow, brownish, discolored	2
QIM score		0-29

(Guillerm-Regost et al., 2006) p 84.

Here in Table 1, we see both the categories that are utilised to assess quality, but also descriptions showing what to look for. This allows the method to be used by untrained individuals, which is beneficial (Guillerm-Regost et al., 2006).

The QIM system has a benefit of giving a linear relationship between freshness/quality score and the remaining shelf life of a product because the score of the product is based on changes that happen during storage. It is then possible to predict remaining shelf life using the QIM system as a score will put the product along a linear scale.

2.2 Chemical quality

The chemical quality of a product is defined by the composition and properties of the compounds. This can be the basic contents of the fish muscle like lipids and proteins but also, and arguably more importantly, the compounds that are produced because of enzymatic and bacterial activity. The muscle structure of fillets depends on the state of the proteins. Some proteins and amino acids act as substrates for enzymatic activity during autolysis, making most of the changes during the initial post-rigor being caused by enzymatic activity (Alasalvar et al., 2010; Oehlenschläger, 2014). In fatty fish, lipids are a significant part of the content of the fish. This is especially important because the polyunsaturated fatty acids (PUFAs) in fish are significant for human health. PUFA are in abundance in fish species like salmon, mackerel and tuna. Unsaturated fatty acids are vulnerable to oxidation, which can cause significant sensory quality loss, reducing the content of the valuable fatty acids. Oxidised unsaturated fatty acids are not healthy, making the product unsuitable for human consumption if these oxidised unsaturated fatty acids achieve sufficient concentrations (Alasalvar et al., 2010). This is a major concern in fatty fish production and processing. The oxidation of lipids mostly causes sensory quality loss in the form of unwanted flavours in the product. Compounds that are created by lipid oxidation and cause flavours which reduces the sensory quality of the product.

There are other chemical processes and compounds that cause negative sensory influences on products. The majority of these are nitrogenous compounds like TMA, dimethylamine (DMA), ammonia and biogenic amines like histamine and cadaverine. Some of these are not only detrimental to the quality of the product but some are also toxic for humans, causing illness when consumed. To transform trimethylamine oxide TMAO into TMA in fish muscle, the TMAO needs to be broken down so that the oxygen is removed and thereby making it into TMA. Equation 1 below shows the reaction that creates TMA from TMAO (Muzaddadi et al., 2016). The nitrogenous compounds often have a notably bad smell, and TMA is a typical cause of bad smell in fish. Additionally, measuring adenosine triphosphate (ATP) levels is also useful as it shows degradation of the product and availability of energy for utilisation for either enzymatic activity or to some extent for microorganisms. ATP-levels are most relevant during the earlier stage's post-mortem. Another ATP-related measurement is K-value, which shows the relative relationship between microbial growth and available substrate. Note that parameters that are mostly based on the contents and structure of chemical compounds like protein structures, water retention, concentration of H+-ions or content of carotenoids can be a part of the physical quality parameters rather than chemical ones. This is due to how the method that is used to measure, rather than what compounds, components or concentration is measured (Alasalvar et al., 2010; Oehlenschläger, 2014).

$$TMAO + 2H^{+} + 2e \xrightarrow{TMAOOxydoreductase} TMA + H_2O$$

Equation 1: The reaction equation for the formation of TMA from TMAO.

The different compounds mentioned above like TMA, DMA and cadaverine can all be detrimental to the quality of the product either through sensory or physiochemical degradation. They can also be detrimental for the health of the consumer. Histamine is a typical biogenic amine that can be detrimental to the consumer's health. These are however only a small part of the compounds usually found in fish products. There are also numerous beneficial compounds and components in fish.

Fish contains vitamins, free amino acids, and minerals, as well as PUFA, all in various concentrations. Vitamins and minerals are beneficial to humans and fish is a decent source of these, especially vitamins A and D. The contents of vitamins depend on species of fish, as fatty fish contains more vitamins in fillets. Note that non-fatty fish like cod have a large abundance of different vitamins (mostly A, D, and some E) as well as other micronutrients in their livers, together with most of their PUFA. As for minerals, fish contains on average mostly potassium and phosphorus, while being relatively low on sodium. This can be beneficial for a low sodium diet (Alasalvar et al., 2010; Oehlenschläger, 2014)

2.3 Microbiological quality

When considering this type of quality, it is important to note that this parameter is based on if there is any presence of harmful microorganisms or not. Harmful in this context can mean either harmful for people, typically pathogens, or harmful for the product. The microorganisms that are harmful for the product are classified as spoilage microorganisms.

However, it is important to note that not all microorganisms are bad. Most microorganisms are harmless, and some can even be helpful. There are multiple ways a microorganism can be helpful. The antibiotic penicillin is a textbook example of microorganisms being helpful. In the context of this thesis, helpful microorganisms are those that are used during processing of food. This is primarily done by fermentation, where autolytic and/or microbial processes are actively used on products to gain certain characteristics like taste or texture.

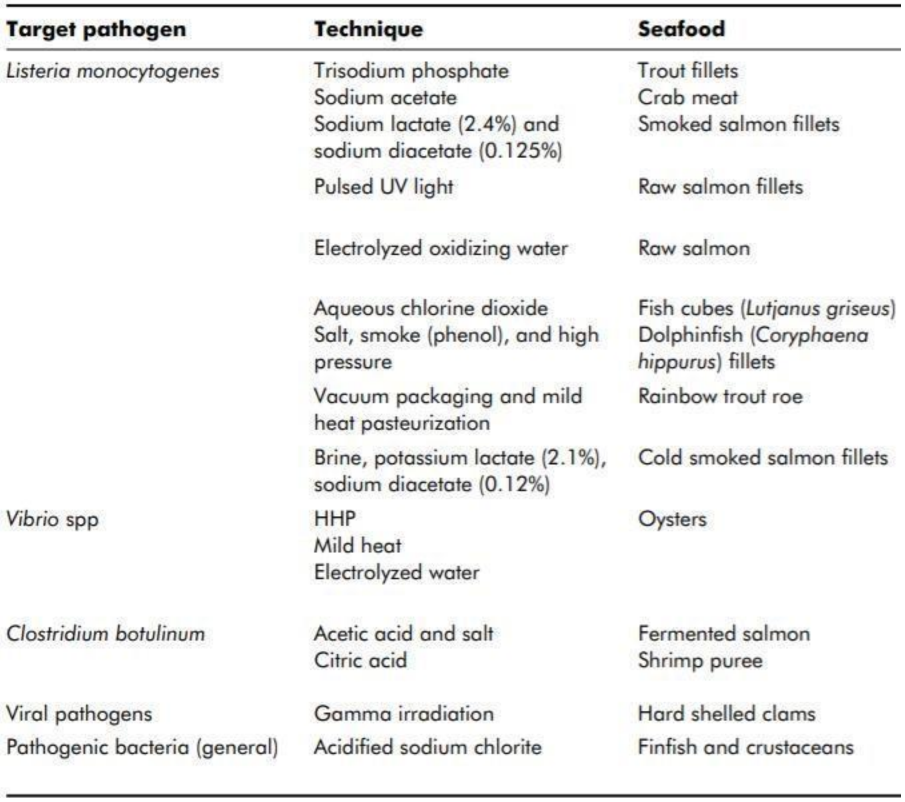
During fermentation it is important to have in mind what microorganisms are used in the fermentation process and to make sure that those microorganisms are the only ones that can exist within the product in a large quantity in addition to making sure the product is safe for consumption. Fermentation of fish is usually achieved by lactic acid bacteria, who both cause some of the intended changes and have an inhibitive effect on other microorganisms. Typically there is also an addition of salt in fermentation of fish. In the fish industry, fermentation is not the most common method of processing. In the Nordics we utilise fermentation as a method to process fish foods in some select products like rakfisk and surströmming and in Asian countries the fermentation process is used for production of fish sauces. As these processes are not the focus of this thesis, I will not go into further detail (Fellows, 2022; Tanasupawat & Visessanguan, 2014).

Pathogens common in fish are *Vibrio spp.* (notable species here are *Vibrio vulnificus* and *Vibrio cholerae*), *Clostridium Botulinum*, *Listeria monocytogenes* and Norovirus. Spoilage bacteria most common in fish products are *Shewanella putrefaciens* and *Photobacterium phosphoreum. Pseudomonas spp.*, *Aeromonas spp.* and *Vibrioacea spp.* also occur, but less commonly. *Aeromonas spp.* organisms can be pathogenic (Bagenda & Yamazaki, 2010; Boziaris & Parlapani, 2014).

The quality impact of spoilage bacteria is the production of spoilage compounds. These are already mentioned above, but to reiterate; TMA is formed by reduction of TMAO, and this process is done by spoilage bacteria. Other spoilage compounds are histamine, sulphides and hydrocarbons like ketones and aldehydes. (Bagenda & Yamazaki, 2010; Boziaris & Parlapani, 2014).

To have a high microbial quality means that the product through processing steps, preservation methods and/or chemical content inhibits growth, so that spoilage bacteria do not produce compounds causing quality loss and the growth of pathogens is prevented. There are many ways to do this, all depending on what species of microorganism is targeted. Generally, salt is not only the most common but a very effective way of preventing microbial growth. Second to salting is heat treatment, which is probably the safest method as enough heat is likely to inactive most pathogens in the product. Other useful methods are drying, smoking, and modified atmosphere packaging often combined with chilling. Notably from this list, smoking is most often used in conjunction with salting. See Table 2 for a more extensive list of treatments for pathogens (Bagenda & Yamazaki, 2010).

Table 2: An overview of some methods to prevent growth of *Listeria monocytogenes, Clostridium botulinum* and *Vibrio spp.* species (Bagenda & Yamazaki, 2010) p.202.



Target pathogen	**Technique**	**Seafood**
Listeria monocytogenes	Trisodium phosphate	Trout fillets
	Sodium acetate	Crab meat
	Sodium lactate (2.4%) and sodium diacetate (0.125%)	Smoked salmon fillets
	Pulsed UV light	Raw salmon fillets
	Electrolyzed oxidizing water	Raw salmon
	Aqueous chlorine dioxide	Fish cubes (*Lutjanus griseus*)
	Salt, smoke (phenol), and high pressure	Dolphinfish (*Coryphaena hippurus*) fillets
	Vacuum packaging and mild heat pasteurization	Rainbow trout roe
	Brine, potassium lactate (2.1%), sodium diacetate (0.12%)	Cold smoked salmon fillets
Vibrio spp	HHP Mild heat Electrolyzed water	Oysters
Clostridium botulinum	Acetic acid and salt	Fermented salmon
	Citric acid	Shrimp puree
Viral pathogens	Gamma irradiation	Hard shelled clams
Pathogenic bacteria (general)	Acidified sodium chlorite	Finfish and crustaceans

Table 2 also shows methods to deal with viral pathogens and a general method of dealing with pathogenic bacteria (Bagenda & Yamazaki, 2010).

2.4 Physiochemical quality

Physiochemical quality is a collection of parameters which are measured by physical methods. This quality is influenced by autolytic and microbial activity. The parameters are typically texture, water holding properties, pH and colour. There are also other parameters that are less common such as conductivity, impedance, and ice formations. In addition, there are several interesting novel methods to measure the quality of fish. These are spectroscopic methods where they use different wavelengths in the electromagnetic spectrum to assess quality. These wavelengths can be in the ultra-violet and near-or mid-infrared range. Additionally, nuclear magnetic resonance is also a novel spectroscopic method that can be utilised to determine chemical content in the food as well as the condition of the water (how well it is bound) in the product (Alasalvar et al., 2010; Oehlenschläger, 2014; Olsson et al., 2007).

Water holding capacity (WHC) is a parameter that measures how well the product manages to hold its water content during influences from external forces. These forces are pressure, thermal processing like heating or chilling or centrifugation and gravity (Gyawali & Ibrahim, 2016). It can be measured by how much liquid is lost over time from the product. This can be determined by measuring the weight of the product several times over time to see how the weight changes, and thereby express how much water has left the product (Alasalvar et al., 2010; Guillerm-Regost et al., 2006; Oehlenschläger, 2014; Olsson et al., 2007). This parameter, also referred to as liquid loss or drip loss, is important for the texture of the product, as there can be a negative correlation between loss of water and changes in texture as seen by Guillerm-Regost et al. (2006). There they tested the changes in the muscles of Atlantic halibut and found that there was a negative correlation between the liquid lost during storage and the texture of the product from day 4 to day 8 (Guillerm-Regost et al., 2006).

pH measures the concentration of H+-ions and has a value between 0 and 14. It is an important quality parameter since changes in pH influences other parameters. Low pH can be used to inhibit growth of certain organisms or reduce activity. pH also affects the WHC by changing the structures of the protein network that holds the water. Lowering the pH values makes the protein structures tighten due to a reduction of repulsion between the proteins. This then affects other parameters like texture because of changes to WHC (Alasalvar et al., 2010; Guillerm-Regost et al., 2006; Oehlenschläger, 2014; Olsson et al., 2007).

Colour can be measured in multiple ways, and the chemicals that act as source of the colour depends on species. The surface structure of the product will also influence the colour, giving internal variance in fillets from the same species. Colour can be measured by sensory methods, by chromameter or by image analysis. Image analysis is a modern method for analysing colour in fish. Here computer methods are used to analyse pictures taken of fillets to measure colour. Colour is an important parameter to measure due to its importance for consumer acceptance. Consumers prefer fish with a colour that fits their expectations. This is more important in fish species where there is a distinct colour. Tuna, salmon, mackerel, and trout are examples of fish species that often carry with them an expectation of how a fillet will look like (Alasalvar et al., 2010; Guillerm-Regost et al., 2006; Oehlenschläger, 2014; Olsson et al., 2007).

Texture is measured by instrumental measurements where the resistance is measured in energy applied to the product to achieve a certain depth or pressure over time. A probe with a defined diameter is pressed into the fish muscle and the force needed to compress the fish muscle to a certain percentage (often 60%) is determined. One can also measure the force at the point where the probe breaks through the surface of the fish fillet. By using texture profile analysis the compression, the elasticity, springiness and cohesiveness can also be determined. Texture can also be measured by sensory methods where human senses are used to measure the texture through tactile evaluations in the mouth or using fingers to feel the texture of the products (Alasalvar et al., 2010; Guillerm-Regost et al., 2006; Oehlenschläger, 2014; Olsson et al., 2007).

The measurements of physical, microbial, and chemical parameters are mostly quantitative with a few qualitative exceptions in the physical and chemical groups like colour, taste, smell and texture.

3.0 Processing methods

As mentioned above, chilling and freezing refers to processing methods and technologies that remove heat from products. This is done to preserve the quality of a product for a longer time, thereby increasing the shelf life of the product. The increase in shelf life is acquired by prevention of the spoilage processes and mechanisms in the product, which are dependent on temperature. These processes and mechanisms are caused by autolysis and bacterial activity, and the different technologies and methods prevent these mechanisms to different extents (Fellows, 2022).

3.1 Chilling; technology and methods

Chilling is a method of removing heat by bringing the product into an environment where the temperature is between -1 and 8°C. This is mostly to prevent the growth of microorganisms, but it also to an extent prevents or reduces activity by enzymes. As the temperature goes down activity is significantly reduced. At chilling temperatures, even psychrotrophic bacteria (bacteria that prefer or can grow in colder temperatures) grow slower than at their optimum temperatures and other types of bacteria do not grow at all (Fellows, 2022; Jessen et al., 2014). Chilling technology is often used in conjunction with other processing methods like salting, drying, heating, and smoking to significantly extend the shelf life of products. The benefit of chilling is that it does not negatively influence sensory and nutritional qualities of products to any large degree, meaning that the process itself is very mild on the product. This is beneficial for other processing methods that also has an intended influence on sensory attributes like smoking and salting. Salting and smoking give a good shelf life when utilised in combination with chilling. It is however important to note that chilling can only be used for short periods of time. This is due to chilling only slowing the processes somewhat and not enough to keep the fish fresh for extended periods of time. Generally speaking, a chilled fish product can last a few weeks and still be considered fresh (Fellows, 2022; Jessen et al., 2014; Kaale et al., 2011).

The equipment utilised for chilling and freezing principally have the same functionally. The methods are categorised after how the heat is removed; mechanically or cryogenically. Mechanical chillers use air, water, brine, or metal surfaces to remove heat from the product, while cryogen chillers utilise liquid nitrogen or CO2 to cool down the product. Both batch and continuous operation is possible for these chilling systems. Blast chillers are equipment that "blasts" air at the product while metal surfaces rely on contact with the product to cool down. Cryogenic chillers spray the product with the medium to cool it down. Refrigerated sea water (RSW) or ice is very often used not only as a cooling medium but as a method of keeping the product cold during transport and storage. RSW is also typically used during transport to land. This works by the ice absorbing heat from the product and then melting. It is also possible to combine RSW and ice in a slurry (Fellows, 2022; Jessen et al., 2014; Kaale et al., 2011).

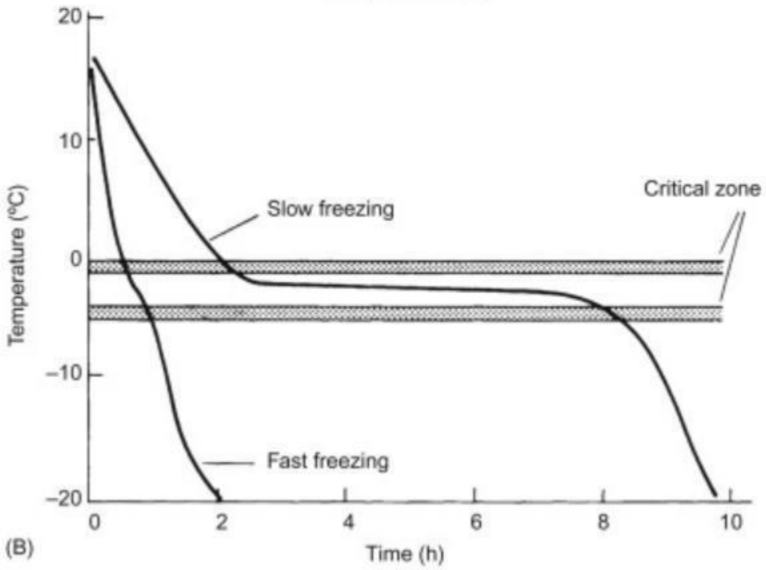
Superchilling is a method of chilling where the product is brought down to temperatures just below the initial freezing point. This method improves shelf life significantly compared to traditional chilling. It was found that superchilling doubles the shelf life of salmon (Kaale et al., 2011; Kaale et al., 2014). Additionally, it also reduces energy and transportations costs because with superchilling temperatures the product acts as its own chilling medium during storage, making ice unnecessary during storage. It can also lead to less freezing and thawing during processing which can increase yield while reducing energy and labour costs. Superchilling causes some liquid loss in products. Superchilling generally uses the same methods as freezing and chilling, but at different temperatures. Notably, superchilling utilises impingement freezing/chilling in addition to more common methods of chilling and freezing like cold storage. Impingement freezing is where the surface layer of air of the product is broken, allowing for a more efficient cooling process (Fellows 2022). How much superchilling is required and how to calculate this is difficult to determine, as well as difficulties retaining to maintaining the superchilled state. More research is needed to optimise this process. When optimised, we could extend the shelf life of some products significantly by using this method. By lowering the temperature to below 0°C, we can significantly increase shelf life without the costs and problems related to fully freezing a product. Few, if any, microorganisms can grow in sub-0 conditions (Fellows, 2022; Jessen et al., 2014; Kaale et al., 2011).

3.2 Freezing; technologies and methods

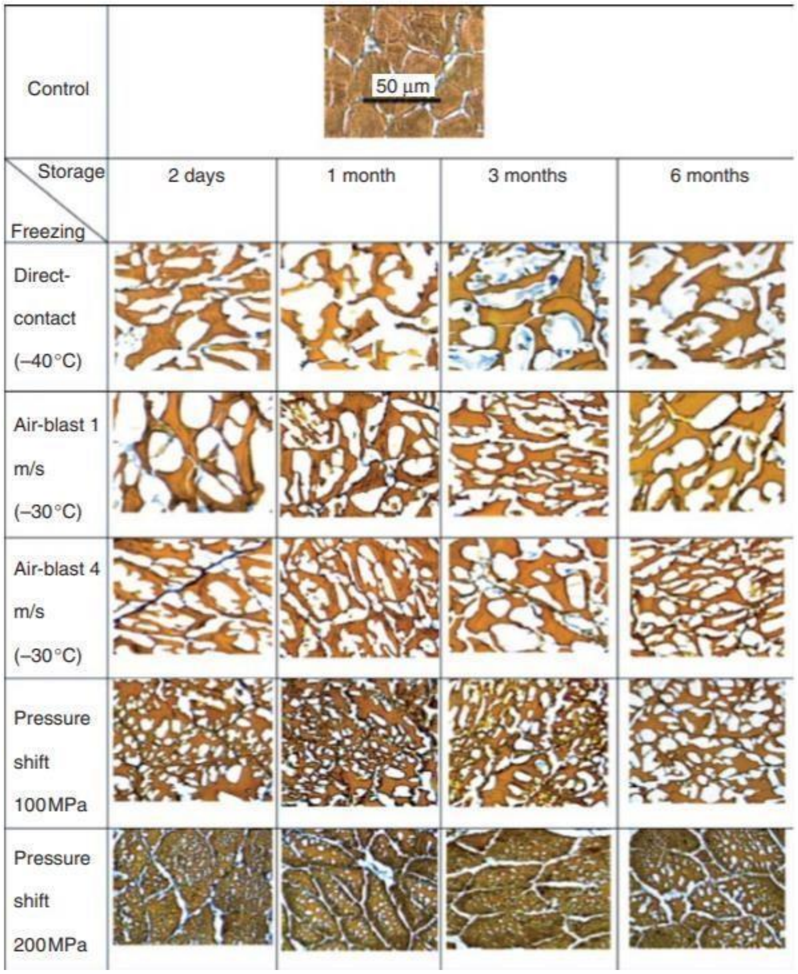
Freezing is different from chilling technologies by reducing the temperature beyond the freezing point of the product to make sure the water in the product freezes. This is an additional prevention that is introduced by freezing, as the other effects of cooling down the product is the same for both chilling and freezing. However, it is important to note that the beneficial preservation effects of freezing are more significant; the prevention of growth and enzymatic activity is even stronger at the low temperatures that freezers are kept at (Fellows, 2022; Jessen et al., 2014). Many of the benefits from cooling are even more effective at lower temperatures. Fewer microorganisms can grow, and processes are slowed. This can increase the shelf life of a fish product by months instead of weeks. This is why freezing technologies are important as they allow for longer transport times while still maintaining acceptable quality for consumption. Just like in chilling, as mentioned in the previous chapter, the technologies in freezing are typically mechanical or cryogenic. Mechanical freezers are air-blast, immersion and direct contact and cryogenic freezers utilise liquid nitrogen and CO2 to quickly remove heat from the product by evaporation of the liquids. Additionally, there are newer methods utilising pressure shifts around the product to cause the freezing to take place or methods that use air to break the surface air layer to improve heat transfer between medium and product called impingement freezing. These two are only mentioned as there are several other methods to freeze a product (Fellows, 2022; Jessen et al., 2014).

When considering the effectiveness of freezing, it is important to consider ice crystal formation. This is what causes additional prevention by freezing compared to chilling, in addition to the difference in temperature alone. Ice-formation has several effects on the product that can increase shelf life. The major effect is the reduction in water activity in the product, while another effect is the relative increase in concentration of solutes. When the water is turned into ice, solutes like carbohydrates, salts, free amino acids and peptides increase in concentration due to the loss of water. This prevents the growth of microorganisms in the product due to osmosis of bacterial cells. As the water outside the bacteria freezes first and thereby increases the concentration of solutes outside of the bacterial cell, the still unfrozen water inside the bacterial cells leave the cell. In addition, the actual formation of ice-crystals can also destroy the cell membrane. When ice-crystals become large enough, they can break the cellular structure of cells. This is because both intra-and-extracellular water can turn to ice during freezing and if the ice crystals become big enough, they will destroy the cell. The effect of ice-crystal formation does not discriminate between beneficial cells or muscle tissue and bacterial cells, and therefore having too large ice crystals is not viewed as a net benefit for the product. To prevent the ice-crystals becoming too large, the time it takes to fully freeze the product needs to be considered.

A comparison of slow and quick freezing can be viewed in picture 1. Different rates of freezing are shown as well as the critical zone where the transition from water to ice creates a flat curve from the heat released by the transition. The area in the figure that is called the critical zone is important because how long the product spends here determines the formation of ice-crystals. Spending long in this zone gives large ice-crystals, and spending a brief time gives smaller ice crystals. When small crystals are formed, the total number of ice crystals increases rather than the formation of fewer, larger ice crystals. However, it is important to note that over time the ice crystals grow. See picture 2 for examples of how ice-crystals develop over longer periods of time and with different technologies (Fellows, 2022; Jessen et al., 2014).



Picture 1: A graph showing the critical zone and how different speeds of freezing occur. Slow freezing spends longer in the critical zone, which in turn makes for larger ice-crystals. The flat part of the curve is caused by heat released by the transition from water to ice (Fellows, 2022) p 421.



Picture 2: Pictures of how different technological solutions develop ice-crystals. Here is an example of how ice crystals form in muscle after freezing. Note how pressure affects the formation of ice (Jessen et al., 2014) p 39.

3.2 Earlier reviews

When conducting searches for articles to be used in this master thesis, five earlier review studies were identified. The oldest was from 2014 and the newest from 2022. Two of the review studies were from Norway (Tolstorebrov et al. 2015, Erikson et al. 2021) and one from China (Cheng et al. 2014), one from Portugal (Duarte et al. 2020), and one from the Czech Republic (Jia et al. 2022).

When looking at the review study published by Cheng et al. (2014) they concluded based on their included studies that texture and structure measurements and evaluations for fish and fish fillets are of significance in freshness quality control and assurance, and product development in the seafood industry. Further, they also concluded that both sensory and mechanical methods can be used for fish texture measurements. Compared with sensory methods, mechanical methods are more objective and reliable. They also described that the structure of fish plays a vital role in showing the internal, subtle changes of connective tissue of fish muscle. These are usually measured by optical microscopy and electron microscopy, and the structure of the fish is paramount for these technologies. The measurement of fish structure could provide more information and further interpretation for texture alterations induced by external conditions such as freezing, chilling, salting, smoking, and others (Cheng et al., 2014).

The article by Tolstorebrov et al. (2016) concludes that the formation of ice in fish tissues stops at temperatures below −35.0 °C. Further decrease in temperature results in the increase of the viscosity of the unfrozen solution. At the same time, decreasing the temperature below the glass transition can damage the structure of fish. However, a temperature of −40.0 °C was enough to stabilise the proteins, inhibit the formation of TMAO in the fish's muscle tissue, and maintain good textural properties of lean fish meat. The oxidation of lipids in the muscle tissue can more effectively be inhibited by applying oxygen barrier materials (packaging, application of vacuum, antioxidants, glaze layer) than by decreasing storage temperatures. The effective temperature for high-quality long-term storage of fish is approximately −35.0 °C. Vacuum packaging with a medium oxygen barrier will be preferable for fatty fish. The use of ultra-low temperatures at −45.0 °C and below gives some benefits, but they are negligible when compared to the price of this technology (Tolstorebrov et al., 2016).

In Duarte et al. (2020) the aim of the review was to summarise strategies to increase the shelf-life of fresh (chilled) and frozen fish, as whole, gutted, or fillet, involving the assessment of different traditional cooling and freezing conditions of different fish species caught in different locations. Although there are other factors that influence the fish shelf-life, such as the fish species and the stress suffered during catch, storage time and temperature and the amount of ice are some of the most important. In addition, the way that fish is stored also contributes to the final quality of the product. In most studies, whole chilled and frozen fish present longer shelf-life than those preserved as gutted and filleted. However other factors related to the organism, capture method, and transport to the preparation/processing industry should be considered for shelf-life extension (Duarte et al., 2020).

In Erikson's (2021) review they investigated how whitefish quality is affected by capture at sea, onboard handling, freezing, double freezing, frozen storage, thawing, and chilled storage. Due to the large variation in experimental designs, choice of parameters defining product quality, experimental conditions, and parameters, direct comparisons of the research shown in the review is hardly possible. Instead, the research should be viewed as a collection of case studies. When evaluating the freeze-chilling concept (a concept developed in the cases studied where the fish was first frozen and then kept at chilling storage) for whitefish, previous research has shown that the method can produce good quality fish products and adequate food safety provided good processing conditions are adhered to. Clearly, the method also offers logistical advantages. When compared quality-wise with fresh fish, the quality of freeze-chilled fish cannot be expected to be as good as unfrozen fish during the first few days of chilled storage post-mortem. Thus, when the transport time of fresh fish to market exceeds this period, the freeze-chilling concept can be an advantageous marketing strategy to consider when product quality alone is considered. Furthermore, fish in modified atmosphere packaging and vacuum are considered stable products, convenient and flexible for market distribution of high-quality products (Erikson et al., 2021).

The last review study is by Jia et al. (2022) and looks at the effect of various freezing methods on the quality of fish and seafood. Freezing temperatures, freezing, and frozen storage temperatures were also analysed and reviewed. The changes in the ice crystal, protein, and lipid affect the fish's quality and nutritional value during freezing and frozen storage. Freezing methods when combined with various additives or preprocessing approaches help improve the efficacy of freezing and frozen storage. Several experimental or emerging methods also have positive effects on the product's quality. According to the metadata reanalysis of quality markers done by Jia et al., freshly frozen fish using different freezing methods may vary in terms of ice crystal diameter, but not others. High-pressure freezing or immersion-freezing-derived fish retains the best quality through frozen storage. More data is required on freezing methods and the commercial's application and investment should be considered in the future. This review sheds light on finding a balance between freezing temperature and the use of certain additives to control freezing-related damages. Future optimization of technologies should be in a way that several processes along the farm to fork such as freezing, frozen storage, thawing, thermal processing of fish, and even refabrication of food should mutually complement each other's needs to deliver safe and high-quality fish to the consumer's plate, even after a prolonged storage time (Jia et al., 2022).

When trying to summarise the conclusions from these review studies, it can be said that there exist numerous different processes of freezing and chilling, as well as other factors, that may influence the quality of the fish. Therefore, choosing the correct type of freezing or chilling (and choosing between freezing or chilling) is of high importance for the quality of the product. But how and why to choose a processing method is not easy. Looking at the different quality parameters individually may be necessary to be able to see how different freezing and chilling methods influence different quality parameters.

3.3 Research questions

The goal of this thesis is to investigate the overarching influences of chilling and freezing on the quality parameters of fish products. On the background of earlier research, theory, and review studies the following research question will be investigated in this thesis.
For this thesis, there are three research questions:

1. What are the chilling and freezing processes used in the included studies?
2. What are the quality parameters measured in the included studies?
3. If and/or how different chilling and freezing processes are correlated to the measured quality parameters?

4.0 Method

The literature review was structured to identify studies describing low-processed fish chilling and freezing processes and the effect of different quality assessments. When conducting a review, the author must structure the research on existing knowledge. A review can be described as a systematic way of gathering and synthesising earlier research (Snyder, 2019). To use a literature review as a research methodology, certain steps of investigation are necessary to make sure the review is accurate, precise, and trustworthy. As with all research, the academic review differs in what was done, what was found, and the clarity of reporting the findings (Snyder, 2019; Moher, 2009). There are several existing guidelines for literature reviews. In this thesis, the semi-systematic review is used for detecting themes (Snyder, 2019; Ward, 2009). In a thematic literature review, the author sorts out and discusses existing research based on themes or theoretical concepts that are important to understanding the topic. Different guidelines described by Moher, et al. 2009, Ward, et al. 2009, and Wong et al. 2013 are used to implement the search and obtain data.

Snyder (2019) offers guidelines for how to conduct a semi-systematic approach for a literature review. The method can be summarised as keywords or key sentences to describe the method. In the article, literature reviews can be categorised by their purpose, research questions, search strategy, sample characteristics, analysis and evaluation and examples of contributions. For a semi-systematic approach, Snyder's (2019) guidelines are as follows:

-The purpose of a review is an overview of the research area and to track the development over longer periods of time

-Research questions are generally broad and generic, rather than very specific, with a purpose to identify general trends

-Search strategy conducted to find suitable sources may or may not be systematic

-The sample characteristics searched for are most commonly research articles

-Analysis and evaluation of the data acquired through the search can either be qualitative or quantitative

(Snyder, 2019, p. 334-335)

Contributions to the review include state of knowledge, themes in literature, historical overview, research agenda, and theoretical model. However, the contribution from a semi-systematic review can also be useful for identifying themes, academic perspectives, or common issues within a particular research discipline. It may furthermore be used to identify components of a theoretical concept (Snyder, 2019).

4.1 Search process

The search was limited to English-language literature and included studies published in the last ten years up to May 2023, with also other inclusion and exclusion criteria, Table 3. Electronic searches were conducted using search engines such as Google and the following databases: Semantic Scholar, PubMed, as shown in Table 4, two searches terms were used to search electronic databases were; -quality changes in fish during chilling, and freezing, - quality changes in fish, super chilled storage.

Table 3: Inclusion and exclusion criteria in the search process

Inclusion criteria	**Exclusion criteria**
Written in English	Other languages than English
Full text available	Not available in full text
Almost pure fish	Fish products (processed fish like fish pudding, fish burgers or cakes and surimi)
Chilling and freezing	Other processes like fried or salted
Single case studies	Review studies
Quality indicators	Other indicators not related to product quality
Different chilling and/or freezing methods	Comparing other storage methods (MAP for instance) while not including chilling and/or freezing

The review process was conducted in two steps (Wong, 2013; Ward, 2009; Moher, 2009). First, all abstracts were examined according to the inclusion criteria, consulting full-text papers if in doubt about inclusion. Second, all full-text papers of the selected abstracts were read to finally decide if the text would be included.

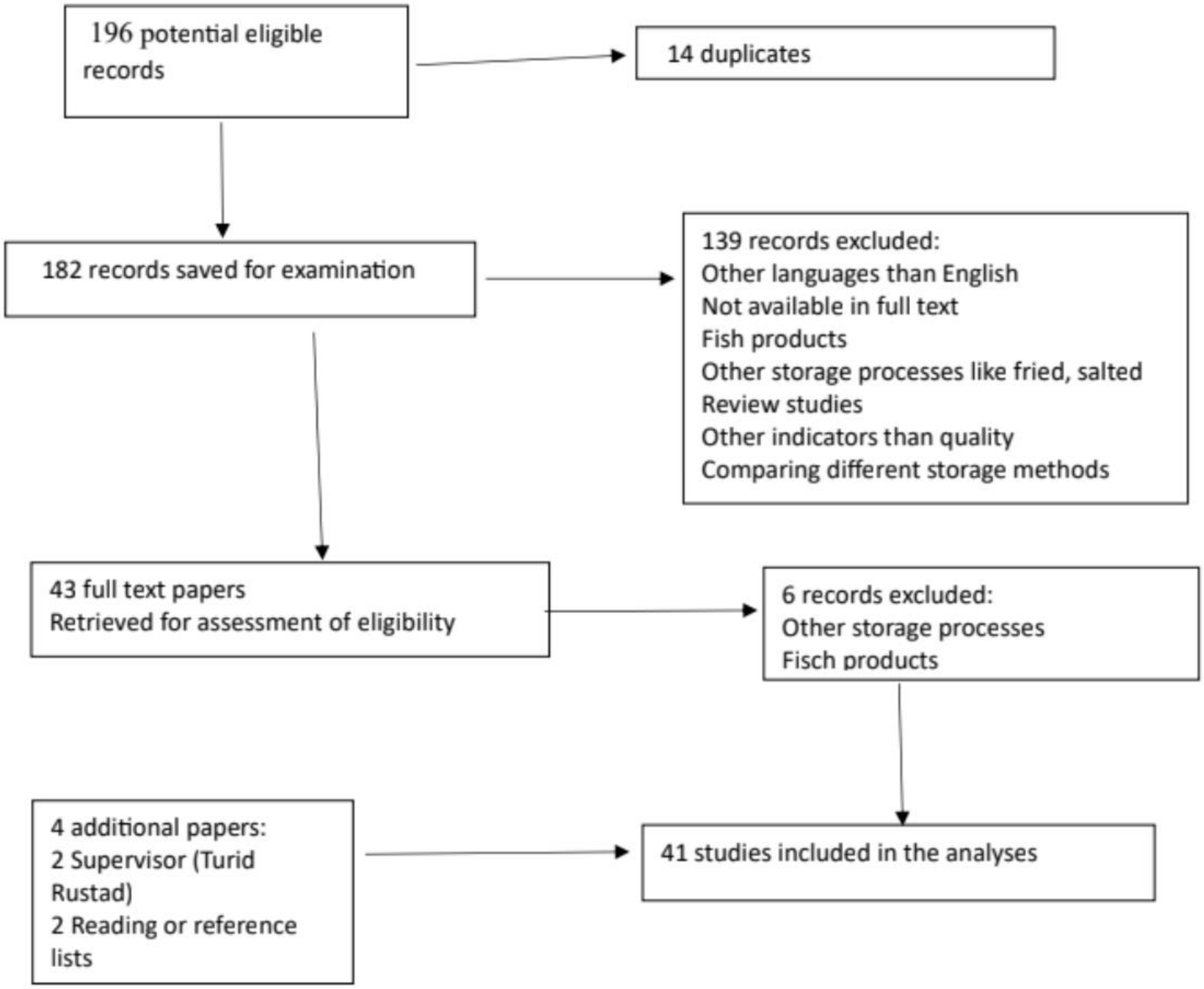


Figure 1: Flowchart of the literature review and selection of papers. Fish products excluded here are as mentioned above processed fish products like fish pudding, cakes, burgers and surimi. Salted and smoked fish were also avoided. The 4 additional papers came were either given by the supervisor as a starting point or were found through the reading or reference lists of other sources.

5.0 Results

The search resulted in 41 studies that met our inclusion criteria. The database search yielded 196 hits. Closer examination showed that 14 of these hits were duplicates. Of the remaining 182 articles, only 43 articles concerned quality changes in fish during storage, chilling, and freezing and were examined further. Of these 43 articles, only 37 met all criteria for inclusion. Most of the excluded studies failed to meet one or more of the inclusion criteria, most frequently because they described different processes done with the fish before freezing, cooling, or super chilling. All 41 studies were identified by systematic search methods; two were found with the help of guidance from the supervisor Turid Rustad (given as a starting point) and two by manual searching reading or reference lists, and 37 by searching electronic databases (see Table 4).

Table 4: Systematic search in databases

Name database/ date	Search word	hits	Included studies
Semantic Scholar	Quality changes in fish during chilling or freezing	180	30
PubMed	Quality changes in fish during chilling or freezing	7	4
PubMed	Quality changes in fish in super chilled storage	9	3

5.1 A General Description of the Studies

A general description of the studies is presented in Table 5, with publication year, country of origin, species of fish, type of chilling/freezing process, and quality indicators. All studies were published between 2014 and 2023. The following tables are sorted by date.

Table 5: An overview of the included studies.

Name of article	Authors	Year	Country	Fish species	Type of treatment	Type of quality parameters
The Effects of Malonaldehyde on Quality Characteristics and Protein Oxidation of Coregonus peled (Coregonuspeled) during Storage	Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., Zhang, J.	2023	China	Peled	Chilling, super chilling	Physiochemical
LC/MS analysis of storage-induced plasmalogen loss in ready-to-eat fish	Chen, Z., Jia, J., Wu, Y., Chiba, H., Hui, SP.	2022	Japan	Tuna	Chilling, freezing,	Chemical
Quality of frozen mackerel during storage as processed by different freezing methods	Zhou, P., Chu, Y., Lv, Y., Xie, J.	2022	China	Mackerel	Freezing,	Physiochemical, chemical.
Quality enhancement of large yellow croaker (Pseudosciaena crocea) during frozen (-18 ºC) storage by spiral freezing	Chu, Y., Cheng, H., Yu, H., Jun Mei, J., Xie, J.	2021	China	Yellow croaker	Freezing	Physiochemical, chemical.
Effects of super-chilling storage on shelf-life and quality indicators of Coregonus peled based on proteomics analysis	Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., Dong, X.	2021	China	Peled	Super chilling	Physiochemical, chemical, microbial.
The Effect of Multiple Freeze–Thaw Cycles on the Microstructure and Quality of Trachurus murphyi	Hu, C., Xie, J.	2021	China	Mackerel	Freezing	Physiochemical, chemical

Effect of chilling technologies on water holding properties and other quality parameters throughout the whole value chain: From whole fish to cold-smoked fillets of Atlantic salmon (Salmo salar)	Chan,S.S., (1), Roth, B., Skare, M., Hernar, M., Jessen,F., Løvdal, T., Jakobsen, A.N., Lerfall, F.	2020	Norway	Atlantic salmon	Chilling Superchilling,	Physiochemical, chemical, microbial
Freezing effects on yield, quality, and microbial load of farmed fish Neolissochilus hexagonolepis (Chocolate Mahseer)	Karki, S., Chowdhury, S., Nath, S., Dora, KC.	2020	India	Chocolate Mahseer	Freezing	Physiochemical, microbial
A comparative study of Atlantic salmon chilled in refrigerated seawater versus on ice: from whole fish to cold-smoked fillets	Chan,S.S., (2), Roth,B., Jessen, F., Løvdal, T., Jakobsen, A. N., Lerfall, F.	2020	Norway	Atlantic salmon	Chilling	Physiochemical, chemical, microbial
Quality changes of little tuna fillet (Euthynnus affinis) during chilling temperature storage	Hizbullah, HH., Sari, NK., Nurhayati,T., Nurilmala,M.	2020	Indonesia	Tuna	Chilling	Sensory, chemical
Quality Retention of Fresh Tuna Stored Using Supercooling Technology	Kang, T., Shafel, T., Lee, D., Lee, CJ., Lee, SH., Jun, S.	2020	USA	Tuna	Super chilling, chilling, freezing	Physiochemical, chemical
Rigor mortis development and effects of filleting conditions on the quality of Tra catfish (Pangasius hypophthalmus) fillets	Le, TT., Nguyen, HT., Pham, MA.	2019	Vietnam	Tra catfish	Chilling, freezing	Physiochemical, chemical

Superchilled, chilled and frozen storage of Atlantic mackerel (Scomber scombrus) fillets – changes in texture, drip loss, protein solubility and oxidation	Cropotova, J., Mozuraityte, R., Standal, I.B., Grøvlen, M.S., Rustad,T.	2019	Norway	Atlantic mackerel	Chilling Superchilling Freezing	Physiochemical, chemical
Freezing methods affect the characteristics of large yellow croaker (Pseudosciaena crocea): use of cryogenic freezing for long-term storage	Truonghuynh, HT., Li, B. Zhu, H., Guo, Q., Li, S.	2019	China	Yellow croaker	Freezing	Physiochemical
Changes in the Nutritional Composition of Fish Condiment Prepared from Thai Pangus (Pangasianodon hypophthalmus) During Storage at Low Temperature for Longer Period	Shikha, FH. Rahman, MA. Hossain, MI.	2019	Bangladesh	Thai Pangus	Chilling, freezing	Physiochemical, chemical, microbial.
Quality and Shelf Life Assessment of Puffer Fish (Lagocephalus guentheri) Fillets during Chilled Storage	Sreelakshmi, KR., Rehana, R. Renjith, RK., Sarika, K., Greeshma, SS., Minimol, VA., K. Ashokkumar, K., Ninan, G.	2019	India	Puffer Fish	Chilling	Physiochemical, chemical, sensory, microbiological
The relationship between degradation of myofibrillar structural proteins and texture of superchilled grass carp (Ctenopharyngon idella) fillet	Yang,F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., Zhan, X.	2019	China	Grass carp	Super chilling	Physiochemical, chemical,

Comparative study of quality changes in physicochemical and sensory characteristics of iced and refrigerated chilled store Indian Mackerel (Rastrelliger kanagurta)	Chudasama, BG., Dave, TH., Bhola, DV.	2018	India	Indian Mackerel	Chilling	Physicochemical, chemical, sensory
Texture characteristics of chilled prepared Mandarin fish (Siniperca chuatsi) during storage	Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L., Li, J., Zhang, Y.	2018	China	Mandarin fish	Chilling	Physiochemical, chemical,
Quality of Filleted Atlantic Mackerel (Scomber Scombrus) During Chilled and Frozen Storage: Changes in Lipids, Vitamin D, Proteins, and Small Metabolites, including Biogenic Amines	Standal, IB., Mozuraityte, R., Rustad, T., Alinasabhematabadi, Carlsson, NG., Undeland, I.	2018	Norway	Atlantic Mackerel	Chilling, freezing	Physiochemical, chemical,
Changes in microbial communities and quality attributes of white muscle and dark muscle from common carp (Cyprinus carpio) during chilled and freeze-chilled storage	Li, Q., Zhang, L., Luo, Y.	2018	China	Common carp	Chilling, freezing	Sensory, chemical, microbial
A study of fractal dimension as a quality indicator of hairtail (Trichiurus haumela) samples during frozen storage	Luan, L., Sun,Y., Chen, S., Wu, C., Hu, Y.	2018	China	Hairtail Fish	Freezing	Physiochemical

Infuence of Mono- and Multilayered Packaging Material on the Quality of Seer Fish (Scomberomorus commerson) During Chilled Storage	Mohan, CO., Ashitha, VA., Kishore, P., Panda, SK., Ravishankar, CN.	2018	India	Seer Fish	Chilling	Physiochemical, chemical, sensory, microbiological
Effect of cryogenic immersion freezing on quality changes of vacuum-packed bighead carp (Aristichthys nobilis) during frozen storage	Qian, P., Zhang, Y., Shen, Q., Ren, L. Jin, R., Xue, J., Yao, H., Dai, Z.	2018	China	Bighead carp	Freezing	Chemical, physiochemical
Biochemical changes in superchilled storage of salmon (Salmo salar) fillets	Kaale, LD., Johansen, T., Rustad, T.	2018	Norway	Salmon	Super chilled	Chemical, physiochemical
Structure of northern snakehead (Channa argus) meat: Effects of freezing method and frozen storage	Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., Hu, Y.	2018	China	Northern snakehead	Freezing,	Chemical, physiochemical
The quality changes of fresh skipjack (Katsuwonus pelamis) during chilling storage	Sormin, RBD., Pattipeilohy, F., Atua, AJ.	2017	Indonesia	Skipjack	Chilling	Chemical, microbial
A comparative study of quality and safety of Atlantic cod (Gadus morhua) fillets during cold storage, as affected by different thawing	Roiha, IS., Jónsson, Á., Backi, CJ., Lunestaad, BT., Karlsdóttir, MG.	2017	Norway	Atlantic cod	Freezing, chilling,	Physiochemical, sensory, microbial, chemical

methods of pre-rigor frozen headed and gutted fish						
Comparative analysis of the quality parameters and the fatty acid composition of two economically important Baltic fish: Cod, Gadus Morhua and Flounder, Platichthys Flesus (ActinoperygII) subjected to iced storage.	Tokarczyk, G., Biebkiewicz, G., Suryn, J	2017	Poland	Cod and Flounder	Chilling	Chemical
Study on the thawing method for frozen spotted mackerel with high freshness	Fuchiyama, Y.,Nakazawa, N., Okumura, K., Osako, K., Okazaki, E.	2017	Japan	Spotted mackerel	Freezing	Physiochemical, chemical
Changes of histamine levels and bacterial growth in Longtail Tuna (Thunnus tonggol) stored at different temperature	Mahusain, MAS., Bayoi, F., Karim, NU., Zainol, MK., Danish-Daniel, M.	2017	Malaysia	Longtail Tuna	Freezing, chilling	Chemical, microbial
Comparison of connective tissue structure and muscle toughness of spotted mackerel Scomber australasicus and Pacific mackerel S. japonicus during chilled and frozen storage	Hashimoto, K., Kobayashi, S., Yamashita, M.	2016	Japan	Spotted mackerel and Pacific mackerel	Chilling, freezing	Physiochemical, chemical
Effects of frozen storage condition abuse on the textural and chemical properties of grass carp	Cheng JH., Sun, DW., Zhu, Z.	2016	China	Grass carp	Freezing	Physiochemical, chemical

(ctenopharyngodoidella fillets)						
Super-chilling (0.7 C) with high-CO2 packaging inhibits biochemical changes of microbial origin in catfish (Clarias gariepinus) muscle during storage	Zhu, Y., Mab, L., Yang, H., Xiao, Y., Xiong, YL.	2016	China	Catfish	Super chilling	Physiochemical, chemical, microbial
Changes of proteins during superchilled storage of Atlantic salmon muscle (Salmo salar)	Kaale, LD., Eikevik, TM.	2016	Norway	Atlantic salmon	Super chilling	Physiochemical, chemical
Effects of freezing storage on the biochemical composition in muscles of Saurida undosquamis (Richardson, 1848) comparing with imported frozen	Mazrouh, MM.	2015	Egypt	Lizardfish	Freezing	Chemical
Comparison of Postmortem Changes in Blunt-Snout Bream (Megalobrama amblycephala) During Short-Term Storageat Chilled and Partial Freezing Temperatures	Bao, Y., Zhu, S., Luo, Y., Shen, H.	2015	China	Blunt-Snout Bream	Chilling, freezing	Physiochemical, chemical
Study the Chemical, Physical Changes and Microbial Growth as Quality Measurement of Fish	Al-Jasser, M., Al-Jasass, F.M.	2014	Saudi Arabia	Spanish mackrel	Chilling Freezing	Physiochemical Chemical Microbiological
Changes in water holding capacity and drip loss of	Kaale, L.D., Eikevik, T.M., Rustad, T., Nordtvedt, T.S.	2014	Norway	Atlantic salmon	Chilling Freezing	Physiochemical

Atlantic salmon (Salmo salar) muscle during superchilled storage						
Quality Characteristics and Shelf Life of Sutchi Cat Fish (Pangasianodon Hypophthalmus) Steaks During Refrigerated Storage	Viji P., Tanuja S., Ninan, G., Zynudheen A.A, Lalitha, K.V.	2014	India	Sutchi Catfish	Chilling	Chemical, physiochemical, microbial, sensory
Comparison of chemical, microbiological and histological changes in fresh, frozen and double frozen rainbow trout (Oncorhynchus mykiss)	Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., Lenhardt, L.	2014	Slovak Republic	Rainbow trout	Freezing	Chemical, physiochemical, microbial

As shown in Table 5, the studies represent a diversity of countries and continents: China with 15 studies (Guo et al. 2023, Zhou et al. 2022, Chu et al. 2021, Fan et al. 2021, Hu & Xie, 2021, Truonghuy et al. 2019, Yang ey a. 2019, Sun et al. 2018, Li et al. 2018, Luan et al.2018, Qian et al. 2018, Jiang et al. 2018, Cheng et al. 2016, Zhu et al. 2016, Bao et al. 2015), Norway with eight studies (Chan (1) et al. 2020, Chan (2) et al. 2020, Cropotova et al. 2019, Standal et al. 2018, Kaale t.al. 2018, Roiha et al. 2017, Kaale & Eikevik, 2017, Kaale et al. 2014), India with five studies (Karki et al. 2020, Sreelakshmi et al. 2019, Chudasama et al. 2018, Mohan et al. 2018, Viji et al. 2014), Japan with three studies (Chen et al. 2022, Fuchiyama et al. 2017, Hashimoto et al. 2016), Indonesia with two studies (Hizbullah et al. 2020, Sormin et al. 2017) and the United States (Kang et al. 2020), Vietnam (Le et al. 2019), Bangladesh (Shikha et al. 2019), Poland (Tokarczyk et al. 2017), Malaysia (Mahusain et al. 2017), Egypt (Mazrouh, 2015), Saudi Arabia (Al-Jasser& Al-Jasass, 2014), Slovak Republic (Popelka et al. 2014) alle with one study each. The sample thus represents a variety of cultures and levels of technological development, but China and Norway have the most studies and most tradition in studying this subject when having studies spread over the ten-year ratio.

5.2 Type and state of fish in the included studies

The type of fish used varied in the included studies, most of the studies have included only one type of fish, but two (Tokarczyk et al. 2017, Hashimoto et al. 2016) have described using two different types of fish. The state of the fish during testing is significant for the results depending on what was specifically measured. If the fish was tested for oxidation, the state of the fish is paramount for the results. If the oxidation test was conducted on filleted or cut fish the amount of oxidation would typically be higher than the oxidation found in whole fish. This is simply due to the difference of availability of molecules between filleted and whole fish.

Table 6: State of fish during testing in the included studies

Authors	Whole fish	Fillet or cut	Not reported
Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., Zhang, J.		x	
Chen, Z., Jia, J., Wu, Y., Chiba, H., Hui, SP.		x	
Zhou, P., Chu, Y., Lv, Y., Xie, J.	x		
Chu, Y., Cheng, H., Yu, H., Jun Mei, J., Xie, J.	x		
Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., Dong, X.		x	
Hu, C., Xie, J.			x
Chan,S.S., (1), Roth, B., Skare, M., Hernar, M., Jessen,F., Løvdal, T., Jakobsen, A.N., Lerfall, F.	x		
Karki, S., Chowdhury, S., Nath, S., Dora, KC.	x		
Chan,S.S., (2), Roth,B., Jessen, F., Løvdal, T., Jakobsen, A. N., Lerfall, J.	x		

Authors	Whole fish	Fillet or cut	Not reported
Hizbullah, HH., Sari, NK., Nurhayati,T., Nurilmala,M.		x	
Kang, T., Shafel, T., Lee, D., Lee, CJ., Lee, SH., Jun, S.		x	
Le, TT., Nguyen, HT., Pham,MA.		x	
Cropotova, J., Mozuraityte, R., Standal, I.B., Grøvlen, M.S., Rustad,T.		x	
Truonghuynh, HT., Li, B. Zhu, H.,, Guo, Q., Li, S.	x		
Shikha, FH. Rahman, MA. Hossain, MI.		x	
Sreelakshmi, KR., Rehana, R. Renjith, RK., Sarika, K.,. Greeshma, SS., Minimol, VA., K. Ashokkumar, K.., Ninan, G.		x	
Yang,F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., Zhan, X.		x	
Chudasama, BG., Dave, TH., Bhola, DV.	x		
Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L.,Li, J., Zhang, Y.	x		
Standal, IB., Mozuraityte, R., Rustad, T., Alinasabhematabadi, Carlsson, NG., Undeland, I.		x	
Li, Q., Zhang, L., Luo, Y.		x	

Authors	Whole fish	Fillet or cut	Not reported
Luan, L., Sun,Y., Chen, S., Wu, C., Hu, Y.		x	
Mohan, CO., Ashitha, VA., Kishore, P., Panda, SK., Ravishankar, CN.		x	
Qian, P., Zhang, Y., Shen, Q., Ren, L. Jin, R., Xue, J., Yao, H., Dai, Z.		x	
Kaale, LD., Johansen, T., Rustad, T.		x	
Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., Hu, Y.		x	
Sormin, RBD., Pattipeilohy, F., Atua, AJ.	x		
Roiha, IS., Jónsson, Á., Backi, CJ., Lunestaad, BT., Karlsdóttir, MG.		x	
Tokarczyk, G., Biebkiewicz, G., Suryn, J	x		
Fuchiyama, Y.,Nakazawa, N., Okumura, K., Osako, K., Okazaki, E.	x		
Mahusain, MAS., Bayoi, F., KARIM, NU., Zainol, MK., Danish-Daniel, M.	x		
Hashimoto, K., Kobayashi, S., Yamashita, M.	x	x	
Cheng JH., Sun, DW., ZHU, Z.		x	

Authors	Whole fish	Fillet or cut	Not reported
Zhu, Y., Mab, L., Yang, H., Xiao, Y., Xiong, YL.		x	
Kaale, LD., Eikevik, TM.		x	
Mazrouh, MM.			x
Bao, Y., Zhu, S., Luo, Y., Shen, H.	x		
Al-Jasser, M., Al-Jasass, F.M.	x		
Kaale, L.D., Eikevik, T.M., Rustad, T., Nordtvedt, T.S.		x	
Viji P., Tanuja S., Ninan, G., Zynudheen A.A, Lalitha, K.V.		x	
Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., Lenhardt, L.		x	
Total	15*	25*	2

In Table 6 above, what state the fish was in when testing was started was reported as either whole fish or filleted or cut (non-whole). Two studies did not give sufficient explanation to whether they used whole or cut fish, and are therefore set as not reported. Lastly, Hashimoto et al. 2016 used both whole and filleted fish for their experiments. To differentiate, what condition the fish was at the time of the main processing step is what counts as whether the fish was whole or not. As an example, if the fish was frozen first as a whole, and then cut later for analysis then it counts as a whole fish.

5.3 Analyses of the processing methods reported

In analysing the 41 studies we condensed the topics of the studies related to the research questions and this is shown in two Tables, 5 and 6. It was decided that a generalisation of methods was in order to simplify the results. Therefore, these three categories were chosen to represent the generalised groups. The two largest groups were chilling and freezing. Chilling was chosen for any study that stated that they chilled or refrigerated the fish. This can either be done by traditional refrigeration (cold storage), ice or RSW. These were all combined into one group.

The other large group was freezing, and here any study that stated they froze the fish was marked. For this it was not differentiated between different freezing technologies like plate, contact, cryogenic or traditional freezing (cold storage). Lastly, it was chosen to have superchilling as its own category. Superchilling is its own method entirely and can not be called either chilling or freezing. Therefore, it was kept separate.

Table 7: Type of processing methods used in included studies

Authors	Chilling	Superchilling	Freezing
Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., Zhang, J.	x	x	
Chen, Z., Jia, J., Wu, Y., Chiba, H., Hui, SP.	x		x
Zhou, P., Chu, Y., Lv, Y., Xie, J.			x
Chu, Y., Cheng, H., Yu, H., Jun Mei, J., Xie, J.			x
Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., Dong, X.		x	
Hu, C., Xie, J.			x
Chan,S.S., (1), Roth, B., Skare, M., Hernar, M., Jessen,F., Løvdal, T., Jakobsen, A.N., Lerfall, J.	x	x	x

Authors	Chilling	Superchilling	Freezing
Karki, S., Chowdhury, S., Nath, S., Dora, KC.			x
Chan,S.S., (2), Roth,B., Jessen, F., Løvdal, T., Jakobsen, A. N., Lerfall, J.	x		
Hizbullah, HH., Sari, NK., Nurhayati,T., Nurilmala, M.	x		
Kang, T., Shafel, T., Lee, D., Lee, CJ., Lee, SH., Jun, S.	x	x	x
Le, TT., Nguyen, HT., Pham,MA.	x		x
Cropotova, J., Mozuraityte, R., Standal, I.B., Grøvlen, M.S., Rustad,T.	x	x	x
Truonghuynh, HT., Li, B. Zhu, H.,, Guo, Q., Li, S.			x
Shikha, FH. Rahman, MA. Hossain, MI.	x		x

Authors	Chilling	Superchilling	Freezing
Sreelakshmi, KR., Rehana, R. Renjith, RK., Sarika, K.,. Greeshma, SS., Minimol, VA., K. Ashokkumar, K.., Ninan, G.	x		
Yang,F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., Zhan, X.		x	
Chudasama, BG., Dave, TH., Bhola, DV.	x		
Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L.,Li, J., Zhang, Y.	x		
Standal, IB., Mozuraityte, R., Rustad, T., Alinasabhematabadi, Carlsson, NG., Undeland, I.	x		x
Li, Q., Zhang, L., Luo, Y.	x		x
Luan, L., Sun,Y., Chen, S., Wu, C., Hu, Y.			x

Authors	Chilling	Superchilling	Freezing
Mohan, CO., Ashitha, VA., Kishore, P., Panda, SK., Ravishankar, CN.	x		
Qian, P., Zhang, Y., Shen, Q., Ren, L. Jin, R., Xue, J., Yao, H., Dai, Z.			x
Kaale, LD., Johansen, T., Rustad, T.		x	
Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., Hu, Y.			x
Sormin, RBD., Pattipeilohy, F., Atua, AJ.	x		
Roiha, IS., Jónsson, Á., Backi, CJ., Lunestaad, BT., Karlsdóttir, MG.	x		x
Tokarczyk, G., Biebkiewicz, G., Suryn, J	x		
Fuchiyama, Y.,Nakazawa, N., Okumura, K., Osako, K., Okazaki, E.			x

Authors	Chilling	Superchilling	Freezing
Mahusain, MAS., Bayoi, F., Karim, NU., Zainol, MK., Danish-Daniel, M.	x		x
Hashimoto, K., Kobayashi, S., Yamashita, M.	x		x
Cheng JH., Sun, DW., ZHU, Z.			x
Zhu, Y., Mab, L., Yang, H., Xiao, Y., Xiong, YL.		x	
Kaale, LD., Eikevik, TM.		x	
Mazrouh, MM.			x
Bao, Y., Zhu, S., Luo, Y., Shen, H.	x		x
Al-Jasser, M., Al-Jasass, F.M.	x		x
Kaale, L.D., Eikevik, T.M., Rustad, T., Nordtvedt, T.S.	x		x
Viji P., Tanuja S., Ninan, G., Zynudheen A.A, Lalitha, K.V.	x		

Authors	Chilling	Superchilling	Freezing
Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., Lenhardt, L.			x
Totalt	**24**	**9**	**26**

When examining the data from all 41 sources, it was found that most of them studied the effects of freezing parameters, having 26 cases. Following this is chilling with 24, superchilling with 9 cases. 15 out of 41 studies measured two or more processing methods, which means that 26 measured one processing method..

The sources that studied only one processing method were (Zhou et al., 2022), (Fan et al., 2021), (Hu & Xie, 2021),(Chu et al., 2021), (Karki et al., 2020), (Hizbullah et al., 2020), (Truonghuynh et al., 2020), (Chan (2) et al., 2020), (Sreelakshmi et al., 2019), (Yang et al., 2019), (Sun et al., 2018), (Luan et al., 2018), (Mohan et al., 2018), (Kaale et al., 2018), (Chudasama et al., 2018), (Qian et al., 2018), (Jiang et al., 2018), (Sormin et al., 2017), (Tokarczyk et al., 2017), (Fuchiyama et al., 2017), (Cheng et al., 2017), (Zhu et al., 2016), (Kaale & Eikevik, 2016), (Mazrouh, 2015), (Popelka et al., 2014), (Viji et al., 2014).

The sources that studied two or more processing methods were (Guo et al., 2023), (Chen et al., 2022), (Chan (1) et al., 2020), (Kang et al., 2020), (Le et al., 2020), (Cropotova et al., 2019), (Shikha et al., 2019), (Standal et al., 2018), (Li et al., 2018), (Roiha et al., 2018), (Mahusain et al., 2017), (Hashimoto et al., 2017), (Bao et al., 2015), (Al-Jasser & Al-Jasass, 2014), (Kaale et al., 2014).

Out of these 15 studies, 3 had more than 2 methods. It was (Chan et al. (1), 2020), (Kang et al. 2020) and (Croptova et al., 2019) that measured the three different processing methods. In all three cases, the study was comparative between the three different methods used. This is common for most of the studies that were conducted on multiple parameters.

5.4 Analysis of measured quality parameters

In Table 8, the specific quality parameters measured were generalised into one out of four groups. The major groups are physiochemical and chemical, followed by sensory and microbial. Physiochemical parameters are those that are measured by physical means. Important parameters here are pH, water holding properties, colour and texture. Chemical parameters are quality parameters related to autolytic processes, chemical processes, chemical content and specific compounds. In this group important parameters are TVB-N (total volatile base nitrogen), K-value, myofibril proteins, ATP, FFA (free fatty acids), FAA (free amino acids) and oxidation of both lipids and proteins. The sensory quality parameters are the parameters measured by sensory methods. These are the characteristics measurable by human senses and they are taste, smell, colour and texture. Additionally, it is also possible to measure by preference scores, but these methods were not present. Lastly, microbial parameters are all about the presence of microbiota in the samples. Typically this can be both specific and general, and in the case of most of the studies included here it is general presence of bacteria, with some cases checking for specific bacteria like *Pseudomonas spp.*

Table 8: Quality parameters measured in the included studies.

Authors	Physiochemical	Chemical	Sensory	Microbial
Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., Zhang, J.	x			
Chen, Z., Jia, J., Wu, Y., Chiba, H., Hui, SP.		x		
Zhou, P., Chu, Y., Lv, Y., Xie, J.	x	x		
Chu, Y., Cheng, H., Yu, H., Jun Mei, J., Xie, J.	x	x		

Authors	Physiochemical	Chemical	Sensory	Microbial
Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., Dong, X.	x	x		x
Hu, C., Xie, J.	x	x		
Chan,S.S., (1), Roth, B., Skare, M., Hernar, M., Jessen,F., Løvdal, T., Jakobsen, A.N., Lerfall, J.	x	x		x
Karki, S., Chowdhury, S., Nath, S., Dora, KC.	x			x
Chan,S.S., (2), Roth,B., Jessen, F., Løvdal, T., Jakobsen, A. N., Lerfall, J.	x	x		x
Hizbullah, HH., Sari, NK., Nurhayati,T., Nurilmala,M.		x	x	
Kang, T., Shafel, T., Lee, D., Lee, CJ., Lee, SH., Jun, S.	x	x		
Le, TT., Nguyen, HT., Pham,MA.	x	x		
Cropotova, J., Mozuraityte, R., Standal, I.B., Grøvlen, M.S., Rustad,T.	x	x		
Truonghuynh, HT., Li, B. Zhu, H.,, Guo, Q., Li, S.	x			
Shikha, FH. Rahman, MA. Hossain, MI.	x	x		x

Authors	Physiochemical	Chemical	Sensory	Microbial
Sreelakshmi, KR., Rehana, R. Renjith, RK., Sarika, K.,. Greeshma, SS., Minimol, VA., K. Ashokkumar, K.., Ninan, G.	x	x	x	x
Yang,F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., Zhan, X.	x	x		
Chudasama, BG., Dave, TH., Bhola, DV.	x	x	x	
Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L., Li, J., Zhang, Y.	x	x		
Standal, IB., Mozuraityte, R., Rustad, T., Alinasabhematabadi, Carlsson, NG., Undeland, I.	x	x		
Li, Q., Zhang, L., Luo, Y.		x	x	x
Luan, L., Sun,Y., Chen, S., Wu, C., Hu, Y.	x			
Mohan, CO., Ashitha, VA., Kishore, P., Panda, SK., Ravishankar, CN.		x		
Qian, P., Zhang, Y., Shen, Q., Ren, L. Jin, R., Xue, J., Yao, H., Dai, Z.	x	x		
Kaale, LD., Johansen, T., Rustad, T.	x	x		

Authors	Physiochemical	Chemical	Sensory	Microbial
Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., Hu, Y.	x	x		
Sormin, RBD., Pattipeilohy, F., Atua, AJ.		x		x
Roiha, IS., Jónsson, Á., Backi, CJ., Lunestaad, BT., Karlsdóttir, MG.	x	x	x	x
Tokarczyk, G., Biebkiewicz, G., Suryn, J		x		
Fuchiyama, Y.,Nakazawa, N., Okumura, K., Osako, K., Okazaki, E.	x	x		
Mahusain, MAS., Bayoi, F., KARIM, NU., Zainol, MK., Danish-Daniel, M.		x		x
Hashimoto, K., Kobayashi, S., Yamashita, M.	x	x		
Cheng JH., Sun, DW., ZHU, Z.	x	x		
Zhu, Y., Mab, L., Yang, H., Xiao, Y., Xiong, YL.	x	x		x
Kaale, LD., Eikevik, TM.	x	x		
Mazrouh, MM.		x		
Bao, Y., Zhu, S., Luo, Y., Shen, H.	x	x		
Al-Jasser, M., Al-Jasass, F.M.	x	x		x

Authors	Physiochemical	Chemical	Sensory	Microbial
Kaale, L.D., Eikevik, T.M., Rustad, T., Nordtvedt, T.S.	x			
Viji P., Tanuja S., Ninan, G., Zynudheen A.A, Lalitha, K.V.	x	x	x	x
Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., Lenhardt, L.	x	x		x
Total	**33**	**36**	**6**	**14**

As stated above, there are four main quality parameters that are measured. These are physiochemical, chemical, sensory and microbial. In this study it was found that chemical quality parameters were the most commonly studied, with 36 studies reporting on changes in chemical parameters. Second most common parameter is physiochemical with 33 studies reporting, followed by microbial parameters with 14 and lastly sensory characteristics and quality parameters with only 6.

It was found in this study that 8 of the included studies only measured 1 parameter, 21 studies measured 2 parameters, 9 studies measured 3 parameters, 3 studies measured all 4 parameters.

The studies that measured only one parameter was (Guo et al., 2023), (Chen et al., 2022), (Truonghuynh et al., 2020), (Luan et al., 2018), (Mohan et al., 2018), (Tokarczyk et al., 2017), (Mazrouh, 2015) and (Kaale et al., 2014).

The studies that measured two parameters was (Zhou et al., 2022), (Zhu et al., 2016), (Hu & Xie, 2021), (Karki et al., 2020), (Hizbullah et al., 2020), (Kang et al., 2020), (Le et al., 2020), (Cropotova et al., 2019), (Yang et al., 2019), (Sun et al., 2018), (Standal et al., 2018), (Qian et al., 2018), (Kaale et al., 2018), (Jiang et al., 2018), (Sormin et al., 2017), (Fuchiyama et al., 2017), (Mahusain et al., 2017), (Hashimoto et al., 2017), (Cheng et al., 2017), (Kaale & Eikevik, 2016) and (Bao et al., 2015)

The studies that measured three parameters was (Fan et al., 2021), (Chan (1) et al., 2020), (Chan (2) et al., 2020), (Shikha et al., 2019), (Chudasama et al., 2018), (Li et al., 2018), (Zhu et al., 2016), (Al-Jasser & Al-Jasass, 2014), and (Popelka et al., 2014)

Lastly, the studies that measured all four parameters were (Sreelakshmi et al., 2019), (Roiha et al., 2018) and (Viji et al., 2014).

5.5 Synthesis of the processing methods and quality parameters in the included studies

A synthesis of results functions as an overview of the most important results. In a synthesis of results, two objects measured in a review are put together. In this case, the processing methods from table 5 and the parameters measured from table 6 are both in the same table. The synthesis was conducted to see if any patterns were clearly visible. If there was a visible correlation between what processing methods were used and what quality parameters were measured, it would be made clear in this table.

Table 9: Synthesis of processing method used and the quality parameters measured in the included studies

Authors	Processing method	Quality parameters
Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., Zhang, J.	Chilling & superchilling	Physiochemical
Chen, Z., Jia, J., Wu, Y., Chiba, H., Hui, SP.	Chilling & freezing	Chemical
Zhou, P., Chu, Y., Lv, Y., Xie, J.	Freezing	Physiochemical, chemical
Chu, Y., Cheng, H., Yu, H., Jun Mei, J., Xie, J.	Freezing	Physiochemical, chemical

Authors	Processing method	Quality parameters
Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., Dong, X.	Superchilling	Physiochemical, chemical & microbial
Hu, C., Xie, J.	Freezing	Physiochemical, chemical
Chan,S.S., (1), Roth, B., Skare, M., Hernar, M., Jessen,F., Løvdal, T., Jakobsen, A.N., Lerfall, J.	Chilling, superchilling	Physiochemical, chemical & microbial
Karki, S., Chowdhury, S., Nath, S., Dora, KC.	Freezing	Physiochemical & microbial
Chan,S.S., (2), Roth,B., Jessen, F., Løvdal, T., Jakobsen, A. N., Lerfall, J.	Chilling	Physiochemical, chemical & microbial
Hizbullah, HH., Sari, NK., Nurhayati,T., Nurilmala,M.	Chilling	Chemical & sensory
Kang, T., Shafel, T., Lee, D., Lee, CJ., Lee, SH., Jun, S.	Chilling, superchilling & freezing	Physiochemical & chemical
Le, TT., Nguyen, HT., Pham,MA.	Chilling & freezing	Physiochemical & chemical
Cropotova, J., Mozuraityte, R., Standal, I.B., Grøvlen, M.S., Rustad,T.	Chilling & superchilling	Physiochemical & chemical
Truonghuynh, HT., Li, B. Zhu, H.,, Guo, Q., Li, S.	Freezing	Physiochemical
Shikha, FH. Rahman, MA. Hossain, MI.	Chilling & freezing	Physiochemical, chemical & microbial
Sreelakshmi, KR., Rehana, R. Renjith, RK., Sarika, K.,. Greeshma, SS., Minimol, VA., K. Ashokkumar, K.., Ninan, G.	Chilling	Physiochemical, chemical, microbial & sensory

Authors	Processing method	Quality parameters
Yang,F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., Zhan, X.	Superchilling	Physiochemical & chemical
Chudasama, BG., Dave, TH., Bhola, DV.	Chilling	Physicochemical, chemical & sensory
Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L., Li, J., Zhang, Y.	Chilling	Physiochemical & chemical
Standal, IB., Mozuraityte, R., Rustad, T., Alinasabhematabadi, Carlsson, NG., Undeland, I.	Chilling & freezing	Physiochemical & chemical
Li, Q., Zhang, L., Luo, Y.	Chilling & freezing	Chemical, sensory & microbial
Luan, L., Sun,Y., Chen, S., Wu, C., Hu, Y.	Freezing	Physiochemical
Mohan, CO., Ashitha, VA., Kishore, P., Panda, SK., Ravishankar, CN.	Chilling	Chemical
Qian, P., Zhang, Y., Shen, Q., Ren, L. Jin, R., Xue, J., Yao, H., Dai, Z.	Freezing	Physiochemical & chemical
Kaale, LD., Johansen, T., Rustad, T.	Superchilling	Physiochemical & chemical
Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., Hu, Y.	Freezing	Physiochemical & chemical
Sormin, RBD., Pattipeilohy, F., Atua, AJ.	Chilling	Chemical & microbial
Roiha, IS., Jónsson, Á., Backi, CJ., Lunestadad, BT., Karlsdóttir, MG.	Chilling & freezing	Physiochemical, chemical, microbial & sensory

Authors	Processing method	Quality parameters
Tokarczyk, G., Biebkiewicz, G., Suryn, J	Chilling	Chemical
Fuchiyama, Y.,Nakazawa, N., Okumura, K., Osako, K., Okazaki, E.	Freezing	Physiochemical & chemical
Mahusain, MAS., Bayoi, F., KARIM, NU., Zainol, MK., Danish-Daniel, M.	Chilling & freezing	Chemical & microbial
Hashimoto, K., Kobayashi, S., Yamashita, M.	Chilling & freezing	Physiochemical & chemical
Cheng JH., Sun, DW., ZHU, Z.	Freezing	Physiochemical & chemical
Zhu, Y., Mab, L., Yang, H., Xiao, Y., Xiong, YL.	Superchilling	Chemical & microbial
Kaale, LD., Eikevik, TM.	Superchilling	Physiochemical & chemical
Mazrouh, MM.	Freezing	Chemical
Bao, Y., Zhu, S., Luo, Y., Shen, H.	Chilling & freezing	Physiochemical & chemical
Al-Jasser, M., Al-Jasass, F.M.	Chilling & freezing	Physiochemical, chemical & microbial
Kaale, L.D., Eikevik, T.M., Rustad, T., Nordtvedt, T.S.	Chilling & freezing	Physiochemical
Viji P., Tanuja S., Ninan, G., Zynudheen A.A, Lalitha, K.V.	Chilling	Physiochemical, chemical , microbial & sensory
Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., Lenhardt, L.	Freezing	Physiochemical, chemical & microbial

In the synthesis of results, it is difficult to ascertain any patterns or connections between the processing method and quality parameters measured. The only thing that is really possible to say is that freezing and chemical parameters were the two most common processing methods and quality parameters measured. This is only by a small margin, as both freezing and chemical quality is only slightly more common than chilling and physichemical quality. In the case of superchilling, it was significantly less common to use as a processing method than the others. Also, sensory quality parameters were not determined when superchilling was used in any of the included studies in this thesis. Additionally, only the physicochemical and chemical quality parameters were measured alone, whereas microbial and sensory quality parameters were only measured together with other quality parameters.

As a further examination, it was thought to determine what specific parameters were most common. As the absolute majority were physiochemical and chemical parameters, they were chosen.

A summary of the physiochemical quality parameters are: pH, texture, colour, Rigor mortis and the“water group” (drip loss, water retention, WHC, centrifugal loss, cooking loss, moisture content, water activity, thawing loss, pressing loss, total loss, expressive drip, yield)

As explained previously, the physiochemical group is defined by how the parameters are measured. This means that for a parameter to be called physiochemical it needs to be measured by physiochemical or physical methods. In the physiochemical group, there are five common parameters; pH, texture, colour, Rigor mortis and what was called the “water group”. pH and Rigor mortis are parameters that can often be associated with chemical quality. pH being an expression of acidity/alkalinity and Rigor mortis being caused by a biochemical process in the fish muscle after death. However, both of these methods are measured by physical methods. Texture and colour are quality parameters derived from the chemical composition and structure of the product. Texture is a consequence of protein structures and water content, while colour is directly affected by what chemical compounds are in the product and how they scatter light. These two quality parameters in the physiochemical group are both different from the rest as they are also measurable by sensory methods, as well as both chemical and physiochemical methods. To simplify this conundrum; texture and colour are *chemically derived* quality parameters that are *sensory characteristics* of the product but are usually measured by physical methods. The “water group” is a term for all the different kinds of parameters or methods tested which all measure changes in water content or how well the water is bound in the muscle. Cooking loss, centrifugal loss and drip loss are all different methods that measure changes in water content, often by expressing how well the muscle tissue can hold onto the water bound in its structure. The standout parameter in the “water group” is water activity, which does not inherently measure changes in water contents but is an expression of the state or condition of the water in the product. And when measured comparatively between samples, it does give an indication of changes in water activity. This value shows how available the water is for reactions and microbial growth

To summarise the chemical quality parameters that were most common: chemical composition, TVB-N, K-value, myofibril proteins, TMA-N, ATP, FFA, FAA, oxidation (both protein and lipid)

In the chemical group, most analyses were about the chemical composition of the fish. This is either a general approximation of the contents of the main components (water, proteins, fatty acids and ash) or more specific kinds of composition, like the composition of different proteins, ratio of saturated fatty acids, free amino acids or free fatty acids. Other than the chemical composition of the fish, chemical analyses were conducted to investigate the K-value or other ATP-related components. K-value shows the relationship between growth rate of microorganisms and concentration of substrate. Another kind of chemical analysis retaining to quality are on the contents of unwanted compounds like volatile base nitrogen, biogenic amines (histamine and cadaverine are examples of typical biogenic amines that are of interest when assessing the chemical quality of fish) and trimethylamine. Lastly, a common chemical quality parameter to measure is oxidation of proteins and fatty acids. This is an important parameter to measure for multiple reasons. Oxidised compounds cause significant sensory quality loss to the product and can be unhealthy and potentially harmful for a consumer. Compounds oxidised in fish are usually fatty acids and proteins.

6.0 Discussion

In the discussion part of this thesis, the results will be discussed considering earlier presented knowledge and the research questions. The research questions are as follows:

1. What are the processes used in the included studies?
2. What are the quality parameters measured in the included studies?
3. How are these processes correlated to the measured quality parameters?

To answer these research questions, each research question will be given their own parts and answered one at a time. Firstly, I will examine results not directly involved in the research questions (6.1) and results that summarise the contents of the included studies (6.2), but that are important to understanding the physical material that is being examined. These are rather straightforward and descriptive of the contents of the included studies. Therefore, the discussion is short as there is little to discuss on the matter. After which the research questions will be answered.

6.1 The use of whole fish vs. filleted/processed/cut fish in the included studies.

In this part, the use of fish used in the included studies was whole or processed. This is of importance because when fish is processed, as in cut or filleted, the product becomes more susceptible to outside influences. A filleted fish is at a much higher risk of contamination or oxidation than a whole fish. An exception to this can be if the fish is not gutted. A whole, ungutted fish, can be contaminated by the naturally occurring processes in the guts of the fish. These processes are either autolytic or microbial (Alasalvar et al., 2010; Muzaddadi et al., 2016; Oehlenschläger 2014). As is shown in the results (Table 6), the majority of the included studies used filleted or cut fish in their studies. It is therefore possible that the findings in the included studies are influenced by outside contamination due to being exposed to open air. This can have increased the influences on the product. Another issue is how the measurement was done. In some cases, a part of the fillet was cut out and measured, whereas others did not process the fillet further. This is potentially a big problem for comparisons between studies. Individual differences in values can be found both on a single fillet and on a single fish. This means a single fish can potentially give multiple values for the same analyses. Typically, a study includes multiple fish. Oftentimes there are some individual differences in values for each fish and each fillet. This can be an issue in a study, but in a review it becomes a much greater issue. This is simply a matter of scale. In this thesis there are 41 included studies, all of which included more than one fillet. This means that the potential differences between the samples in total are large. On top of this, different species of fish also give different results and react differently to exposure. This enforces that a qualitative approach is more suitable compared to a quantitative approach. These are bigger problems for a quantitative approach since the values are too different, which makes it very difficult to compare the studies. Whereas in a qualitative approach, the numerical results are less important than what they show. In a qualitative approach, rather than looking at values and trying to gain some insight into trends or correlations, what the results show in a general sense and what these results show is what is important in a qualitative approach. As an example, instead of trying to compare the different measurements of texture, chemical composition or WHC numerically which vary a lot per fish and fillet as well as per study, try to compare the results and what those results mean. Ask the questions of what does the change in WHC mean for the product rather than what is the change in WHC in certain situations. Therefore it is easier to compare different results when the individual numerical differences are less important. This also applies to the differences between whole and filleted fish. The difference between whole and filleted fish can impact the results, but they do not impact what the results mean. There is one exception, and that would be in the case where a measurement is impacted in such a way that the interpretation of the result is entirely altered based on if the fish was whole or not. For instance, if in a comparison of two studies investigating chilling technologies where one processing method shows no impact and another shows a lot of impact and the only difference between the two samples was that one was whole and the other a fillet, it is of vital importance that this is taken into consideration. Generally speaking given enough scale this should not be an issue. As in this case there are 41 studies and the majority were cut or filleted, the differences should not impact the results much.

6.2 What are the processes used in the included studies?

Chilling is a form of technology where temperature is lowered to around or just above the freezing point of water. This can be done by technology like traditional refrigeration (cold storage), RSW and ice. Ice and RSW is commonly combined in a slurry to maintain the lower temperature for a longer period of time. Typically ice can be added to seawater to make RSW or slurry. Chilling is an important method of maintaining the quality of fresh fish, but it is not enough to extend the shelf life of fish for long periods of time. Even combined with other methods like smoking and salting, the extended shelf life is limited to a few weeks at most. And the quality loss is not insignificant in that timeframe. Autolytic and microbial processes still occur during chilled temperatures, and chilling only prevents the microorganisms already present from growing. It does not kill or destroy microorganisms, like some other methods do. Chilling is easy to do as it does not require very low temperatures, but it does only slow (and not stop) the processes post mortem.

Freezing is in principle the same as chilling. However, there is one very obvious difference between the two and that is the temperature. The temperature used in freezing is much lower than the temperature in chilling. Where chilling tries to avoid being below the freezing point of water, freezing is often at significantly lower temperatures. This is because the point of freezing is to freeze the water in the product. There are many different ways to freeze fish. There are more traditional methods such as cold storage in freezing temperature, blast freezers or plate freezers and there are also more modern methods like cryogenic freezing, pressure shift freezing and impingement freezing. The traditional methods tend to expose the product to very cold environments or in direct contact with a very cold object. The newer methods tend to lean more towards exposing the product to very specific conditions to improve freezing time or in direct contact with a freezing medium. The differences are small, but significant. Freezing has the benefit of increasing the shelf life significantly. Due to the very cold temperatures used in freezing processes, autolytic and microbial processes are slowed down, thus keeping the quality for a longer period of time. However, some chemical processes are not impacted much but freezing. Oxidation processes occur even during freezing and even if they are slowed down significantly unsaturated marine lipids are still susceptible to oxidation. Lipids and proteins are more vulnerable to oxygen when the product is frozen as they are less protected by water. Another issue with freezing is WHC. The problems surrounding this are discussed further below (6.3), but it is important to note how freezing impacts water. Due to the freezing process, water is often lost. This happens when water evaporates during freezing, the formation of ice crystals and when the product thaws. Water loss is particularly high when there are multiple freezing-thawing cycles. Freezing causes irreversible water loss due to denaturation of the proteins in the product. Freezing can kill or destroy microbial cells, and very few microbial processes can continue during frozen storage. It is however not an effective and consistent way of killing microorganisms and is primarily used to stop growth for an extended period of time. The same can be said about enzymatic activity, the only difference being that it does not stop like growth of microorganisms does. It only slows down, however it does slow down significantly. All in all, freezing improves the shelf life significantly, but may come at the cost of certain quality parameters.

Superchilling is a modern technology where the product is brought to or just below the freezing point. This gives some of the benefits of both chilling and freezing in one solution. It has the lower temperature of freezing while giving the more gentle influence of chilling. It carries the characteristics of a “best of both worlds"-approach. It is important to note that superchilling does not provide the same level of prevention of microbial growth and enzymatic activity that freezing does, but it allows for a greater prevention than what is found in chilling. Superchilling uses the same methods as chilling and freezing, but at different times and temperatures. The main benefit of superchilling is during storage and transportation. Superchilled fish products do not need a cold medium like ice or RSW to stay cold, they function as their own cold medium. This is significant for costs and convenience of transport. Ice takes up a lot of space and weight both in boats and trucks, which equates to a lot of costs. In addition, transporting that much ice and water only to keep the product cool causes a lot of unnecessary environmental impacts. Superchilling also improves some elements of WHC, as there are less freezing-thawing cycles needed during processing. Which will reduce the water loss during handling since it is sometimes necessary to thaw a product before it can be filleted, which then often becomes frozen again. This is more common in cases where fish is frozen as catch or otherwise frozen during transport. There are however some practical issues when considering superchilling. Generally speaking, more research is needed to figure out correct temperatures to maintain the superchilled state. And even if there are less freezing-thawing cycles, which does reduce the water loss, the process itself has some issues relating to water loss. Drip loss is not a very large issue in superchilling, but there are some reductions in WHC in some species like cod.

The results show that in the included studies, freezing is the most measured processing technology. This is followed closely by chilling. These two processing methods eclipsed superchilling, at less than half the number of studies of chilling and freezing (Table 7). This should not be surprising, as the search words specified chilling and freezing. We can therefore conclude that chilling and freezing form roughly one-half each of the entirety. It is in this case important to remember that some studies that covered more than one process. Fifteen studies assessed two or more processes.

Freezing has the most cases, chilling second most followed by the others at noticeably lower numbers. Twenty-six studies documented only one method, and fifteen studies documented more than one method. Three out of these fifteen measured more than two processing methods (Table 7). What was found by these studies and how that information could be used is discussed below in chapter 6.4. However, generally speaking there were three different types of studies. They either compared the methods with each other, they compared different types of methods to each other (as in plate and cryogenic freezing) or they documented the effects of one or more methods. Typically, methods that only measured one method documented the effects whereas studies that measured more than one compared the methods to each other. Comparative studies usually reported that one method was more suitable than the others and the studies that documented the effects generally noted loss of quality compared to fresh fish or that certain processes and activity still occurred during storage.

6.3 What are the quality parameters measured in the included studies?

Chemical quality parameters are the most common parameter with thirty-six of the included studies using this, and it is followed by physiochemical quality parameters which are used by thirty-tree of the included studies. Microbial quality parameters are much less common in only fourteen of the included studies used and sensory is the least common quality parameter used by only six studies that tested sensory parameters (Table 8). Only seven of the included studies measured only one parameter, while twenty of the included studies measured two quality parameters. Eleven of the included studies measured three quality parameters and only three measured all four quality parameters (Table 8).

The quality parameters most common in the included studies were chemical composition, pH, texture, colour, ATP-related compounds, TMA-N, TVB-N and measurements related to water contents (the “water group”). As many of the measurements of quality parameters reported in the included studies do not share the same name, grouping them into generalised groups is helpful because it allows for an overview. This will be covered more extensively below in chapter 6.4, but the groups most common in the included studies are chemical composition, ATP-related compounds and the “water group”. Based on the definition given earlier on in this thesis, the “water group” can also be summarised as WHC. It is interesting that there are so many different ways to measure WHC. However, the problem of all the numerous ways of measuring what could be summarised as WHC could be the theory used in this thesis rather than the included studies using different methods to measure the same things. It is debatable that all the water content analyses can be summarised as WHC. Drip loss, cooking loss and centrifugal loss are all methods to record WHC during specific conditions. But moisture content and water activity are expressions of the content and condition of the water in the product, while WHC is the product's ability to contain or hold its water. This makes comparing the values and results of WHC difficult, as well as grouping it all up under the WHC group. WHC covers drip, cooking and centrifugal loss quite well, and can by extension cover methods retaining to moisture content if the measurements are expressed as changes. However, grouping up water activity with the others seems wrong as it is a measurement of the availability of water for reactions and microbial activity. There is a simple solution, and it needs both the “water group” and WHC to be used as terms for the groups of these kinds of quality parameters. WHC can be used as a general term when not involving measurements like water activity or water content measurements not expressed as changes. The “water group” term can be used as a general term when involving any measurement of water contents. Since the results in this thesis are mostly expressed as change in value, grouping them in the “water group” can be considered.

Another group of measurements, in chemical parameters, is both chemical composition and ATP-related compounds. ATP-related compounds are a narrower group than chemical composition. The larger of the groups is the chemical composition group where both specific and general chemical composition analysis can be found. Specific chemical composition analysis are the types of analyses where a specific compound is targeted in the study. This was mostly TMA-N and TVB-N, but others measured FFA and FAA. General chemical composition is a term that is slightly misleading, as these compounds are also targeted specifically, but in a larger view. As an example, when analysing the chemical composition of a fish fillet, proteins, fatty acids, ash and water are all specifically targeted. The idea is not to specifically target the compounds individually, but to use the data to get an overview over the total contents in the fillet. ATP-related compounds were reported as either that or they were measured as K-value. K-value is a way to describe activity occurring in the product as it shows the relationship between microbial growth and solubles. Lastly, biogenic amines are also a very important part of chemical quality. Most commonly tested in the included studies was TMA, which was very common. However, other important biogenic amines like cadaverine and histamine were mostly left out.

In the majority of the sensory cases, scoring or QIM-style sensory analyses or organoleptic analyses were conducted. The cases about microorganisms were analyses of total contents or presence of bacteria. It makes sense that research into freezing was more concerned with chemical and physiochemical parameters, but I find it intriguing that cases studying chilling were not so interested in microbial contents. It could simply be a matter of time and resources, as is probably the most logical conclusion. Microbial analyses can often take a long time compared to other analyses and therefore the authors might not have had the available time and resources to conduct such an analysis. Another argument for the lack of microbial analyses could be that the products are not meant to be consumed raw, and it is assumed that most if not all would be removed by later processing steps like salting or drying, thereby making an analysis of microbial contents wasted. That is however an unlikely reason to why there are so few microbial analyses, as for industry production and sales to consumers, microbial contents are a requirement. And this is potentially the third argument for why there are no microbial counts. As it is a requirement for production, the test of microbial counts may be viewed as unnecessary, as it's always done and not of interest. I rate this as the second most likely candidate, just below the most likely reason: time and resources.

The results in the included studies focused mostly on the processing methods, and therefore concluded based on that. An example is Guo et al. (2023), Zhou et al. (2022), Chu et al. (2021), Fan et al. (2021) and Chan et al. (2020) (1) & (2) that all documented the effectiveness of various processing methods. This means that these results represent only one out of the parts of the problem, the quality parameters were mostly left out. Therefore, these results were left out of this thesis. Additionally, the intention of the review is only to investigate the general trend of what can be said, and not the specific results of each study.

6.4 If and/or how different chilling and freezing processes are correlated to the measured quality parameters?

In this paragraph of the thesis, the synthesis of the results (Table 9) will be used to discuss the results. It is difficult to ascertain any patterns or correlations between the processing method and quality parameters.

Physiochemical and chemical quality parameters were measured alone and microbial and sensory were only present with other quality parameters. It seems like the included studies both described several processes and several quality parameters in the same study.

For freezing, chilling and superchilling, there are two different ways to describe the results. Either, it is a comparison between the different processing methods (comparative studies between chilling, freezing and superchilling), a comparison of different types of processing methods (different kinds of freezing methods like cryogenic and plate freezers), or it is a documentation of the effect of the processing methods on the product. These three can all be done simultaneously, and in some cases there are. Mostly it was the second and third cases that were most common.

The reason it is difficult to see any correlations between processing methods and quality parameters can be divided in two. Reason number one is that the results would be far too generalised to be of much use. In the included studies freezing is the most common processing method, followed closely by chilling and superchilling trailing significantly further behind. Considering quality parameters, chemical parameters are slightly more common than physiochemical, both of which are much more common than sensory and microbial quality parameters. Therefore it can be concluded that when studying the effects of chilling, superchilling and freezing, physiochemical and chemical quality parameters are measured most often. And it can be said that the most common physiochemical quality parameters are pH, texture, colour and the “water group”, while the most common chemical quality parameters are chemical composition, ATP-related compounds, TMA-N, TVB-N and biogenic amines. The problem comes when trying to tie it all together. Even in generalised forms (as in ATP-related compounds, chemical composition, the “water group” and biogenic amines), the parameter groups are far too specific to compare to each other and the most common parameters occur in all three processing methods. This is simply because comparing two parameters that measure two sometimes very different things is difficult. How do you compare a pH value to a measurement of biogenic amines.They are probably correlated in some way and matter in the big picture of the condition of fish. However, comparing them would not make sense. It could make sense to compare one pH measurement to another, and one biogenic amines measurement to another, and comparing them could be relatively straight forward, given that both studies used roughly the same method or methods that give roughly similar results. This kind of comparison has even been done in previous reviews (Tolstorebrov et al., 2016). But now we are in a different problem that will be covered in the next paragraph. To be able to compare the quality parameters, it is easiest to keep them on the most general terms. Which brings us back to the original problem; the larger groups of parameters are too general to give any specific results. They only give indications to what parameters are common.

Reason number two, it is possible to say that analysing and testing frozen products is slightly more common than chilling and both chilling and freezing is much more common than superchilling. However, not much more is possible to ascertain on a general level in this thesis based on the included studies. It is important to remember that the intention of this thesis is not to investigate the individual studies results, but to try to get an overview and see if any correlations can be found in general terms. This current review study revealed that the included studies used a number of different quality parameters and also numerous processing methods. This makes it challenging to look at the results in the individual studies.

Looking at the proposed problems, there seems to be some obvious solutions; narrow the scope. By narrowing the scope a large point of doing a review is lost. Reviews are supposed to be generally descriptive, and therefore narrowing down too much loses the point of doing a review.

A method of review that sustains both an appropriate scope and is narrow enough to function must be found. A similar statement can be made about the previous reviews found. Reviews can suffer from being too general or broad. Tolstorebrov et al. (2016) is an example of only studying one processing method, which can seem like a suitable method of reducing the scope. However, that review is limited not only to freezing, but to very low temperature freezing. This leads to the review not adding a lot of new information nor does it answer anything but the very specific questions asked. Tolstorebrovs work is not bad, on the contrary, it is very good. But as a review, I can't help but think that it is too narrow. Other reviews like Erikson et al. (2021) and Duarte et al. (2020) have the opposite problem, more similar to the issues found here. The scopes are quite large and the reviews cover comprehensive subjects. Interestingly, these two reviews use language like "case study" and "mini-review" to describe their own work. So, possibly a suitable solution to larger reviews is a change of language from calling it simply a review to a more general, less formal language like case study.

However, I would like to offer a different solution. This solution is a middle ground between narrowing down and generalising. First, a generalisation of a quality parameter. A good example is the "water group", the group of different water content measurements. Generally in the included studies the measurements on water content was done by measuring the differences from A to B, for instance the loss of weight between point A and point B which would show the loss of water during storage. This parameter is often called drip loss. After picking a generalised quality parameter, the next step would be to assess processing methods. Now, as the review is narrowed down to one quality parameter and generalised, there are a few options from here. By narrowing down more, only pick one processing method. If one processing method is too little, then at this stage it is possible to pick multiple. This will help with giving a better overview of the situation as a whole, but does come at the cost of specifics. Something that could help the larger reviews is more consistency in methods and measurements. If everyone measured the same things in the same way or used the same measurement for the same data, large scale cross method comparisons could be possible. If, as an example, everyone used drip loss as a way to express changes in water content (and by drip loss, everyone meant the same thing) and everyone used the same method of measuring drip loss then comparing across different processing methods should be possible. However, even with a parameter as seemingly easy to measure the same way as drip loss, this is not an easy thing to ask. Therefore, a more generalised approach is probably the most fruitful for large reviews.

7.0 Conclusion

To conclude this thesis, we must first look at the proposed research questions. The research questions are as follows:

What are the processes used in the included studies?
What are the quality parameters measured in the included studies?
If and/or how different chilling and freezing processes are correlated to the measured quality parameters?

The processes used in the included study are generally freezing, chilling and superchilling. In these generalised groups, there are both different freezing and chilling methods. Freezing can either be traditional or modern. Traditional methods are cold storage, plate or contact freezers and air blast freezers. Modern methods are cryogenic, impingement and pressure shift freezing. The latter two were not frequently present in the included studies, but cryogenic freezing was sometimes used. In chilling, the typical methods used are cold storage, ice and RSW. In the included study, freezing was most used, followed closely by chilling. Superchilling is much less common to investigate as a processing method for fish.

Quality parameters are a very large group, and therefore were generalised into four categories; chemical, physiochemical, microbial and sensory quality. Typically, chemical quality was measured as chemical composition, ATP-related compounds, TMA-N, TVB-N and biogenic amines while the most common physiochemical parameters were pH, texture, colour and water content. Microbial quality was measured as the presence of microorganisms, and sensory quality was measured by scoring or QIM-style analyses.

In the included studies, there was not much of a correlation to be found between the processing methods and quality parameters. From those results, it can be said that the majority of the cases in the included studies used freezing and/or chilling processing methods and measured chemical and/or physiochemical quality parameters. It was most common to measure two quality parameters and only one processing method. Reducing the scope can give more accurate results, however it is important to note the intention of a review is to identify general trends and reducing the scope can compromise that.

A possibility is to compromise by both generalising and narrowing down. One can narrow down to a specific group of quality parameters, preferably not an entire group of parameters but rather a sub group like water contents or ATP-related compounds, and from there investigate what processing methods are used and their impacts. It is also possible to narrow down to a processing method, but it is common to measure multiple quality parameters on the same processing method, making it very hard to compare the processing methods. It is easier to compare processing methods and therefore narrowing down to one quality parameter group might be the most convenient way to satisfy the intention of a review study, while also gaining more distinct results.

The included studies did not investigate correlations between different quality parameters. An example of this is how texture can be impacted by protein structure, pH and/or WHC, as mentioned in previous chapters.

In this review study, the included studies presented a variety of processing methods and quality parameters. Future work may concentrate on one quality parameter group (as in the “water group” or chemical composition) and test different processing methods related to that quality parameter group. It will be easier to compare findings from different studies and present more substantial recommendations. Based on conclusions from this review study, it seems to be easier to compare processing methods than quality parameters because of the internal variation in quality parameters, and the use of quality parameters groups is therefore better. In the future it may also be beneficial to focus more on research on superchilling. This is an effective method for the storage and transport of fish products and is beneficial to be concentrated on in future research.

Alasalvar, C., Grigor, J. M., & Ali, Z. (2010). Practical Evaluation of Fish Quality by Objective, Subjective, and Statistical Testing. I *Handbook of Seafood Quality, Safety and Health Applications* (s. 11–28). https://doi.org/10.1002/9781444325546.ch2

Al-Jasser, M. S., & Al-Jasass, F. M. (2014). Study the chemical, physical changes and microbial growth as quality measurement of fish. *Annual Research & Review in Biology,* 1406–1420.

Bagenda, D. K., & Yamazaki, K. (2010). Food-Borne Pathogens in Seafood and Their Control. I *Handbook of Seafood Quality, Safety and Health Applications* (s. 195–205). https://doi.org/10.1002/9781444325546.ch16

Bao, Y., Zhu, S., Luo, Y., & Shen, H. (2015). Comparison of postmortem changes in blunt-snout bream (Megalobrama amblycephala) during short-term storage at chilled and partial freezing temperatures. *Journal of Aquatic Food Product Technology*, *24*(8), 752–761.

Boziaris, I. S., & Parlapani, F. F. (2014). Microbiological Examination of Seafood. I *Seafood Processing* (s. 387–418). https://doi.org/10.1002/9781118346174.ch15

Chan (1), S. S., Roth, B., Skare, M., Hernar, M., Jessen, F., Løvdal, T., Jakobsen, A. N., & Lerfall, J. (2020). Effect of chilling technologies on water holding properties and other quality parameters throughout the whole value chain: From whole fish to cold-smoked fillets of Atlantic salmon (Salmo salar). *Aquaculture*, *526*, 735381.

Chan (2), S. S., Roth, B., Jessen, F., Løvdal, T., Jakobsen, A. N., & Lerfall, J. (2020). A comparative study of Atlantic salmon chilled in refrigerated seawater versus on ice: From whole fish to cold-smoked fillets. *Scientific Reports*, *10*(1), 17160.

Chen, Z., Jia, J., Wu, Y., Chiba, H., & Hui, S.-P. (2022). LC/MS analysis of storage-induced plasmalogen loss in ready-to-eat fish. *Food Chemistry*, *383*, 132320.

Cheng, J., Sun, D., & Zhu, Z. (2017). Effects of frozen storage condition abuse on the textural and chemical properties of grass carp (Ctenopharyngodon idella) fillets. *Journal of Food Processing and Preservation*, *41*(1), e13002.

Cheng, J.-H., Sun, D.-W., Han, Z., & Zeng, X.-A. (2014). Texture and Structure Measurements and Analyses for Evaluation of Fish and Fillet Freshness Quality: A Review. *Comprehensive Reviews in Food Science and Food Safety*, *13*(1), 52–61. https://doi.org/10.1111/1541-4337.12043

Chu, Y., Cheng, H., Yu, H., Mei, J., & Xie, J. (2021). Quality enhancement of large yellow croaker (Pseudosciaena crocea) during frozen (-18 ^{o}C) storage by spiral freezing. *CyTA-Journal of Food*, *19*(1), 710–720.

Chudasama, B., Dave, T., & Bhola, D. (2018). Comparative study of quality changes in physicochemical and sensory characteristics of iced and refrigerated chilled store Indian Mackerel (Rastrelliger kanagurta). *Journal of Entomology and Zoology Studies*, *6*(4), 533–537.

Cropotova, J., Mozuraityte, R., Standal, I. B., Grøvlen, M. S., & Rustad, T. (2019). Superchilled, chilled and frozen storage of Atlantic mackerel (Scomber scombrus) fillets–changes in texture, drip loss, protein solubility and oxidation. *International Journal of Food Science & Technology*, *54*(6), 2228–2235.

Duarte, A. M., Silva, F., Pinto, F. R., Barroso, S., & Gil, M. M. (2020). Quality Assessment of Chilled and Frozen Fish—Mini Review. *Foods*, *9*(12). https://doi.org/10.3390/foods9121739

Erikson, U., Uglem, S., & Greiff, K. (2021). Freeze-Chilling of Whitefish: Effects of Capture, On-Board Processing, Freezing, Frozen Storage, Thawing, and Subsequent Chilled Storage—A Review. *Foods*, *10*(11). https://doi.org/10.3390/foods10112661

Fan, X., Jin, Z., Liu, Y., Chen, Y., Konno, K., Zhu, B., & Dong, X. (2021). Effects of super-chilling storage on shelf-life and quality indicators of Coregonus peled based on proteomics analysis. *Food Research International*, *143*, 110229.

Fellows, P. J. (2022). *Food processing technology: Principles and practice*. Woodhead publishing.

Fuchiyama, Y., Nakazawa, N., Okumura, K., Osako, K., & Okazaki, E. (2017). *Study on the thawing method for frozen spotted mackerel with high freshness*.

Guillerm-Regost, C., Haugen, T., Nortvedt, R., Carlehöug, M., Lunestad, B. T., Kiessling, A., & Rørár, A. M. B. (2006). Quality Characterization of Farmed Atlantic Halibut During Ice Storage. *Journal of Food Science*, *71*(2), S83–S90. https://doi.org/10.1111/j.1365-2621.2006.tb08926.x

Guo, X., Wang, N., Wei, Y., Liu, P., Deng, X., Lei, Y., & Zhang, J. (2023). The Effects of Malonaldehyde on Quality Characteristics and Protein Oxidation of Coregonus peled (Coregonuspeled) during Storage. *Foods*, *12*(4), 716.

Gyawali, R., & Ibrahim, S. A. (2016). Effects of hydrocolloids and processing conditions on acid whey production with reference to Greek yogurt. *Trends in Food Science & Technology*, *56*, 61–76. https://doi.org/10.1016/j.tifs.2016.07.013

Hashimoto, K., Kobayashi, S., & Yamashita, M. (2017). Comparison of connective tissue structure and muscle toughness of spotted mackerel Scomber australasicus and Pacific mackerel S. japonicus during chilled and frozen storage. *Fisheries science*, *83*, 133–139.

Hizbullah, H., Sari, N., Nurhayati, T., & Nurilmala, M. (2020). *Quality changes of little tuna fillet (Euthynnus affinis) during chilling temperature storage*. *404*(1), 012015.

Hu, C., & Xie, J. (2021). The effect of multiple freeze–thaw cycles on the microstructure and quality of trachurus murphyi. *Foods*, *10*(6), 1350.

ISO. (2015). *ISO 9000: 2015 Quality management systems—Fundamentals and vocabulary*. https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en

Jessen, F., Nielsen, J., & Larsen, E. (2014). Chilling and Freezing of Fish. I *Seafood Processing* (s. 33–

59). https://doi.org/10.1002/9781118346174.ch3

Jia, H., Roy, K., Pan, J., & Mraz, J. (2022). Icy affairs: Understanding recent advancements in the freezing and frozen storage of fish. *Comprehensive Reviews in Food Science and Food Safety*, *21*(2), 1383–1408. https://doi.org/10.1111/1541-4337.12883

Jiang, Q., Okazaki, E., Zheng, J., Que, T., Chen, S., & Hu, Y. (2018). Structure of northern snakehead (Channa argus) meat: Effects of freezing method and frozen storage. *International journal of food properties*, *21*(1), 1166–1179.

Kang, T., Shafel, T., Lee, D., Lee, C. J., Lee, S. H., & Jun, S. (2020). Quality retention of fresh tuna stored using supercooling technology. *Foods*, *9*(10), 1356.

Karki, S., Chowdhury, S., Nath, S., & Dora, K. C. (2020). *Freezing effects on yield, quality, and microbial load of farmed fish Neolissochilus hexagonolepis (Chocolate Mahseer)*.

Kaale, L. D., & Eikevik, T. M. (2016). Changes of proteins during superchilled storage of Atlantic salmon muscle (Salmo salar). *Journal of food science and technology*, *53*, 441–450.

Kaale, L. D., Eikevik, T. M., Rustad, T., & Kolsaker, K. (2011). Superchilling of food: A review. *Journal of Food Engineering*, *107*(2), 141–146. https://doi.org/10.1016/j.jfoodeng.2011.06.004

Kaale, L. D., Eikevik, T. M., Rustad, T., & Nordtvet, T. S. (2014). Changes in water holding capacity and drip loss of Atlantic salmon (Salmo salar) muscle during superchilled storage. *LWT- Food Science and Technology*, *55*(2), 528–535.

Kaale, L. D., Johansen, T., & Rustad, T. (2018). *Biochemical changes in superchilled storage of salmon (Salmo salar) fillets*.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (Bd. 2). Springer.

Le, T. T., Nguyen, H. T., & Pham, M. A. (2020). Rigor mortis development and effects of filleting conditions on the quality of Tra catfish (Pangasius hypophthalmus) fillets. *Journal of food science and technology*, *57*, 1320–1330.

Li, Q., Zhang, L., & Luo, Y. (2018). Changes in microbial communities and quality attributes of white muscle and dark muscle from common carp (Cyprinus carpio) during chilled and freeze-chilled storage. *Food microbiology*, *73*, 237–244.

Luan, L., Sun, Y., Chen, S., Wu, C., & Hu, Y. (2018). A study of fractal dimension as a quality indicator of hairtail (Trichiurus haumela) samples during frozen storage. *Scientific Reports*, *8*(1), 16468.

Mahusain, N. A. S., Bayoi, F., Karim, N., Zainol, M., & Danish-Daniel, M. (2017). Changes of histamine levels and bacterial growth in longtail tuna, Thunnus tonggol stored at different temperature. *Journal of Sustainability Science and Management*, *3*, 38–46.

Mansfield, B. (2010). “Modern” industrial fisheries and the crisis of overfishing. I *Global political* *ecology* (s. 98–113). Routledge.

Mason, L., Boyle, T., Fyfe, J., Smith, T., & Cordell, D. (2011). National food waste assessment. *Final Report, Institute For Sustainable Futures, Uts*, 78–80.

Mazrouh, M. M. (2015). Effects of freezing storage on the biochemical composition in muscles of Saurida undosquamis (Richardson, 1848) comparing with imported frozen. *International Journal of Fisheries and Aquatic Studies*, *3*(2), 295–299.

Mohan, C., Ashitha, V., Kishore, P., Panda, S. K., & Ravishankar, C. (2018). Influence of mono-and multilayered packaging material on the quality of seer fish (Scomberomorus commerson) during chilled storage. *Journal of Packaging Technology and Research*, *2*, 67–76.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Annals of Internal Medicine*, *151*(4), 264–269.

Muzaddadi, A. U., Devatkal, S., & Oberoi, H. S. (2016). Chapter 9—Seafood Enzymes and Their Application in Food Processing. I G. S. Dhillon & S. Kaur (Red.), *Agro-Industrial Wastes as Feedstock for Enzyme Production* (s. 201–232). Academic Press. https://doi.org/10.1016/B978-0-12-802392-1.00009-5

Oehlenschläger, J. (2014). Seafood Quality Assessment. I *Seafood Processing* (s. 359–386). https://doi.org/10.1002/9781118346174.ch14

Olsson, G. B., Seppola, M. A., & Olsen, R. L. (2007). Water-holding capacity of wild and farmed cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) muscle during ice storage. *LWT-Food Science and Technology*, *40*(5), 793–799.

Popelka, P., Nagy, J., Pipová, M., Marcinčák, S., & Lenhardt, L. (2014). Comparison of chemical, microbiological and histological changes in fresh, frozen and double frozen rainbow trout (Oncorhynchus mykiss). *Acta Vet. Brno*, *83*, 157–161.

Qian, P., Zhang, Y., Shen, Q., Ren, L., Jin, R., Xue, J., Yao, H., & Dai, Z. (2018). Effect of cryogenic immersion freezing on quality changes of vacuum-packed bighead carp (Aristichthys nobilis) during frozen storage. *Journal of Food Processing and Preservation*, *42*(6), e13640.

RESULTS. (u.å.). Google Docs. Hentet 6. juli 2023, fra https://docs.google.com/document/d/1paBZqjg8ARW8jVnB4x2S84EpZ7L_tpnDauqlLyaSgeI/edit?pli=1&usp=embed_facebook

Roiha, I. S., Jónsson, Á., Backi, C. J., Lunestad, B. T., & Karlsdóttir, M. G. (2018). A comparative study of quality and safety of Atlantic cod (Gadus morhua) fillets during cold storage, as affected by different thawing methods of pre-rigor frozen headed and gutted fish. *Journal of the Science of Food and Agriculture*, *98*(1), 400–409.

Sensorisk Studiegruppe. (2015). *Sensorikk-Måling med menneskelige sanser*.

Shikha, F., Rahman, M., & Hossain, M. (2019). Changes in the Nutritional Composition of Fish Condiment Prepared from Thai Pangus (Pangasianodon hypophthalmus) During Storage at Low Temperature for Longer Period. *Worl. J. of Dair. & Food Scie*, *14*(1), 10–16.

Skare, M., Chan, S. S., Handeland, S. O., Løvdal, T., Lerfall, J., & Roth, B. (2021). A comparative study on quality, shelf life and sensory attributes of Atlantic salmon slaughtered on board slaughter vessels against traditional land-based facilities. *Aquaculture*, *540*, 736681.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sormin, R. B., Pattipeilohy, F., & Atua, A. J. (2017). *THE QUALITY CHANGES OF FRESH SKIPJACK (Katsuwonus pelamis) DURING CHIILING STORAGE*. 055–060.

Sreelakshmi, K., Rehana, R., Renjith, R., Sarika, K., Greeshma, S., Minimol, V., Ashokkumar, K., & Ninan, G. (2019). Quality and shelf life assessment of puffer fish (Lagocephalus guentheri) fillets during chilled storage. *Journal of Aquatic Food Product Technology*, *28*(1), 25–37.

Standal, I. B., Mozuraityte, R., Rustad, T., Alinasabhematabadi, L., Carlsson, N.-G., & Undeland, I. (2018). Quality of filleted Atlantic mackerel (Scomber scombrus) during chilled and frozen storage: Changes in lipids, vitamin D, proteins, and small metabolites, including biogenic amines. *Journal of aquatic food product technology*, *27*(3), 338–357.

Sun, Y., Ma, L., Ma, M., Zheng, H., Zhang, X., Cai, L., Li, J., & Zhang, Y. (2018). Texture characteristics of chilled prepared Mandarin fish (Siniperca chuatsi) during storage. *International Journal of Food Properties*, *21*(1), 242–254.

Tanasupawat, S., & Visessanguan, W. (2014). Fish Fermentation. I *Seafood Processing* (s. 177–207). https://doi.org/10.1002/9781118346174.ch8

Tokarczyk, G., Bienkiewicz, G., & Suryn, J. (2017). Comparative analysis of the quality parameters and the fatty acid composition of two economically important Baltic fish: Cod, Gadus morhua and flounder, Platichthys flesus (Actinopterygii) subjected to iced storage. *Acta Ichthyologica et Piscatoria*, *47*(3), 249–258.

Tolstorebrov, I., Eikevik, T. M., & Bantle, M. (2016b). Effect of low and ultra-low temperature applications during freezing and frozen storage on quality parameters for fish. *International Journal of Refrigeration*, *63*, 37–47.

Tolstorebrov, I., Eikevik, T. M., & Bantle, M. (2016a). Effect of low and ultra-low temperature applications during freezing and frozen storage on quality parameters for fish. *International Journal of Refrigeration*, *63*, 37–47. https://doi.org/10.1016/j.ijrefrig.2015.11.003

Truonghuynh, H. T., Li, B., Zhu, H., Guo, Q., & Li, S. (2020). Freezing methods affect the characteristics of large yellow croaker (Pseudosciaena crocea): Use of cryogenic freezing for long-term storage. *Food Science and Technology*, *40*, 429–435.

Viji, P., Tanuja, S., George, N., Zynudheen, A. A., & Lalitha, K. V. (2014). Quality characteristics and shelf life of Sutchi cat fish (Pangasianodon hypophthalmus) steaks during refrigerated storage. *International Journal of Agriculture and Food Science Technology*, *5*(2), 105–116.

Ward, V., House, A., & Hamer, S. (2009). Developing a Framework for Transferring Knowledge Into Action: A Thematic Analysis of the Literature. *Journal of Health Services Research & Policy*, *14*(3), 156–164. https://doi.org/10.1258/jhsrp.2009.008120

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: Meta-narrative reviews. *Journal of Advanced Nursing*, *69*(5), 987–1004. https://doi.org/10.1111/jan.12092

Yang, F., Jia, S., Liu, J., Gao, P., Yu, D., Jiang, Q., Xu, Y., Yu, P., Xia, W., & Zhan, X. (2019). The relationship between degradation of myofibrillar structural proteins and texture of superchilled grass carp (Ctenopharyngodon idella) fillet. *Food Chemistry*, *301*, 125278.

Zhou, P., Chu, Y., Lv, Y., & Xie, J. (2022). Quality of frozen mackerel during storage as processed by different freezing methods. *International Journal of Food Properties*, *25*(1), 593–607.

Zhu, Y., Ma, L., Yang, H., Xiao, Y., & Xiong, Y. L. (2016). Super-chilling (− 0.7° C) with high-CO2 packaging inhibits biochemical changes of microbial origin in catfish (Clarias gariepinus) muscle during storage. *Food Chemistry*, *206*, 182–190.

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