OPTIMIZATION OF QUALITY AND YIELD OF STOCKFISH BY END-DRYING IN CLIMATIC CONTROLLED STORAGE

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ABSTRACT

Stockfish is gutted and de-headed unsalted fish, and airdried outdoor by hanging on racks. Cod *(Gadus morhua)* is the high-quality stockfish product and is dominant in volume. After outdoor drying from March, the stockfish is taken down from the racks in May/June, and normally end-dried in traditional warehouses with open gates to the surrounding air. New warehouses with controlled temperature and humidity has been built, and optimal storage air parameters have been established. Industrial test has been performed over two seasons at seven industrial producers, with comparison of quality and yield at different warehouses. By using controlled temperature at 2-4°C and relative humidity at 88-90%, it was shown that the stockfish quality was higher and the sales weight of this high cost product increased by 5-10%, compared with traditional methods. Another consequence was increase in quality and yield after rehydration, which is beneficial for the customers. Technical aspects of the heat pump system in controlled warehouses is discussed.

Keywords: Stockfish, Cod, End-drying, Warehouse, Refrigeration, Heat pump, Quality, Yield.

1. INTRODUCTION

Stockfish from Lofoten ('Tørrfisk fra Lofoten'[(IGM)]) has been an important export food product from Norway since the 10th century, where Italy is the main market. Today, the annual production of stockfish is above 1000 tons. Cod, Haddock, Pollack and Cusk are fish-species normally used for drying, but Cod *(Gadus morhua)* is by far the main product. In February/March, huge amounts of Cod enter the coast area of North Norway from the Barents Sea, to spawn. At this period, the harvest of good quality fish is very high, and this fish is the raw material for the stockfish production. The Lofoten area is one of the few places suited for outdoor drying of stockfish due to stable low, but non-freezing temperatures during winter and spring, because of the location in the Gulf Stream. Freezing temperatures during outdoor hanging causes damages on the core meat, and give reduced quality. Stable low temperature ensures a controlled enzymatic ripening, and there are no insects during the wintertime. It has been identified 80 volatile components in stockfish (Bjorkevoll et.al., 2008), which gives the distinctive odor, taste and characterization of the 'Stockfish from Lofoten'.

Fresh, unsalted Cod is gutted, headed (HG-fish) and hanged on outdoor racks continuously during the winter cod fishing in February and March. The outdoor drying and ripening process is finished in May and June, and the stockfish is taken down and put on pallets inside the warehouses. At this time, there are still some humidity inside the core of the fish, and the water content is of course varying depending on the size of the fish and outdoor drying parameters. This period of intake is a critical period regarding the quality of the stockfish. Normally, the temperature is low until June in Lofoten, but in May and June there may be periods with sun and high temperatures which causes the inner part of the fish to get an undesirable and sourer odor. The stockfish is hard as wood, but after longer periods with rain, the skin can be slightly rewetted and give challenges with fungus if it is taken into the warehouses in this condition. The intake period is challenging; a) the fish need to be dry enough to ensure the rest-water inside the fish to be removed indoor the warehouses without getting problems with fungus, b) prevent outdoor over-drying and reduced yield, c) intake before hot temperature period, and d) avoid intake during rainy periods. Normally, the period of intake is around 10-12 weeks after hanging (Tidemann&Joensen, 2009), but there have not been performed any studies to find the correlation of quality and yield of the stockfish related to variation in time for intake.

Traditionally, the stockfish warehouses are wooden or concreate buildings in various sizes, with open gates and doors. The openings are covered with insect nets. The inner rest-water in the fish needs to be removed during the end-drying of the stockfish within some weeks. If the temperature and relative humidity in warehouses is too high, there will be challenges with reduced quality due to fungus. If the relative humidity is too low, the high-priced stockfish will over-dry and reduce the yield. Because of the open gates and doors, the outdoor air affects the end-drying and ripening process inside the warehouses. Earlier lab-scale studies performed by Nofima has shown that the relative humidity should be below 80% at the typical temperatures of 10-12°C to prevent growth of microorganisms on the product surface. In warehouse with controlled temperature, a level of 80% relative humidity was suggested (Tidemann, 2009). Stockfish is very physically hard, and it take 1-2 weeks for the product surface water activity to get equalized with the relative humidity in the ambient air. This makes it challenging to find the most optimal storage parameters. Test performed during the start-up time of the first industrial warehouse with controlled temperature and humidity, showed that it was possible to increase the relative humidity in the air to at least 83% at 3-4°C (Frydenlund&Widell, 2013). By study the quality and yield within 7 warehouses presented in this paper, the conclusion of optimal storage parameters for stockfish is finalized.

Figure 1: Left: Stockfish hanging for drying outdoor. Middle: Traditional stockfish warehouse with open gates. Right: Warehouse with controlled temperature and relative humidity.

The traditional stockfish production and storage has been more or less unchanged for centuries. Challenges regarding the weather condition especially during and after intake of the stockfish seems to be increasing due to global warming and more humidity in the air. The Norwegian Seafood Research Fund (FHF) and Innovation Norway (IN) have in recent years financed research- and development projects to meet this challenge. A commercial refrigeration company has in cooperation with the producers and the research institutes SINTEF and Nofima developed the first industrial-size stockfish warehouse with controlled temperature and relative humidity. In addition to regulating the air parameters for optimal end-drying and storage, the ability to remove the humidity in the air coming from the fish is much higher in this warehouse than for traditional warehouses. This gives a possibility to regulate the intake period to be earlier than normal which causing higher air in the warehouse. This technology may also be seen in connection with the world-wide challenge of the 'Dry chain', a term established by Bradford et.al. (2018), addressing the trouble with Mycotoxins on i.a. rice, corn and pies in warehouses due to high humid atmosphere.

As mentioned, the traditional intake period and storage solutions of the stockfish has been decided based on experience and assumptions, and the stockfish industry has for many years asked for scientific documentations of the consequences for various production procedures. The latest project financed by FHF and IN, presented in this paper, addresses these questions in addition to comparing the stockfish quality and yield after end-drying and storage in a series of industrial warehouses. The results from this work will make the producers of stockfish better suited to ensure higher degree of high quality products, and to optimize the yield both for the producers and for the customers after rehydration of the stockfish. This optimization address both the period for intake of stockfish, and manipulation of the indoor air in traditional stockfish warehouses, compared with storage in warehouse with controlled temperature and relative humidity.

2. MATERIALS AND METHODS

Experiments and tests were performed at seven stockfish producers, sited at five different locations in the Lofoten area at the coast of North Norway. The experiments were performed over two seasons (2015 and 2016). The work was done by the producers own employees in cooperation with researchers from SINTEF and Nofima.

2.1. Intake of outdoor dried stockfish

Each of the seven producers individually marked and weighted 30-40 small fish (1.5-2.0 kg), 60-90 medium fish (2.8-3.3 kg) and 30-40 large fish (4.5-5.0 kg) each season. The weight was measured by use of the producers own table weighting machines (various manufactures). All weighting machines were calibrated within the range of 0.1-10 kg, with minimum accuracy of 10 gram. The third week in March, each producer hanged their fresh headed and gutted fish (HG-fish) on racks outdoor at the producer's normal locations. Temperature and relative humidity in the outdoor air were recorded at each site.

The fish was taken into storage for end-drying at 4 different occasions (25 % of the fish each time): after 7 weeks (extra early), 9 weeks (early), 11 weeks (normal) and 13 weeks (late). Each fish was weighted at intake, and again after 2, 4, 6, 8 and 12 weeks in the warehouses. Six traditional stockfish warehouses, and one warehouse with controlled temperature and relative humidity.

The water content (W_b) of cut- and homogenized loin of fresh fish (n=6) was measured. At each intake, the water content (W_b) was measured by taking samples from the loin and tail of the fish (n=3). Stockfish is hard as wood, inhomogeneous, and it is challenging to measure the accurate water content. Cross-sections of loin- and tail areas were cut by saw, and homogenized. The weight of each sample was measured by lab-scale weight machine before and after drying in oven at 103°C for 20 hours. These results on water content were used as reference, and correlated to total weight on the fish. All other calculations of water content were related to this by total weight and weight-loss of the fish.

2.2. Staking of pallets, temperature and relative humidity in traditional warehouses

Each of the seven warehouses were instrumented to measure temperature and relative humidity (Easylog, EL-USB-2-LCD+) during the storage period, each with 2-5 loggers. In addition, there were performed manual registrations of air velocity and flows (TSI VelociCalc 9565-P with Propeller probe 995) at each warehouse. The stacking of pallets with product was registered in each warehouse.

Traditional warehouses for stockfish is as mentioned typically wooden or concrete buildings with open gates and doors to the outdoor. The rest-water in core of the stockfish after intake needs to be removed by a flow of ambient air through the warehouse. Normally, one or two fans are placed close to the gates, to suck the air through the room. The curves presenting the relative humidity inside a traditional warehouse in Figure 5 (left) shows that the relative humidity inside follows the ambient air. This was shown for all traditional stockfish warehouses. After stocking, it is critical that the relative humidity is below 82% at 10-12°C to prevent growth of microorganisms on the product surface. During wet weather periods, the indoor humidity is too high. In addition, there are often areas inside the rooms that do not have air flow, and local higher relative humidity due to evaporation from the product on pallets. Measurements the last 12 years, shows a weekly average variation in outdoor relative humidity of 15-20 % between seasons, with a 2-3 °C variation in temperature. Between different locations in the Lofoten area, a variation of 5-8% is measured during the same period. Up to 30-40% of the stock has been seen with growth of fungus some seasons.

A traditional stockfish warehouse with two even floors was used to test and demonstrate a manipulation of the indoor air during storage. The room at the ground floor was stacked traditionally, with pallets placed close together (Figure xx). In the room at the first floor, the product was stack with aisle between rows of pallets. Six fans were placed in different aisles to make air circulation through the entire room area (DriEaz ventilation fan, 0.4kW, with capacity 3600 m^3/h). In addition, three condenser dehumidifiers were placed at various location in the room (Dantherm CDT90, 1.65kW, with condensing capacity of 3.9 kg water/h (at 30°C, 80%RH) circulating 1000m^3/h). Temperature and relative humidity in the two floors were logged.

2.3. Quality measurement and yield

The quality of each finished dried stockfish was measured sensorial (color, smell and general physical condition) by trained personnel from Nofima and from the industry. The stockfish was ranged in 4 industrially used quality categories: Prima, Secondo, B and BB, where BB is lowest quality. The trained personnel (8 persons) also judged the quality of rehydrated stockfish (ready for cooking) and soaked in potash lye (for Lutefisk, traditional Norwegian dish), important parameters for the market. The results regarding 'Lutefisk' is not discussed in this paper (Joensen&Indergaard, 2017) Gapping was set in a scale 1-5, where 5 in no gapping. Whiteness in 3 categories; 0=white, 1=some darkness, 2=dark. Brown color at the bones; 0=no brownness, 1=some brownness, 2=much brownness. Mucoso (gel-like condition after rehydration); 0=non, 1=some, 2=a lot.

The quality and the yield of the stockfish from each warehouse was compared, including 6 traditional storages and one storage with controlled temperature and relative humidity. A part of the stockfish from each warehouse was stored from one season to the next. The yield the stockfish from each warehouse was calculated by the weight of the finished dried product in percent of the weight of the hanged fresh fish.

2.4. Water removal rate, energy and functionality of climatic controlled warehouse

The climatic controlled warehouse has a capacity of 300 tons of stockfish (Figure 1, right) In the center of the room, the aggregate is located under the ceiling above the pallets of product. In addition, fans (4x0.4kW) are placed in each corner to make air circulation throughout the entire storage room. 30.000 m^3 air per hour passes through the aggregate by use of fans (2x5.5kW, frequency-controlled). After the filter, the air is cooled down in the evaporator and water condense and drains out. Evaporator temperature is set to +0.2°C to prevent icing. In the first period after intake the water removal rate from the product is higher, and an electrical defrosting is set on the evaporator to handle freezing temperatures in the evaporator. The cold air is then heated by the condenser to the desired cold room temperature at 3-4°C. Typically, the condensing temperature is around 40°C. In the last step, the air gets more humid by use of a nozzle humidifier to the desired relative humidity at 88-90%. The cooling capacity in the evaporator is 45 kW, and the heat pump system is run by 4x3.2kW compressors. The heat load to the condenser is regulated towards a secondary external condenser outside (fan 1.8 kW), and there are installed a 0-30 kW backup electricity heater after the condenser.

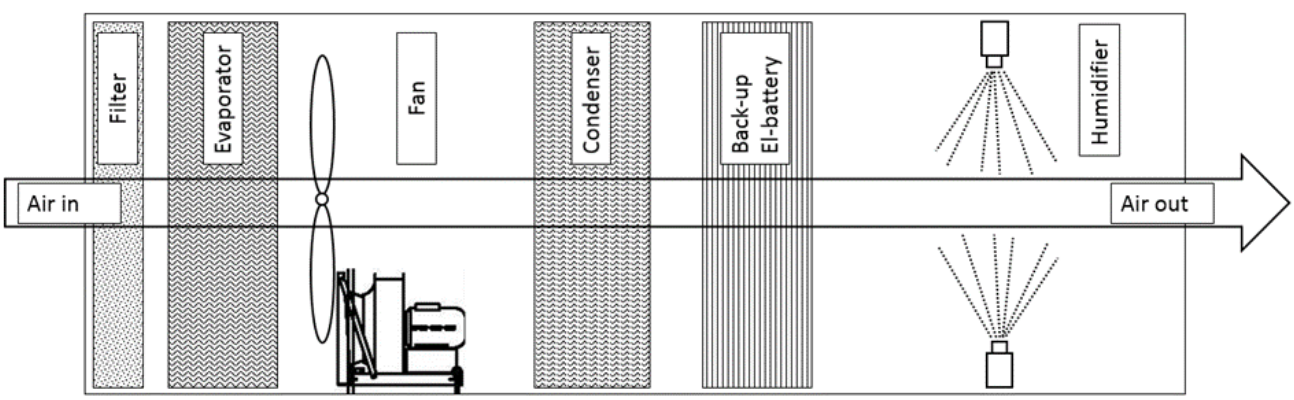

Figure 2: Sketch of climatic aggregate for control of temperature and relative humidity in warehouses.

During end-drying after the stocking in May, June and July, the outdoor temperature and water removal from the stocked product is at the highest. The design of cooling capacity of the heat pump system is therefor based on the parameters in the warehouse during these three months. The earlier the fish is taken into the warehouse; more water needs to be removed per hour to prevent growth of fungus on the product. By using the weight of the fish, related to water content, measured at each intake and during end-drying, the water removal rate has been found.

3. RESULTS AND DISCUSSION

The work presented in this paper has been performed over two seasons (2015-2016) at seven producers of stockfish sited at 5 different areas in Lofoten, North Norway. Six traditional stockfish warehouses, and one warehouse with controlled temperature and relative humidity. The focus was a) optimal time for intake after outdoor drying, b) quality and yield of the stockfish during and after end-drying in different warehouses, and c) study of climatic controlled stockfish warehouse.

3.1. Hanging on racks, outdoor drying and intake of stockfish

The third week in March, each producer hanged individually marked and weighted fish. 30-40 small (1.5-2.0 kg), 60-90 medium (2.8-3.3 kg) and 30-40 large (4.5-5.0 kg) headed and gutted fresh fish (HG-fish) each season. Average water content (W_b) of cut and homogenized loin of HG-fish was found to be 81,6 ±0.8% (n=6). This is used as reference for calculation of water content in all other semi-dried fish based on weight loss and dry matter. After 7 (extra early), 9 (early), 11 (normal) and 13 (late) weeks, 25% of the hanged fish were taken into the warehouses for end-drying and storage. Each fish was weighted, and average yield at each intake calculated (Figure 3).

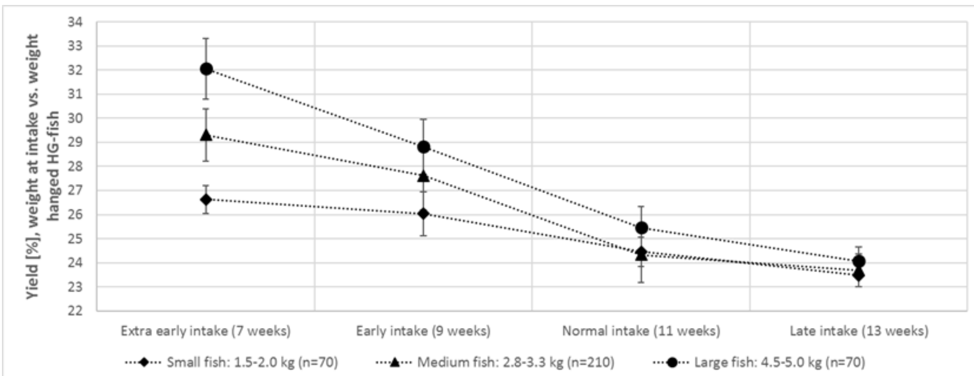

Figure 3: Yield of stockfish during drying related to kg hanged headed and gutted (HG) fish.

One of the goals in the project was to establish a method to find the optimal time for intake based on weight loss, and not based on absolute water content due to real challenges to find this parameter. To get an understanding of the water distribution in the semi-dried stockfish during the outdoor drying period, water content in loin and tail were found at various partly-dried stockfish. Water content (W_b) of three fish of each size and each intake was measured by sawing cross-sections of loin- and tail areas and homogenized the parts. The results are shown in Figure 4.

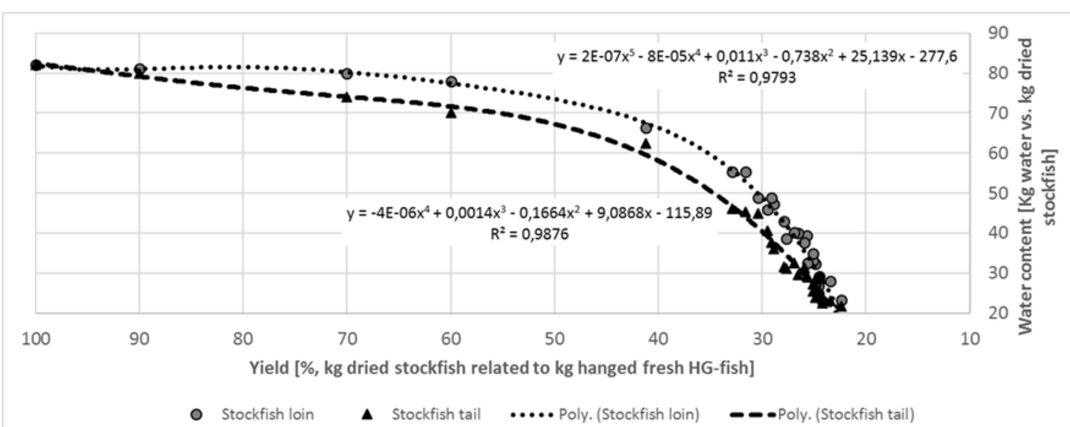

Figure 4: Yield of stockfish during drying related to kg hanged headed and gutted (HG) fish.

The water content in the loin and tail of the stockfish during drying based on weight loss can be presented as multi-polynomial equation as shown in Figure 4. For the period relevant for intake of stockfish (22%<yield<34%), the water content in the product related to yield can be presented as:

(1) Loin: $y = 3.49x – 55.60$
$R^2 = 0.9082$

(2) Tail $y = 2,64x - 39,10$
$R^2 = 0,9309$

Where y = water content, W_b [%] and x = yield [%] (weight, semi-dried towards fresh HG-fish)

3.2. Stacking of pallets, temperature and relative humidity in traditional warehouses

Traditional warehouses for stockfish is typically wooden or concrete buildings with open gates and doors to the outdoor. The rest-water in core of the stockfish after intake needs to be removed by a flow of ambient air through the warehouse. Normally, one or two fans are placed close to the gates, to suck the air through the room. The curves presenting the relative humidity inside a traditional warehouse in Figure 5 (left) shows that the relative humidity (RH) inside follows the ambient air. This was shown for all the six traditional stockfish warehouses, but there was variation in RH levels between warehouses at different locations.

After stocking, it is critical that the relative humidity is below critical level to prevent growth of microorganisms on the product surface. It was found in this project that the critical level is 82 % at the typical temperatures in traditional warehouses at 10-12°C. During wet weather periods, the indoor humidity is often too high. In addition, there may be areas inside the rooms that do not have air flow, and local higher relative humidity due to evaporation from the product on pallets (Circles in Figure 6, left). Measurements the last 12 years, shows a weekly average variation in outdoor relative humidity of 15-20 % between seasons, with a 2-3 °C variation in temperature. Up to 30-40% of the stock has been seen with growth of fungus some seasons.

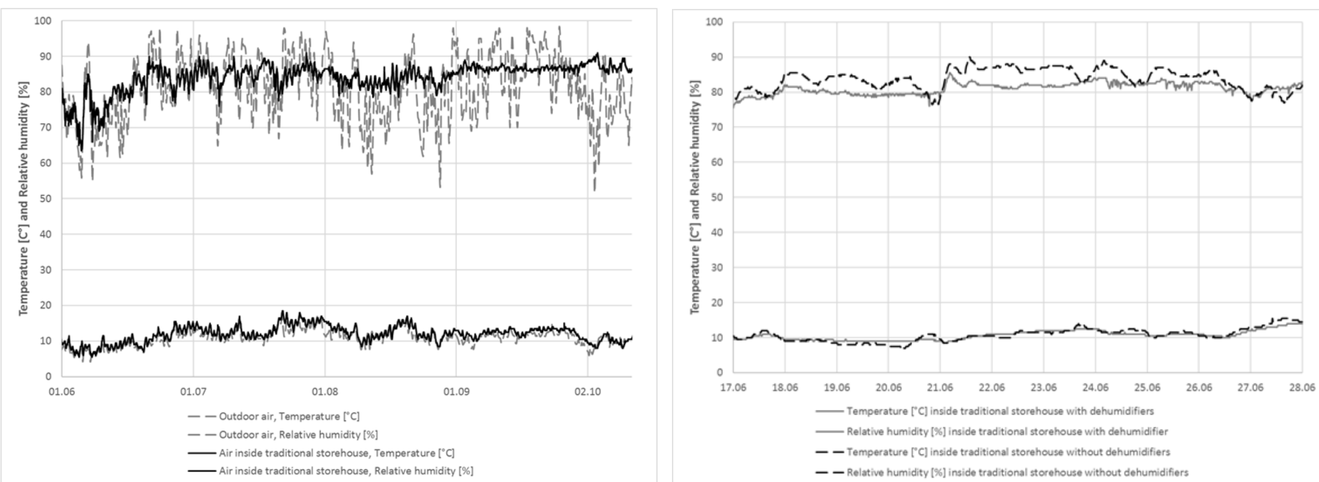

Figure 5: Left: Temperature and relative humidity inside traditional stockfish warehouses follows the outdoor air parameters. Right: Manipulation of indoor air by dehumidifiers and fans.

A traditional stockfish warehouse with two even floors was used to test and demonstrate a manipulation of the indoor air during storage. The room at the ground floor was stacked traditionally, with pallets placed close together (Figure 6, left). In the room at the first floor, the product was stacked with aisle between rows of pallets (Figure 6, right). Six smaller fans were placed in different aisles to make air circulation through the entire room area. In addition, three condenser dehumidifiers were placed at various location in the room. Temperature and relative humidity in the two floors were logged.

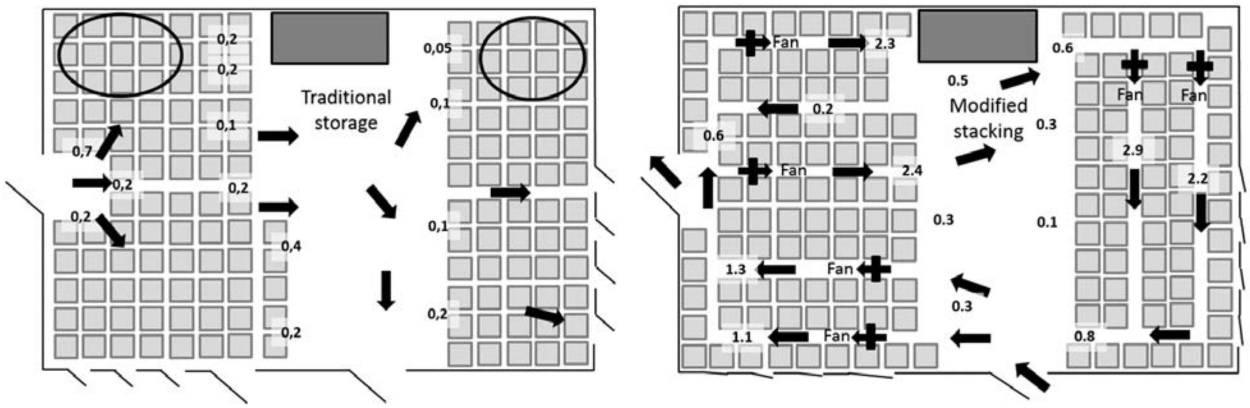

Figure 6: Two even warehouse rooms with traditional stacked pallets (Left), and stacked with aisles and inserted fans and dehumidifiers (Right). Arrows and numbers present the measured air direction and velocity [m/s]

During dry weather periods, only the fans were running, and during the wet weather periods also the dehumidifiers were running. The gates were closed during the periods when the dehumidifiers were running to prevent humidity from the ambient air to enter the room.

During a 10 days wet weather period, the relative humidity in the indoor air was lowered 5-8% using fans and dehumidifiers (Figure 5, Right). Also, the temperature had less fluctuation during this period. This made it possible to keep the relative humidity below the critical 82% limit for most of the time. The quantification of fish with microbiological growth was done by the producer during the following autumn while shipping the product to the market. Based on the producer, 3-4 pallets with stockfish had surface with some microbiological growth in the traditional stacked room. In the room with fans and dehumidifiers, less than 1 pallet was found with microbiological growth.

3.3. Intake and water removal rate from stockfish

After intake, the rest-water inside the semi-dried stockfish needs to be removed. Larger fish contains more water than smaller fish, and the earlier the stockfish is taken inside, more water needs to be removed in the warehouses (Figure 7). To design a climatic controlled warehouse, or manipulate the air inside traditional warehouses with dehumidifiers, it is necessary to find the water removal rate from the fish base on weight and intake time.

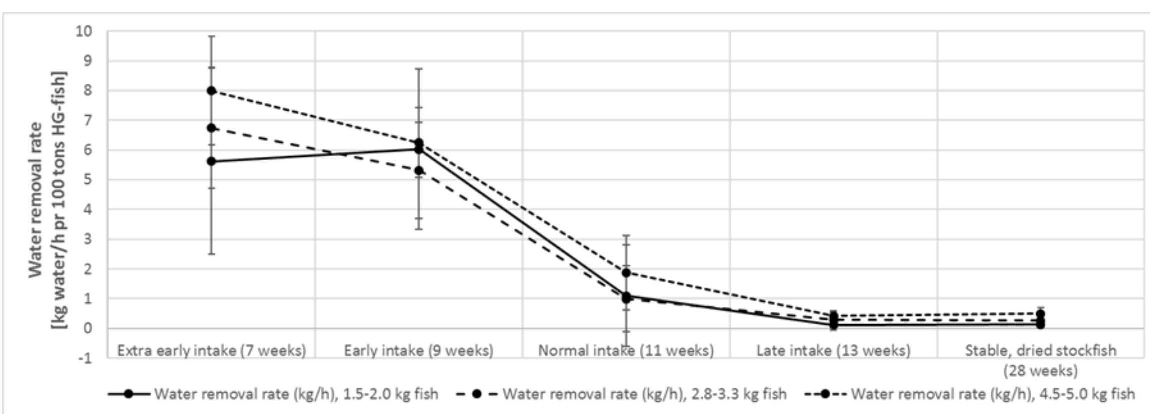

Figure 7: Yield of stockfish during drying related to kg hanged headed and gutted (HG) fish.

Average water removal rate [kg/h] from the stocked fish after intake is based on weight reduction of fish from 7 producers. At each of the 4 intake periods, the weight of totally 70 small, 70 large and 210 medium fish were measured, with a continued weight registration every 2 weeks after intake. The water removal rate is calculated by dividing the weight reduction per hour in the 2 weeks between each measurement, related to 100 tons hanged HG-fish.

The water removal rate shown in Figure 7, shows that 5-8 kg water needs to be removed from the indoor air per hour per 100 tons hanged HG-fish (≈23 ton finished stockfish) after early and extra early intake. After normal and late intake, the corresponding rate is 0.5-2 kg/hour. The water removal rate from the product after extra early intake will be challenging for traditional stockfish warehouses. Approximately 90% of the water removed from the HG-fish to produce finished stockfish is dried outdoor before extra early intake. An earlier intake than extra early intake may influence the ripening process outdoor, and will have huge impact of the design of cooling capacity of the refrigeration system inside climatic controlled warehouses.

3.4. Quality measurement and yield

For high priced product like stockfish, it is very important to optimize the quality and yield during production. Stockfish is as mentioned very dense, and it take more than a week for the product to absorb water from the air be equalized with the relative humidity in the air. Over two seasons, seven producers weighted finished dried stockfish (n=1050 and n=1470) after 16 weeks in the warehouses, and yield related to fresh hanged HG-fish calculated. The yield refers to the average indoor air relative humidity the last 14 days before the weight measurement and shown in Figure 8.

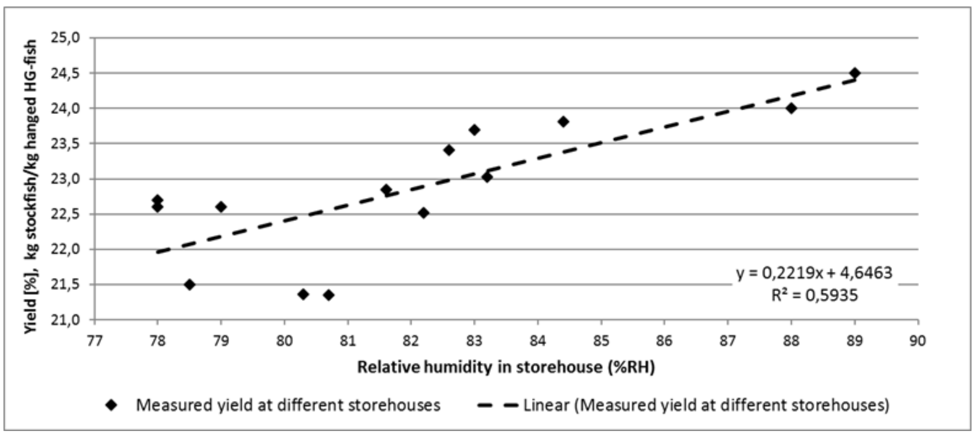

Figure 8: Percent yield of dried stockfish correlated to Relative humidity in different warehouses, over two seasons

The six traditional stockfish warehouses had a variation between 78-85% relative humidity, and climatic controlled warehouse had 88-90% relative humidity. The results are shown in Figure 8, and the stockfish yield can be expressed as a linear function of the average relative humidity in the warehouse.

$$Y = 0{,}222x+4.646 \qquad R^2=0.594 \tag{3}$$

where Y = yield [%], kg finished dried stockfish vs. kg hanged fresh HG-fish.

and x = %RH, the average relative humidity in the warehouses the last 14 days before weighting

The yield from a traditional stockfish warehouse with and average relative humidity of 82-83% is about 23%. This is approximately the maximum before the microbiological growth occur, and most of the traditional storages have less yield than 23%. The yield from climatic controlled warehouse (3-4°C, 88-90%RH) was above 24.0%. An increase in yield from 23 to 24%, corresponding to an increase in sales-weight of 4.3%.

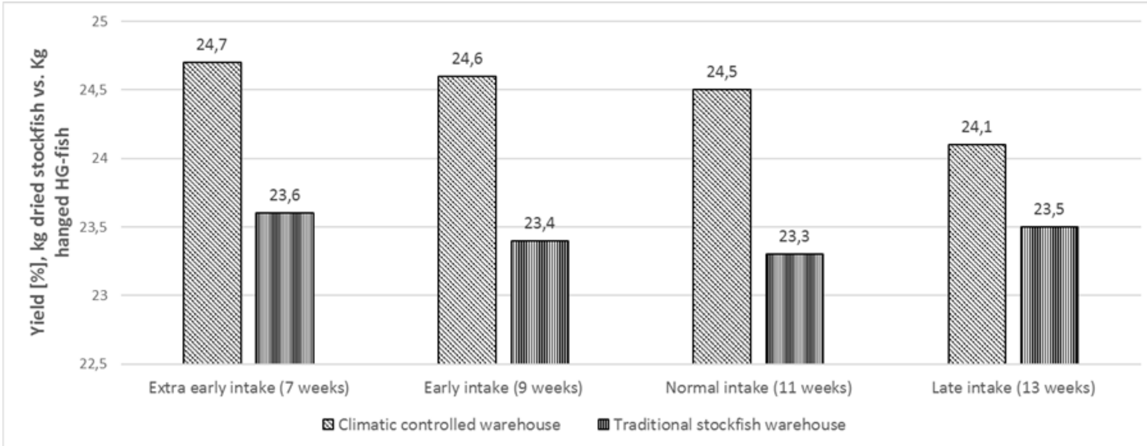

Figure 9: Final yield of dried stockfish between various intake periods, stored at traditional and climatic controlled warehouses.

The final yield of the dried stockfish is also related to the time for intake. Figure 9 shows that the final yield for climatic controlled warehouses increase with 0.6% at extra early intake compared with late intake. This is corresponding to an increase in sales-weight of 2.5%. It is the same trend also for traditional stockfish warehouses, except for late intake. This is probably due to an over-drying if the fish is hanging outside too long, and that this fish will not be able to absorb the same amount of humidity from the humid air inside the warehouse.

The individual quality of finished dried stockfish taken into warehouses at different periods was measured sensorial by trained personnel. The stockfish was separated into small, medium and large fish, and the stockfish quality was ranged in 4 industrially used quality categories: Prima, Secondo, B and BB, where BB is lowest quality (Figure 10). Rehydrated stockfish (ready for cooking) was also judged (Figure 11).

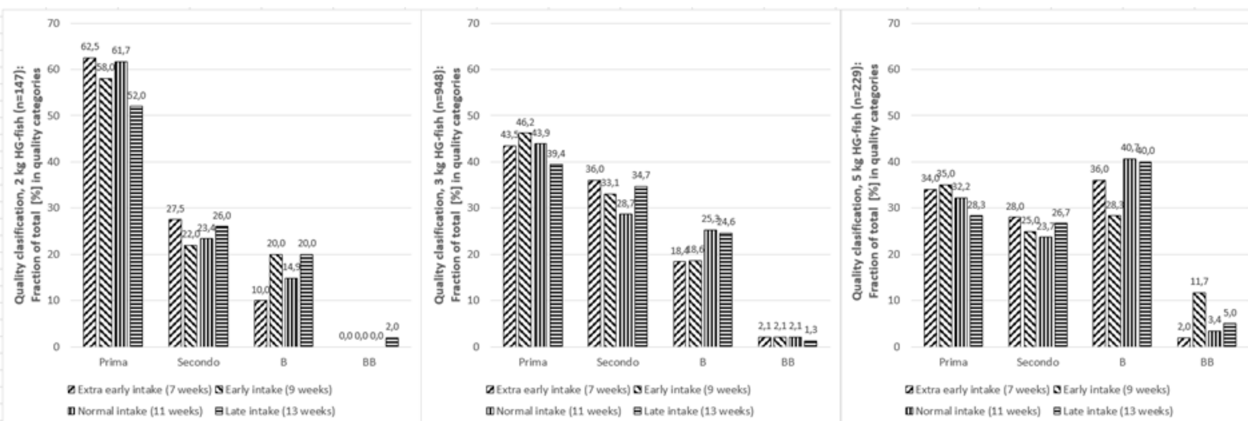

Figure 10: Small (n=147), medium (n=943) and large (n=229) finial stockfish classified in the industrial quality classification Prima, Secondo, B and BB.

An increase in quality of the stock, where the fraction of the highest priced classes Prima and Secondo increases, will also increase the value of the total stock. From Figure 10, it is shown a trend that extra early intake after 7 weeks outdoor, gives the highest fraction of Prima and Secondo quality. The fraction of these two high priced classifications decreases as longer the fish hangs outdoor on racks. The economical consequence is that the stock value increases by 2.2% for the extra early intake compared with the late intake. This is bases on a typical variation in stock, with 10% small, 50% medium and 40% large stockfish, and a price of €20, €18, €14 and €12 for Prima, Secondo, B and BB, respectively.

It takes 5-7 days in running cold water to rehydrate the stockfish. This is normally done by the customers in the respective countries of market. After rehydration, the product has increased approximately 200 % in weight, and is ready for cooking. Stockfish taken into the warehouse at the 4 different intake periods (30 fish for each period) was rehydrated for 7 days, and sensorial judged by trained persons. The results showed that there were not any differences in whiteness or brownness in any of the stockfish from the various periods of intake. The color was good. There was also found only an insignificant few individuals with Mucoso. The judgement of gapping is shown in Figure 11.

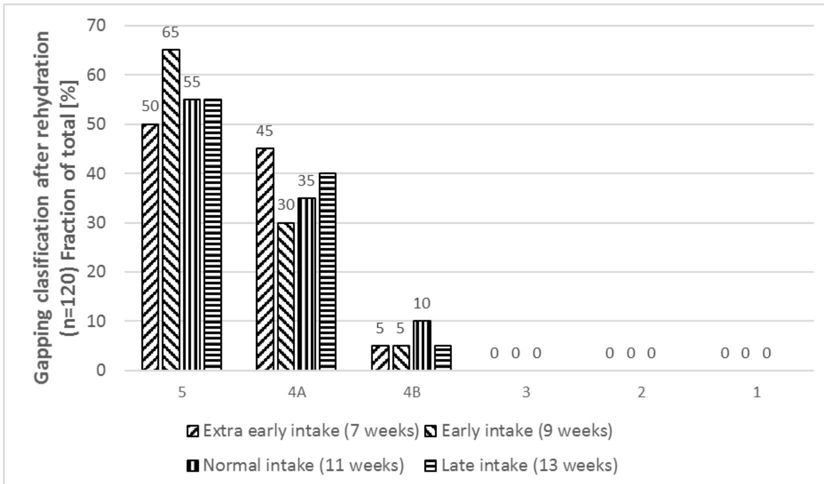

Figure 11: Stockfish (n=120), rehydrated in 7 days judged for gapping, and classified in the industrial classification 5, 4A, 4B, 3, 2 and 1, where 5 is no gapping.

All the rehydrated stockfish were judged in into the classification 4B, 4A and 5, which is little or no gapping. The quality of all rehydrated stockfish was generally good.

It is important that the yield after rehydration, the product ready for cooking, is as high as possible. The yield related to the raw material (HG-fish) is shown in Figure 12.

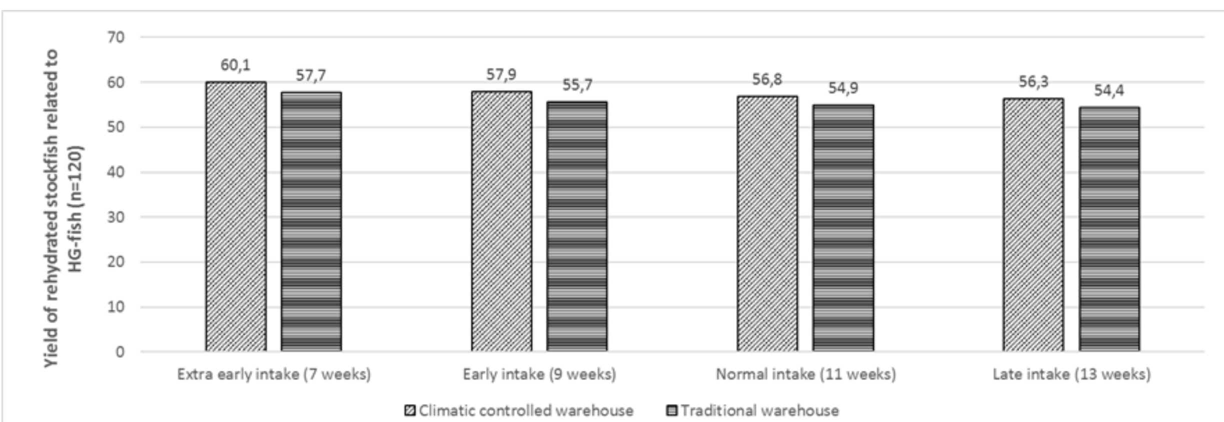

Figure 12: Yield of rehydrated stockfish related to hanged HG-fish, taken into warehouse after various outdoor drying time, and stored in traditional and climatic controlled warehouses.

It is clear that the yield after rehydration also follows the same trend as the dried stockfish. The yield is higher for extra early intake of stockfish, and lowest for late intake. Also, end-dried stockfish in climatic controlled warehouses is higher than for traditional warehouses. A rehydrated stockfish taken extra early into a climatic controlled warehouse has 5.7% higher yield than a rehydrated stockfish taken late into a traditional warehouse.

3.5. Energy and functionality of climatic controlled warehouse

The climatic controlled warehouse parting this study has a capacity of 300 tons of dried stockfish. The aggregate located under the ceiling above the pallets of product acts to keep the temperature steady at 3-4°C, with a relative humidity at 88-90%. As seen in Figure 13, the air parameters are controlled as desired.

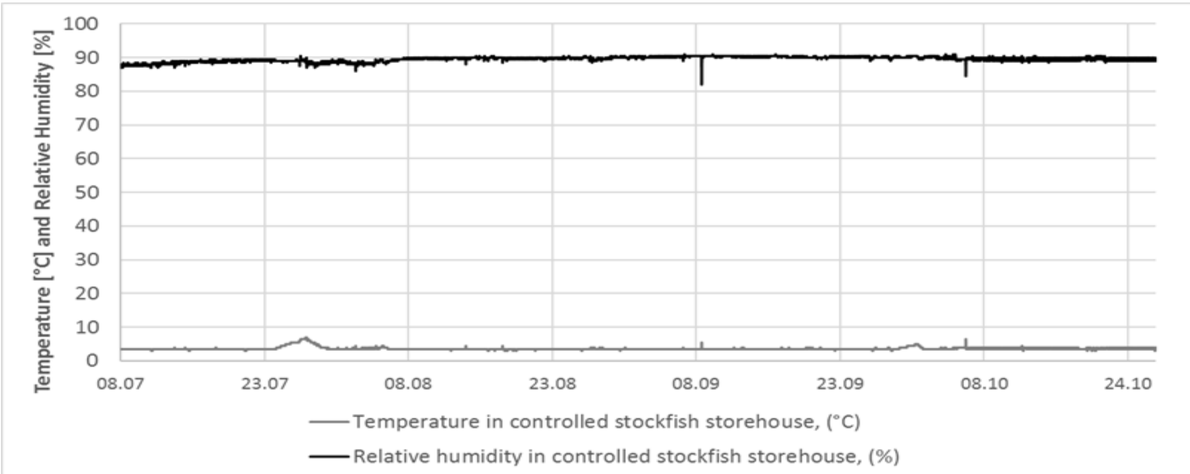

Figure 13: Temperature [°C] and Relative humidity [%] stockfish warehouse with heat pump system

A total use of 155.000 kW (Figure 14) during the storage time of 300 tons of stockfish gives an energy use of approximately 520 kWh per ton. Stockfish is a high-priced product, €12-20 per kg dependent on quality. With the Norwegian electricity price of €0.1 per kWh, the energy use represents less than 0.5% of the stock value.

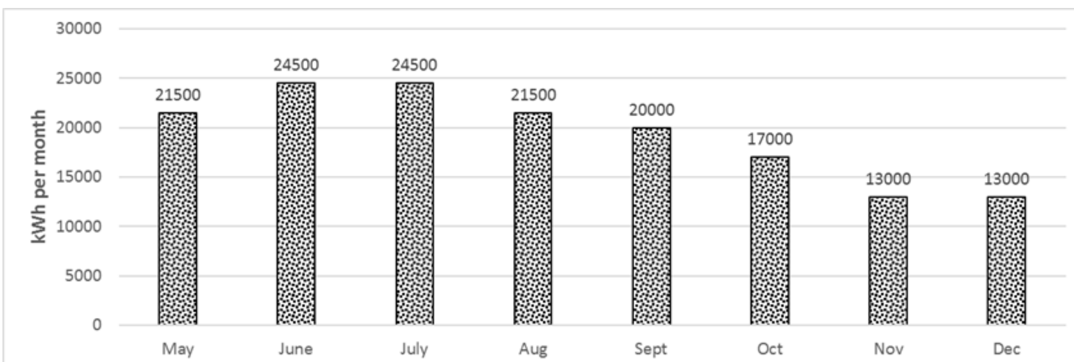

Figure 14: Total energy use during stocking-season in warehouse with climatic control.

By using a climatic controlled warehouse for end-drying and storage of stockfish, it is possible to take the outdoor semi-dried stockfish into the warehouse earlier than for traditional warehouses. It is shown that this increases the yield and quality. In addition, it is possible to increase the yield of final dried stockfish by increasing the relative humidity in the air by lowering the temperature. The investment- and operational cost of a new climatic controlled warehouse will be paid off within 3-4 years.

4. CONCLUSIONS

The objective of the work presented in this paper was to optimize the time when outdoor semi-dried stockfish should be taken indoor for final end-drying, and find the best possible conditions for the indoor end-drying and storage of stockfish in different storage facilities, including climatic controlled warehouse.

The results of experiments (7 producers) over two seasons shows that semi-dried fish can be taken in earlier than normally done today, and that fish taken in early have better yield both as stockfish and rehydrated fish. An earlier intake alone, may increase the yield by 0.6%, corresponding to an increase in sales-weight of 2.5%. The quality is also higher compared with fish taken in later, and a larger fraction of high priced classification increase the value of the stock by 2.2%. When the fish has about 30% of original weight, it is ready for end-drying and storage. It is stable when the weight is 23-24 % of original weight.

The highest potential for increasing the yield is by reducing the warehouse temperature, which makes it possible to increase the relative humidity in the storage without getting any growth of mould. The relative humidity should not get above 82 % in traditional storage facilities (normally at 10-12 °C), and not above 90 % in climatic controlled warehouses (3-4°C) to prevent microbiological growth. However, for every 5% increase in the average relative humidity in air in the warehouses, the yield increases by 1%, which corresponds to 4.5% increase in sales weight. It is likely to increase the yield by 1-2% (4.5-9.0% increase of sales-weight) in a climatic controlled warehouse compared with traditional stockfish warehouses. An investment of a climatic controlled warehouse will be paid off within 3-4 years.

The producers should weigh a certain number of fish when hanging; and follow the fish's weight during the entire drying process to be ensure of optimal time for intake for end-drying. Temperature and humidity control in the storage facilities is essential.

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NOMENCLATURE

HG	Headed and gutted fresh fish	*Yield*	[%] kg dried/semi-dried fish vs. kg HG-fish
RH	Relative humidity (%)	*y*	Water content [%], W_b

REFERENCES

Bjorkevoll, I., Landfald, B., Ernesten, M.H., Joensen, S., Tidemann, E., 2008. Growth of bacteria during natural drying of Stockfish – Comparison of normal- and mucoso-tissue (In Norwegian). Report Nofima Marine,

Bradford, K.J., Dahal, P., Asbrouck, J.V., Kunusoth, K., Bello, P., Thompson, J., Wu, F. 2018. The dry chain: Reducing postharvest losses and improving food safety in humid climate. Trends in Food Science & Technology 71, 84–93s.

Frydenlund, F., Widell, K.N., 2013. Measurement of climatic controlled stockfish warehouse (In Norwegian). Report SINTEF Energy – TRA7298

Joensen, S., Indergaard, E., (2017). End-drying and storage of stockfish (In Norwegian). Nofima and SINTEF-report, ISBN: 978-82-8296-496-8

Tidemann, E., Joensen, S., 2009. Stockfish on racks (In Norwegian). Report Nofima Marine.

Tidemann, E., 2009. Ripening and storage of stockfish (In Norwegian). Report Nofima Marine. ISBN 978-82-7251-697-9

Vines, G., 2008., Viking longships brought rape, pillage and cod. New Scientist, Volume 198, Issue 2662, p52-53