A comparative study on quality, shelf life and sensory attributes of Atlantic salmon slaughtered onboard slaughter vessel against traditional land-based facilities

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Abstract

This thesis aims to compare two different slaughtering and storage methods of fish and study how these affect the quality and shelf-life of farmed Atlantic salmon. It is divided into three sections; The Hav Line method, Paper 1 and Paper 2. The Hav Line method introduces the slaughter vessel Norwegian Gannet and how its slaughter method can improve various challenges within the aquaculture industry. These include environment, infection and escape risk, fish health, better and longer quality and shelf life of the fish, and reduced waste and transport costs. Paper 1 investigates the quality and shelf life of whole Atlantic salmon slaughtered onboard Norwegian Gannet and stored in -0.8 ^oC refrigerated seawater (RSW) tanks compared to traditional land-based slaughtering facilities storing fish on ice. The shelf life and quality were measured on fresh and cold-smoked fillets including blood spot counts, fillet gaping, texture hardness, microbial counts, Quality Index Method (QIM) and sensory analysis. No significant differences were detected in blood spots counts nor texture hardness. Fresh fish slaughtered onboard the vessel had significantly lower QIM scores, fillet gaping scores, total mesophilic counts and H_2S producing bacteria at the end of storage (21d) than those from the facility. In Paper 2, the effect of different chilling technologies on quality and water holding parameters was investigated on Atlantic salmon throughout the entire value chain. In this study, all fish were slaughtered onboard Norwegian Gannet and divided into four different chilling methods; whole fish superchilling by RSW (S) or ice (I), followed by fillet chilling with liquid nitrogen (SS, IS) or ice (SI, II). The shelf life and quality were measured on fresh and cold-smoked fillets, including blood spot counts, fillet gaping, QIM, drip loss, water holding capacity and water content, colour and texture analysis, cathepsin B and L analysis and microbiological counts. Fish stored in RSW had lower H_2S producing bacteria for raw fillets, and lower gaping and blood spot counts after smoking. Firmness, breaking force and water holding capacity were higher for smoked than raw fillets, while colour parameters, muscle pH and water content were higher for raw than smoked fillets. Both papers concluded that fish slaughtered onboard vessels like Norwegian Gannet and transported in superchilled RSW presents good quality and improves shelf life over time.

Content

The Hav Line Method; Slaughtering at Sea

1. Background/Introduction

Over the last four decades, the salmon industry has gradually moved from a small side production in Norwegian agriculture to a big industry across the globe. The demand for salmon is high, and the list of guidelines and requirements to follow is long. Sustainability in the aquaculture industry is also receiving increased attention from farm to fork, which poses many challenges ranging from using small pelagic species as feed to utilizing the fresh cut and by-products from the farmed fish production (Naylor et al. 2021, Tacon and Metian. 2009).

Today the aquaculture industry faces two major problems: infestation of sea lice and high mortality (Naylor et al. 2021). Increasing the efficiency of the industry and focus on animal welfare and quality are significant steps towards solving the problems related to the increased health problems and mortality rate. Furthermore, the increase in Norwegian fish export imposes a greater demand for logistics transport to deliver good quality fish. Most of the seafood is currently being transported to Europe by road and to Asia by air transport (Rotabakk et al. 2020). Still, there are negative environmental, operational and financial impacts associated with these transportation methods. One way of contributing to more sustainable practice and significant socio-economic profitability in aquaculture is to move the slaughterhouses from land to sea. There are already existing vessels that stun and bleed the fish on site before it is transported to the land-based factory (Midling et al 2011), therefore utilizing the sea transport along the Norwegian coastline on a larger scale. This contributes to solving the following issues; environment, fish health, infection and escape risk, reduced transport costs, improved quality of the fish, achieve a longer shelf life of the fish and reduced waste during transport and in waiting cages (Midling et al. 2011, Skare et al. 2021, Chan et al. 2020, Philis et al. 2019, Rotabakk et al. 2020). To address the mentioned challenges within the aquaculture industry the Hav Line group AS has introduced a new concept of “The Hav Line method”.

2. Hav Line – Norwegian Gannet

The main idea of the Hav line method is to harvest fish directly from the cage before slaughtering the fish onboard the world´s largest slaughter vessel, Norwegian Gannet (Figure 1). The fish is then superchilled in refrigerated seawater (RSW) tanks onboard with ice slurry to below 0 °C, immediately after slaughter. This vessel (94 m long, 18 m wide) uses a diesel-electric hybrid engine (Wartsila, Norway) to reduce CO_2 emissions and contains 8 electric stunning machines, 14 gutting machines and 10 RSW tanks (Fishfarmingexpert.com, 2019). One load from the vessel can deliver as much as 1000 tons of fish to be transported to Hirtshals, Denmark, within 80 hours for further processing and delivery (Hav Line Metoden, 2018). The Hav Line method has been developed to create an innovation. Its goal is to contribute to the sustainability of the aquaculture industry by improving the traditional way of handling, slaughtering and transporting of farmed fish. The method can therefore deliver a product of high quality, as the welfare of the fish has been put into focus.

Figure 1; A picture of Norwegian Gannet (Retrieved from: own)

3. Fish welfare and Quality

Good fish welfare is an important prerequisite for good fish health, good quality, good profitability and low mortality and is gaining increased attention from both producers and consumers (Noble et al. 2018). Good welfare in aquaculture means that the fish showed normal behavior, have a high growth rate and remain healthy (Huntingford and Kadri, 2014). The Animal Welfare Act has requirements for good fish welfare, where several regulations are provided for both the establishment and operation of aquaculture facilities, as well as for the slaughter of farmed fish (Mattilsynet, 2021). Although the aquaculture industry is closely regulated, large numbers of fish can be injured, stressed or die during slaughter procedures and transport due to misfortunate actions. This can further lead to severe adverse effects such as lower quality of the product and large amounts of declassified fish (Santurtun et al. 2018).

Statistics show that an average of 24,000 salmonids gets declassified every year at the slaughterhouses, and the mortality rate has had an average of 43,000 deaths annually for the last decade (Fiskeridirektoratet, 2021). Based on the Fish Health report in 2020, the total mortality of farmed salmon was 60.3 million fish, where 52.1 million of these were reported as dead fish. Various factors such as bad conditions during transport and slaughter, stress, algal infections and infectious diseases are problems that contribute to these results every year (fiskehelserapporten, 2020).

The procedures involved in pre-slaughter are recognized as critical points in managing fish welfare and have important effects on meat quality (Lines and Spence, 2012). In the pre-slaughter phase, fish are stocked at high densities and procedures associated with crowding, pumping, transport, and harvest, result in stress from increased physical activity.

Pumping is a central part of fish retrieval but has been shown to cause stress. The problem with how fish is transferred today is not about the pumping itself but also the circumstances during the transfer. The environment around the process needs to be adapted to improve fish welfare during the pumping. The process with the most significant challenges considering applying stress to the fish is the crowding process. In the study of Roth et al. (2012), it was shown that increased pumping capacity would relieve the crowding density and thus also stress, giving a physiological status that is much better for the fish in the cage. Based on Skare and Hernar (2019), lactate measurements were taken during the slaughter process onboard the slaughter vessel. The results showed fish in physiological balance post crowding, pumping and electrical stunning. This forms a belief that a large pumping capacity contributes to good welfare and less stressed fish since the need for crowding is reduced. Thus, fish welfare has major significant potential for improvements as the aquaculture industry will continue to expand, and several aspects of how fish are farmed are likely to change. Meeting biological needs, stock monitoring, and environmental control are all increasingly challenging technologically but needs to be prioritized to improve fish welfare (Huntingford and Kadri, 2014). These challenges are addressed during the recent development of the innovative Hav Line method.

Physiological factors such as increased glucose, chloride levels and plasma cortisol are used to determine the degree of stress in animals (Fantini et al. 2020). However, stress can make the metabolism more anaerobic, resulting in lower glycogen content, faster decrease in pH and an early onset of rigor mortis. Monitoring this process is crucial for the technical and sensory quality of the meat and shelf life. The sea temperature and how the fish are treated before, during and after slaughter will affect the time fish goes into rigor (Balevik and Slinde, 2004, Skare and Hernar, 2019). Filleting can only be carried out successfully when the fish is in pre- or post-rigor condition. Stress is, therefore, a harmful factor for the aquaculture industry. The onset and strength of rigor mortis affect the fillet quality due to faster autolysis and greater ruptures in connective and muscle tissues (Ageeva et al. 2018).

A proper stunning procedure is required to render fish unconscious before slaughtering to ensure good welfare and quality. There has been a rapid development of various anesthesia and killing methods over the last 10 years, either using electricity or percussive stunning (Grimsbø, 2016). Today, electricity is the most common method for stunning farmed fish, which is also practiced onboard Norwegian Gannet. Previous studies showed that electricity has an advantage as a fast and effective anesthesia within 0.5 seconds (Lamboojii et al 2010, Roth et al 2003). Still, there is a risk of spinal injuries and disruptors of large aorta and veins, which are the most severe consequences that can downgrade the fillet quality (Lamboojii et al 2010, Roth et al 2003). The risk depends on the types of current, strength and frequency. This also applies to percussion machines, when the risk to fish welfare and quality lies in the missing punch percentage in automated systems (Lamboojii et al 2010). Although fish can be stunned unconscious within 0.5 seconds with electricity, commercial practices often involves exposing the animal for 5-15 seconds. This ensures a prolonged anesthesia where it is known that the duration of an unconscious condition and the likelihood of mortality increases with electrical current and duration (Robb and Roth, 2003). This is beneficial from a welfare point of view, but could pose negative consequences on the quality. Animals that are stimulated with electricity are known to empty their muscle of adenosine triphosphate (ATP), as well as stimulate anaerobic glycolysis and thus reduce muscle pH, which in turn can lead to an earlier outbreak of rigor mortis, softer texture, higher muscle tension, and higher color loss (Roth et al 2010). Through the Hav Line method, slaughtering the fish by the cage could give a longer pre-rigor time as it involves fewer operations that stress the fish compared to the traditional slaughter procedure (Midling et al 2011).

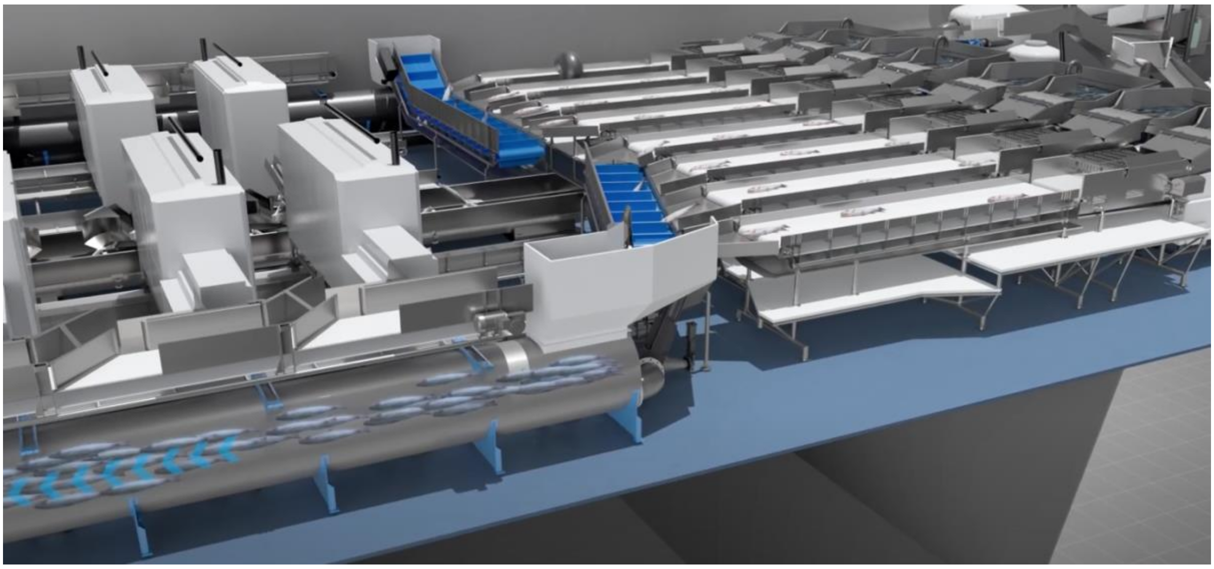

Figure 2; Drawing of the slaughter factory in Norwegian Gannet (Retrieved from: https://ilaks.no/animasjonsfilm-viser-hvordan-hav-lines-slaktebat-skal-fungere-i-praksis/)

The fish can have an overall better slaughter process (Figure 2) using the Hav line method. In a study where fish was directly pumped to Norwegian Gannet, the initial pH was found to be 7.22 (Chan et al 2020, Skare and Hernar 2019), which was within the same range as found in previous studies on unstressed fish (Lerfall et al 2015, Hultmann et al 2012, Erikson et al 2016). The lactate values in the study of Skare and Hernar 2019 were 1.70 mmol/L in contrast to Lerfall et al 2015, who measured 0.37 mmol/L from an uncrowded group in the seacage. Lerfall et al 2015 also measured 3.95 mmol/L from a crowded group in the seacage, which continued to increase when the fish were further chilled. These results indicate that the fish pumped to Norwegian Gannet did not undergo hypoxia or expressed escape responses in the pumping process and therefore had an overall better slaughter process.

The traditional harvesting method involves several crowding and pumping steps through transport and slaughter. For the Hav Line method, the fish only undergoes one crowding and pumping step. The SeaQuest fish pump (SeaQuest Systems, Ireland) used by the vessel provides a large capacity and gently handles fish. The fish will also avoid a long starvation period during transport to land as they are directly slaughtered onboard. Slaughtering by cages provides less stress on the fish and thus better animal welfare and lower mortality.

4. Alternatively use and disease control

Transporting dead fish in closed systems could positively affect the environment in terms of preventing the spread of disease concerning the use of both waiting cages and transport in well boats with open systems.

Infectious diseases are a constant threat to industrialized farming, characterized by the high density of farm animals and farms (Aldrin et al. 2015). The rapid expansion of the aquaculture industry, where open-cage production has increased, has not occurred without challenges regarding the environment, fish health and fish welfare. Pancreas disease (PD) is a viral disease that has become a major problem in the last decade, with significant welfare and economic impacts due to poor growth, reduced harvest quality and high mortality rate (Jansen et al. 2015). These problems indicate that waiting cages cannot be used in the areas with a lot of spread, as the disease can be transmitted both within facilities, and during transport of live fish (Vetinst.no, 2019, Midling et al 2011). This presents an essential factor for using the alternative method of fish slaughter directly by the cage.

If an open system well boat sails through an area contaminated with fish pathogens, or if the boat is loaded with sick fish and sails through an area with fresh fish, contamination can happen (Iversen et al. 2005). A closed system is preferable concerning the water quality in the tanks if it cannot be shown that open transport is biosafe (Rosten, Kristensen, 2010). The size of the fish quantities in the transport tanks is decisive for the result of the transport. An increase in biomass increases demands on oxygenation simultaneously as total ammonia excretion will increase. The weather affects the stress level of the fish in a well boat (Gunnes et al. 1998). These problems could be avoided with the Hav Line method as the fish is slaughtered before transportation in closed systems.

The vessel has proven to be of great support especially during the toxic algal blooms that hit the sea cages in Northern Norway in 2019 (Salmonbusiness.com, 2019). As the attacks of deadly algae can cause a significant volume in fish mortality, there was a tight race against time to retrieve the fish out from the pens quickly. The vessel could harvest the fish straight out from the cage within a few hours and reduce the damage and mortality rate, adding value to this slaughter method. Norwegian Gannet also sailed to Iceland to help slaughter a great volume of dead fish for Arnalax in Arnafjordur, February 2020 due to bad weather and low sea temperatures that resulted in challenging farming conditions and large amounts of dead fish (Berge, 2020). Therefore, the problems connected to the contamination that occurs if an open system well boat loaded with sick fish sails through an area with fresh fish, or if fresh fish is exposed to an area contaminated with fish pathogens can be avoided with Norwegian Gannet.

5. Transportation of slaughtered and chilled high-quality salmon to market

Superchilling is a food preservation method by partial ice-crystallization that lowers the temperature of the fish between conventional chilling and freezing, maintaining quality and extending the shelf life of food products (Banerjee and Maheswarappa 2019). Subzero storage temperature must be taken into account; if the shelf life of a particular fish product in ice is 14 days, the shelf life at -1, -2 and -3 ^{o}C is predicted to be 17, 22 and 29 days, respectively (Erikson et al. 2011). In relation to food processing, superchilling has presented many advantages. It minimizes labour, energy and transport costs and environmental impact (Kaale et al. 2011). The heat from the interior and the temperature equilibrates within the superchilled product are absorbed by the ice crystals formed at the surface layer. There is no need for external ice around the product during distribution or storage because the small amount of free water converted to ice will be used as an internal cold reservoir (Kaale and Eikevik 2014). In contrast, ice represents 20-30% of the total weight of each box of fish in traditional chilling. This directly incurs extra costs to both consumers and producers (Magnussen et al. 2008). Therefore, the superchilling technology can reduce transport costs, the need for styrofoam boxes, and the use of a necessary amount of ice.

The superchilling concept has been under continuous development over the last 10-20 years, and today there are several methods of superchilling (Kaale and Eikevik 2014). One method is RSW slurry, a binary system consisting of water with microscopic ice crystals (Chan et al. 2020, Piñ Eiro, C., Barros-Velázquez, J., Aubourg, S.P., 2004). Seawater has a higher transfer coefficient than ice and therefore removes heat at a faster rate and maximizes the contact between seawater and fish, as used in the Hav Line method. As a result, the fish achieves a more even temperature distribution because of the rapid heat transfer. The seawater cleans the gutted fish in the RSW tanks, so that blood remnants do not remain. In addition, tanks are being thoroughly cleaned and process water filtered, ozone-treated and chlorinated after every slaughter process to ensure cleanliness (Chan et al. 2020, Hav Line Metoden, 2018). The RSW tanks (Figure 3) containing seawater onboard the vessel inhibits further growth of microorganisms and opens up the opportunity of transporting the fish to further processing and distribution without the use of ice as the fish is being chilled down to -1ºC (Erikson et al. 2011). By doing so, the temperature of the fish is already kept at superchilled conditions during the early stages of the value chain (Chan et al. 2020).

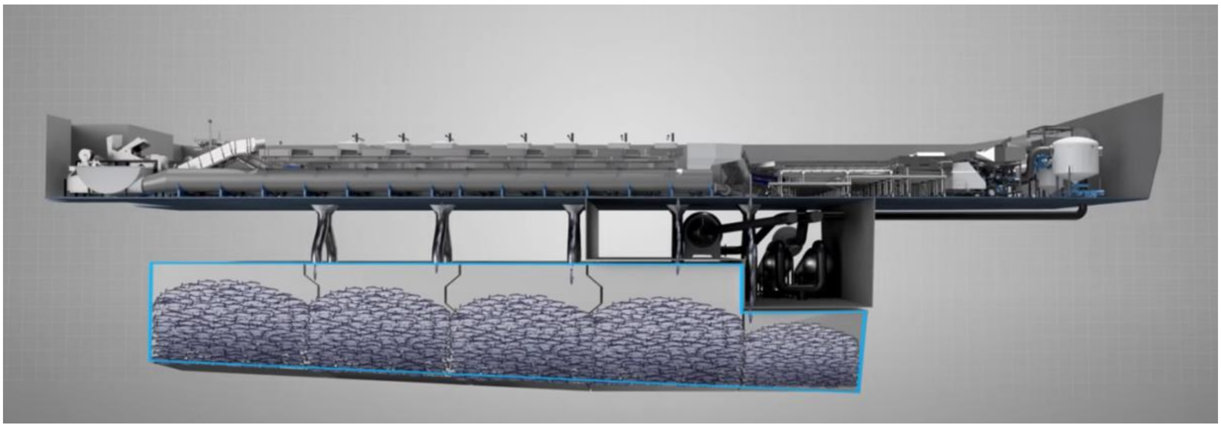

Figure 3; Illustration of the slaughter factory and RSW tanks in Norwegian Gannet (Retrieved from: https://ilaks.no/animasjonsfilm-viser-hvordan-hav-lines-slaktebat-skal-fungere-i-praksis/)

The method ensures pre-packed fish in Hirtshals, and the fish can be further transported by trains to large parts of Europe. The transport emissions will be minimized compared to the traditional method, where the fish is packed at facilities in Norway, transported to Europe then further out internationally. This method saves the roads in Norway from tons of heavy transport a year, which is better for the environment and safer for the population (Skare and Hernar 2019).

6. Concluding remarks

There are multiple benefits mentioned using the Hav Line method, which may potentially revolutionize the aquaculture industry without compromising fish quality. With a shorter harvesting and packing process, the fish can reach the market faster and be ready for delivery from Hirtshals. The transport options are many and efficient from Hirtshals, so it can take less time before the fish is on the market shelves than if it was shipped from Norway. The multiple benefits mentioned using the Hav line method are conductive to improve the welfare and quality of the fish as the escape and spread of disease and degree of stress applied to the fish is lowered. This results in fish being delivered fresher, providing a sustainable product with better quality and longer shelf life.

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