TR A7583 - Unrestricted

# Report

## Superchilling of organic food

Part 1: Concept, State-of-the-Art and Potential for small scale implementation


**Authors**
Michael Bantle
Ingrid Camilla Claussen
Ignat Tolstorebrov (NTNU)



**SINTEF Energy Research**
Efficient Energy usage
2016-08-01

SINTEF

**SINTEF Energi AS**
SINTEF Energy Research

Address:
Postboks 4761 Sluppen
NO-7465 Trondheim
NORWAY

Telephone:+47 73597200
Telefax:+47

energy.research@sintef.no
www.sintef.no/energi
Enterprise /VAT No:
NO 939 350 675 MVA

KEYWORDS:
Partial freezing
Cold chain
Organic meat
Organic fish
Extended shelf life

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**VERSION**
Final

**DATE**
2016-08-01

**AUTHORS**
Michael Bantle
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Ignat Tolstorebrov (NTNU)

**CLIENTS**
ERA-NET and NFR

**CLIENT'S REF.**
SusOrganic / NFR247220

**PROJECT NO.**
SusOrganic 502000972

**NUMBER OF PAGES/APPENDICES:**
22

**ABSTRACT**

## Superchilling of organic food

The present report is a part of the ERA-NET project *SusOrganic: Development of quality standards and optimised processing methods for organic produce*. The superchilling concept and the state-of-art of the technology are summarized with focus on potential implementation for small scale organic production.

Production of processed organic food is mostly carried out by small and medium enterprises in demanding, competitive market conditions due to competition from highly cost-efficient large scale producers of conventional products and producers of locally grown food without certification requirements. The superchilling concept can be applied for organic meat and fish products, hereby helping the producer to supply the market with high-quality organic products. The extended shelf life of superchilled products will be beneficial during storage with respect to production and seasonal variations and transportation in order to reach new and far-distant markets. Strict control of the chilling process as well as storage temperature and time, is necessary in order to apply the concept. For these reasons, it might be difficult to apply superchilling towards the end of the cold chain at the retailer or consumer without significant alterations to the cold chain.

**PREPARED BY**
Michael Bantle

**SIGNATURE**
Michael Bantle

**CHECKED BY**
Anne Karin Hemmingsen

**SIGNATURE**
Anne K. Hemmingsen

**APPROVED BY**
Petter E. Røkke

**SIGNATURE**
Petter E. Røkke

| REPORT NO. | ISBN | CLASSIFICATION | CLASSIFICATION THIS PAGE |
|---|---|---|---|
| TR A7583 | 978-82-594-3671-9 | Unrestricted | Unrestricted |

# Document history

| VERSION | DATE | VERSION DESCRIPTION |
|---|---|---|
| Version No. 1 | 2016-03-31 | Summarization of the concept of superchilling, the state-of- art and potential with focus on small-scale organic producers. Parts of this report are published on the 4th IIR Conference on Sustainability & the Cold Chain (www.iccc2016.com). This report is part 1 of 2 about superchilling of organic food products and is part of the ERA-NET project SusOganic: Development of quality standards and optimised processing methods for organic produce. |
| Final | 2016-08-01 | Final version |

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# 1 The Norwegian Marked for Organic Food Products[1]

The organic food producers in Norway are in recent years under constant pressure from large scale producers of conventional products and producers of locally grown food, and the organic production is reduced on a yearly basis. For 2015 the reduction was -3.6 % from 2014. The total area in Norway used for organic production in 2015 was 4.5 % of the total Norwegian farming area (Table 1). In contrary, the annual turnover for organic products in supermarkets has been constantly increasing for the last 10 years (Figure 1). However, only 1.6 % of the sold products in supermarkets were organic in 2015. Organic meat products can mainly be found in supermarkets with a broad assortment, while organic eggs and dairy products are also found in discount supermarkets.

In the year 2000, the Norwegian parliament approved an action plan which aimed to increase the amount of organic food products to 10 % by the year 2010[2]. This aim was adjusted in 2009 to be 15 % by the year 2020. Recent numbers show that the organic sector represents only a market share of 1-2 %, and it seems that the 15 % target is far from being reached. Even more important is that the trend in organic production is negative, despite several efforts to increase the market share of organic products.

A details overview of organic production per sector is given in Table 1. It can be seen that organic products are mainly sold in daily grocery stores (approximately 80 %). Around 500 million NOK of the (registered) annual turnover was reported to the Norwegian Agricultural Agency as products sold from large household production facilities, farmers markets, subscription sales, independent bakeries (not related to groceries) and other specialised selling points, but not including health-food shops and state-owned liquor store. Based on these numbers it can be seen that the organic turnover is increasing despite the fact that less organic products are produced in Norway. Most likely, this is a result of an increased import of organic products.

**Table 1: Overview of organic production in Norway for 2014 and 2015 including total share [1].**

| | Total organic production | | Change | Share of total organic production | |
|---|---|---|---|---|---|
| | 2014 | 2015 | | 2014 | 2015 |
| organic area (decare) | 459739 | 443166 | -3.6 % | 4.7 % | 4.5 % |
| area with restrictions (decare) | 38530 | 33230 | -13.8 % | - | - |
| Grain (ton) | 10938 | 9295 | -15.0 % | 0.8 % | 1.0 % |
| Milk (million litres) | 52 | 51 | -0.8 % | 3.4 % | 3.4 % |
| Meat (cattle, sheep/lamb, pig, goat; ton) | 2231 | 2278 | 2.1 % | 1.0 % | 1.0 % |
| Poultry (ton) | 185 | 165 | -10.8 % | 0.2 % | 0.2 % |
| Egg (ton) | 2825 | 3160 | 11.9 % | 4.7 % | 0.5 % |

[1] The following report is used as reference if not specified otherwise: Landbruksdirektoratet (2016). Produksjon og omsetning av økologiske landsbruksvarer - Rapport for 2015. R. N. 2016. Oslo, Norway, Landbruksdirektoratet
[2] Stortingsmelding Nr. 19 (1999-2000)

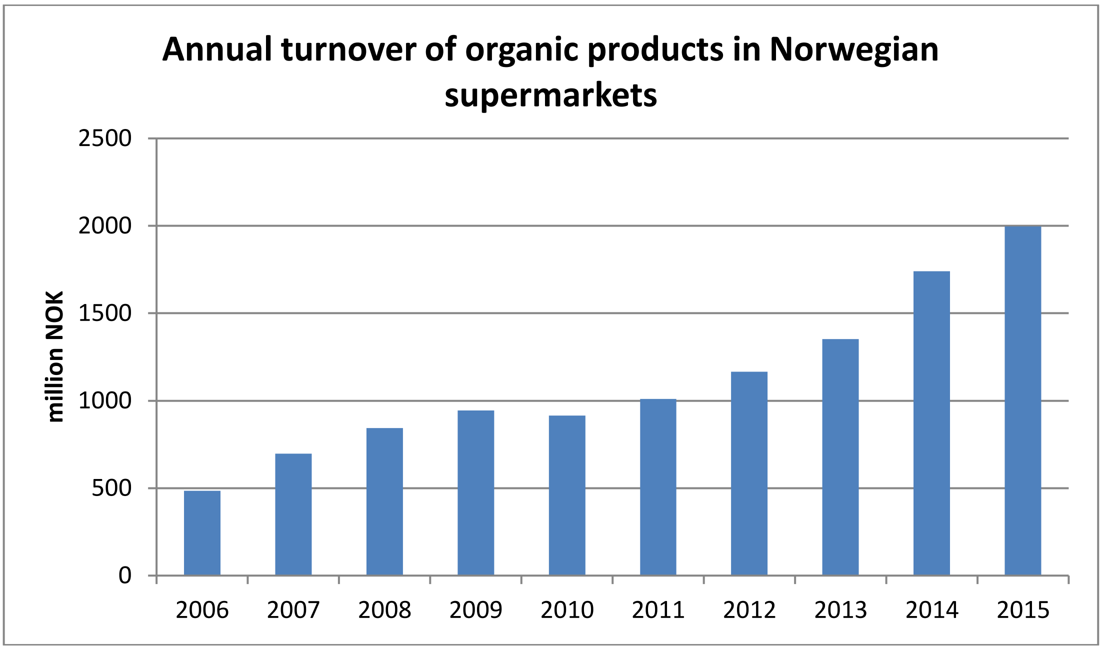


**Figure 1: Annual turnover of organic products in Norwegian supermarkets.**

**Table 2: Annual turnover of organic food in grocery trade and other sales channels for 2014 and 2015 in million NOK**

| | Turnover [MNOK] | | Change | Organic share [%] | |
|---|---|---|---|---|---|
| | 2014 | 2015 | | 2014 | 2015 |
| Dairy products | 308 | 323 | 4.7 | 1.7 | 1.8 |
| grain, corn and bakery products | 139 | 154 | 10.9 | 1.0 | 1.1 |
| Meat | 60 | 65 | 8.2 | 0.3 | 0.3 |
| Egg | 136 | 164 | 20.3 | 7.0 | 8.0 |
| Fruits, berries and nuts | 157 | 202 | 28.3 | 1.7 | 1.9 |
| Vegetable and potatoes | 396 | 480 | 21.3 | 3.4 | 3.8 |
| **Total food in grocery trade** | **n.a.** | **1999** | **14.9** | **1.5** | **1.6** |
| other channels of sales | n.a. | 469 | 22.1 | n.a. | n.a. |
| **Total registered turnover** | **n.a.** | **2468** | **16.2** | **n.a.** | **n.a.** |

## 1.1 Organic meat sector in Norway

The accumulated organic meat production (cattle, sheep/lamb, goat and pork) increased with 2.1 % between 2014 and 2015. In total 2278 tons of meat (excluding poultry) was produced in Norway, which is a marked share of 0.95 % of the total meat production. Organic production of cattle increased with 8.3 % while the production of sheep/lamb and goats increased with 8.5 %. Organic pork production was reduced significantly by 23.4 %, because of market corrections in 2014.

Nortura SA had a market share of 80 % of all meat sales in 2015, and is the biggest single producer when it comes to slaughtering of organic animals (marked share of 71 % on the total Norwegian market). The second largest is Fatland AS (3 slaughterhouses) with a marked share of 15 %. Other producers are small local slaughterhouses.

**Table 3: Organic produced meat in Norway over the last years, in kilogram**

| Year | cattle | sheep/lamb | pork | goat | total |
|---|---|---|---|---|---|
| 2005 | 883 555 | 359 320 | 45 417 | 1 939 | 1 290 231 |
| 2013 | 1 236 803 | 545 821 | 381 019 | 4 226 | 2 167 869 |
| 2014 | 1 272 907 | 570 584 | 384 479 | 2 824 | 2 230 794 |
| 2015 | 1 378 994 | 602 363 | 294 410 | 1 917 | 2 277 684 |
| ***Change (last year)*** | ***106 087*** | ***31 779*** | ***-90 069*** | ***-907*** | ***46 890*** |

For the largest slaughter houses the production increased by 7.2 % while at the same time the sale of organic, labelled meat almost doubled. However, only 49 % of the organic produced meat is sold as organic, which means that still more than half of the organic meat products are sold as conventional meat.

**Table 4: Share of organic meat sold under organic labelling for selected Norwegian producers, in ton**

| Product | 2007 | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| Organic produced meat | 1435 | 1758 | 1821 | 1952 |
| Sold as organic meat | 608 | 532 | 494 | 959 |
| **Share of sold organic meat** | **42 %** | **30 %** | **27 %** | **49 %** |

The organic poultry production was decreased in 2015, which was caused by the limited capacity of the producers in the market. The amount of organic poultry was low, with 0.18 % of the total poultry market in 2015.

## 1.2 International development of organic products

The development in Norway is contrary to the global trend, where for 2014 the increase in organic farming area was 1.3 %, reflecting the increase in total production and sales of organic products. Sweden alone increased its organic production area by 15 % in 2014, while the trend in Norway (and also in Denmark) at the same time was negative (-3.6 %). In Sweden the turnover of organic products was 21 billion NOK in 2105 compared to Norway with 1.7 billion NOK in the same period.

**Table 5: Global organic production areas in 2014 (in hectares)**

| | Organic production area 2013 | 2014 | Change 2013 to 2014 | Amount, global |
|---|---|---|---|---|
| Oceania | 17 321 733 | 17 342 416 | 0.12 % | 39.7 % |
| Europe | 11 460 773 | 11 625 001 | 1.43 % | 26.6 % |
| Latin America | 6 611 636 | 6 785 796 | 2.63 % | 15.5 % |
| Asia | 3 425 939 | 3 567 474 | 4.13 % | 8.2 % |
| North-America | 3 047 710 | 3 082 419 | 1.14 % | 7.1 % |
| Africa | 1 227 008 | 1 263 105 | 2.94 % | 2.9 % |
| **Total** | **43 094 799** | **43 666 211** | **1.33 %** | **100 %** |

**Table 6: Organic production area for selected countries in 2014 (in hectares)**

| | Organic production area | Share of total production area | Share on global organic production |
|---|---|---|---|
| Australia | 17 150 000 | 4.2 % | 39.3 % |
| Argentina | 3 061 965 | 2.2 % | 7.0 % |
| USA | 2 178 471 | 0.6 % | 5.0 % |
| China | 1 925 000 | 0.4 % | 4.4 % |
| Spain | 1 710 475 | 6.9 % | 3.9 % |
| Italy | 1 387 913 | 10.8 % | 3.2 % |
| Uruguay | 1 307 421 | 8.8 % | 3.0 % |
| France | 1 118 845 | 4.1 % | 2.6 % |
| Germany | 1 046 733 | 6.3 % | 2.4 % |
| Canada | 903 948 | 1.3 % | 2.1 % |
| Sweden | 501 831 | 16.4 % | 1.2 % |
| Finland | 212 653 | 9.4 % | 0.5 % |
| Denmark | 165 773 | 6.3 % | 0.4 % |
| Norway | 49 827 | 4.9 % | 0.1 % |

## 1.3 Discussion and conclusions

The presented numbers in this chapter are based on the annual evaluation of production and turnover of organic agriculture products. In general, it can be seen that the organic sector is small but growing in a global perspective. Also for some sectors in the organic Norwegian agriculture production an increase can be reported. However, the overall tendency is that the agricultural production is decreasing for 2015 (compared to 2014). This is a tendency that has been ongoing for several years. Reasons for this development are not investigated.

The intention of the Norwegian government is still to increase the market share to 15 % by 2020. Based on the presented numbers it is highly unlikely that this aim will be reached. The more urgent target will be to reverse the trend of the recent years and achieve a growing organic market, and the reasons for the reduced organic production should be investigated.

The *SusOrganic* project executed a survey among consumer, retailer and producer. The response to the retailer and producer survey was marginal and the survey was therefore not evaluated further. In contrast, over 600 consumers did answer the consumer survey. It became clear that locally grown food production, was considered as a sustainable alternative to organic labelled food. Around 50 % of the consumers think that conventionally produced food is produced more sustainable than organic. Even though the survey cannot be considered as representative (for that it would need 1000 responses), it outlines a general problem of the organic sector in Norway; market competition from local producers and "wrong" reputation of organic products.

The retail of organic products in Norway can be considered as one-sided, since 80 % of the turnover is generated in conventional groceries. There are only three supermarket chains in Norway (Reitangruppen AS, Norgesgruppen AS and COOP) which are competing. Consequently, organic producers have not many distribution or retail channels in order to sell their products. This might be one of the reasons why the share of organic products in the market is no more than 1.6 %. Geographical distances between producers and consumer is another element that may influence on the organic market share in Norway.

Only half of the organic meat production is sold with organic labelling. This indicates that the consumer is not aware of or willing to purchase organic meat, and consequently the meat is sold as a conventional product. This actually designates an overproduction when it comes to organic meat. The market dominance of one meat producer holding 70-80 % of the market could also influence the consumer demand for organic products. One of the Norwegian supermarket chains plans a sales-offensive for 2016. This could force the competitors to increase their organic production, and hereby supporting the organic sector. It is also interesting to notice that organic meat products are quite often sold in a processed state, e.g. as sausages.

Since the annual turnover for organic products in Norway is increasing despite the fact of reduced production, this clearly indicates an increased importation of organic food products to Norway, instead of being produced locally.

Based on the presented evaluation it is safe to conclude that the organic production and market in Norway is in a demanding, competitive market situation and has to be considered as a niche-market. Producers and retailers have to find better ways to bring their products to the market with the purpose to increase (or generate) consumer demand. Supporting actions will be necessary and beneficial in order to establish a significant market share for organic products.

## 2 Concept of superchilling

Food security is one of many challenges mankind is facing in the future and depends closely on the growing population, available agricultural area and energy resources on the planet. Food and Agriculture Organization of the United Nations (FAO) estimates that each year, approximately one third of all food produced for human consumption in the world is lost or wasted[3]. These losses represent a missed opportunity for the global food security, especially when considering limited agricultural resources and the fact that still around 1 billion people are suffering from hunger. FAO identifies, among others, the meat industry as a global environmental hotspot related to food wastage for consideration by decision-makers wishing to engage into waste reduction. Even if wastage volumes of meat are comparatively low, they generate a substantial impact on the environment in terms of land occupation and carbon footprint, especially in high-income regions where about 67 % of the meat is wasted and in Latin America.

The organic meat market in Norway is small and only half of the organically produced meat is sold under organic labelling. The reasons for this are not investigated in this project, however, during contact with small producers it became clear that valuable time is lost in the cold chain between slaughtering, processing and packaging before the product is ready to reach the market. In some cases, small producers do not have the infrastructure/possibility to slaughter themselves and they need to send their animals to certified slaughterhouses. After slaughtering the unprocessed raw meat is sent back to the producers for further processing and/or packaging and labelling. First then the meat can be sent out to the retailer. The organic meat is therefore a few days old before the consumer has the possibility to purchase it because of the distances, place of production and time necessary for transport and processing. Consequently, the organic meat is already exposed to quality reduction compared to traditionally produced meat in the supermarket. It can be estimated that the shelf life of organic meat is reduced by 50 % for certain cases when compared with conventional meat. Possibilities to extend the shelf life and improve the quality of organic meat would help the producers to be more competitive in the market. It would also enable local producers to reach far distance markets, which are currently not exploited due to transportation time.

Meat and fish products are mostly preserved by traditional refrigeration processes, and needs to be sustained through the cold chain from the production facilities until it reaches the plate of the consumer. Preservation in the form of drying, dry-curing or salting is also applied for meat and fish. Compared to the global meat and fish production, this represents a non-substantial volume. Most modern storage plants today have installed refrigeration systems, chilling/freezing equipment and cold store facilities, which also fulfil certain demands on energy efficiency and environmental impact. Worldwide, the relocation of people to urban areas has required more food preservation, transportation and greater distribution of perishable food.

Consumer behaviour, especially in high-income regions, require high quality meat and fish products, which fulfil health and security requirements in the supply chain. Especially the producing and processing industry in the cold chain are facing challenges during preservation and distribution of fresh perishable products, which are accepted by the consumer. The most important factors for the quality of meat and fish products are storage temperature and time, which directly influences the shelf life and quality. For constant storage

[3] FAO (2013). Food wastage footprint: Impacts on natural resources, Summary Report Food and Agricultural Organization of the United Nations.

temperatures, the shelf life of a product is a simple function of the storage time (e.g. Figure 2). For each product, certain variations in the shelf life occur depending on product variations as well as processing and packaging.

Industrial countries normally have a sufficient cold chain where the different parts are controlled during production, processing, transportation and storage. Different studies and measurements have outlined that the segments transport and sales have challenges holding the required maximum temperature of the cold chain. This includes errors and lack of chilling in transfer operations or transport equipment[4].

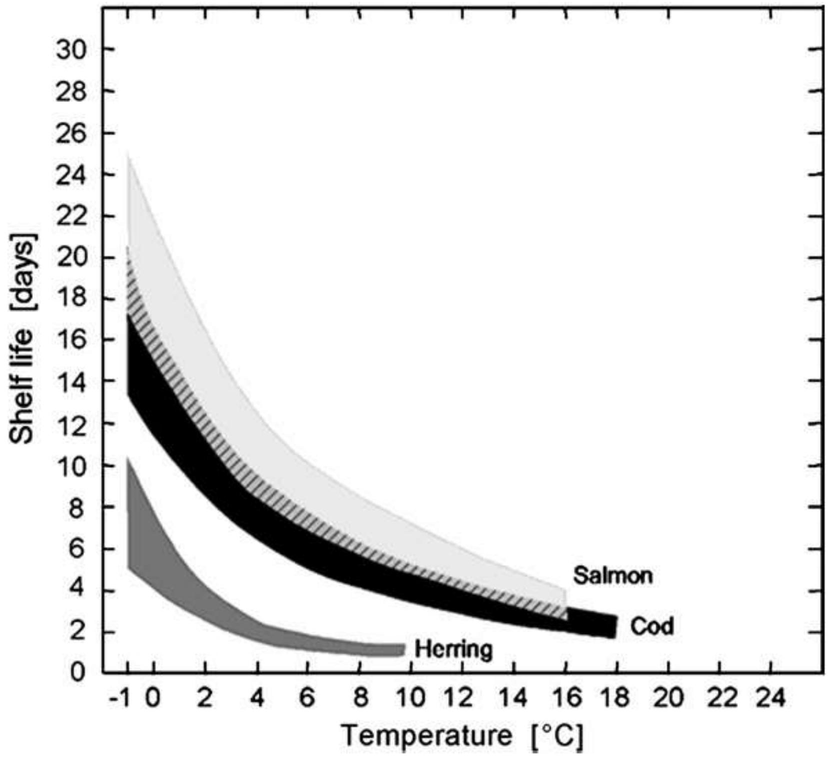


**Figure 2: Generally accepted shelf life for selected Norwegian fish species. The shaded area shows estimated effects of product-processing[5]**

Superchilling is in principal a partial freezing of a product with an ice content from 5 % to 20 %[6]. There is no definition of superchilling commonly agreed upon in literature and in some publications an ice content of up to 30 % was considered as superchilled. The main idea behind superchilling is that the product appear non-frozen despite the presence of ice. Hence, the acceptable amount of ice formation must be considered for each product. In literature, the term supercooling can be found for food products, which is different from superchilling. Supercooled products are also stored at temperatures below the initial freezing point, but without the presence of ice inside the food matrix. This is reached by special product handling which avoids

[4] Hemmingsen, A. K. T., et al. (2004). "Challenges in distribution of fresh food." Scandinavian Refrigeration 5: 40-45.
[5] Magnussen, O. M. (1993). Energy consumption in the cold chain . Proceedings IIR - Commissions B1, B2, D1, D273. Palerston North, New Zealand
[6] Kaale, L. D., et al. (2011). "Superchilling of food: A review." Journal of Food Engineering 107(2): 141-146.

initial ice nucleation. Superchilled products on the contrary, will have a certain fraction of ice present inside the food matrix.

The challenge for producing a superchilled product is how to control the amount of ice formation. The water present in food is embedded inside the solid material of the product, and ice formation in food products occurs over a certain temperature range. This is in contrast to ice formation of pure water which occurs exactly at 0°C and the temperature of a pure water-ice mixture can first be reduced below 0°C when all liquid water is frozen to ice. For food products the initial freezing point is normally one or two Kelvins below the freezing point of water and the temperature of the product can be reduced further (normally down to around -20°C) despite the fact that liquid, unfrozen water, is present. This is illustrated in Figure 3 and Figure 4, where the change in the specific enthalpy for food products is a smooth curve starting from the initial freezing point and stretching over a certain freezing range; instead of a sharp fall at the freezing temperature. The water in the product is partly present as ice and partly present as liquid water even at temperatures down to -20°C (also illustrated in Figure 3). Consequently, the amount of present ice for a certain product is a function of the temperature and if the storage temperature is controlled to certain stable temperature level, the amount of formed ice in the product can be controlled as well.

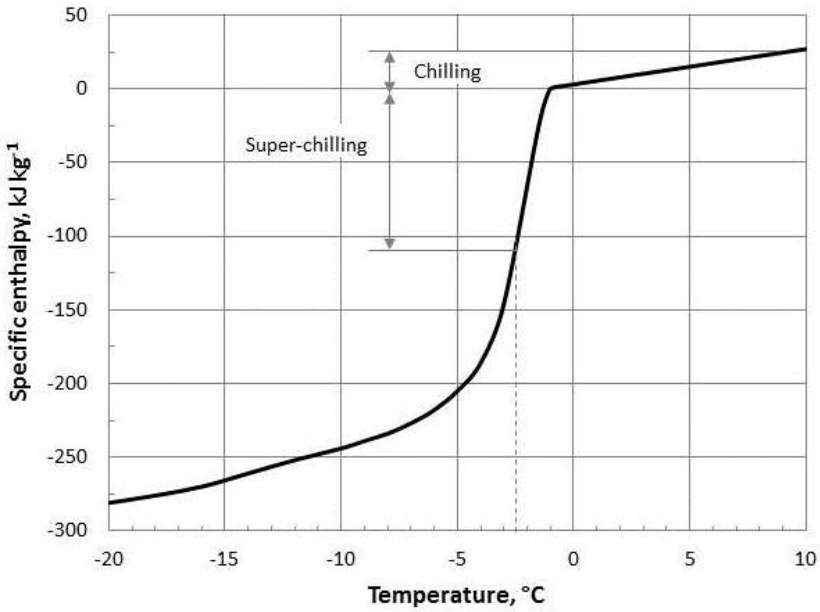


**Figure 3: Energy in food products on the example of codfish filets, according to Valentas (1997)[7].**

[7] Valentas, K. J. (1997) Handbook of food engineering practice / edited by Kenneth J. Valentas, Enrique Rotstein, R. Paul Singh.

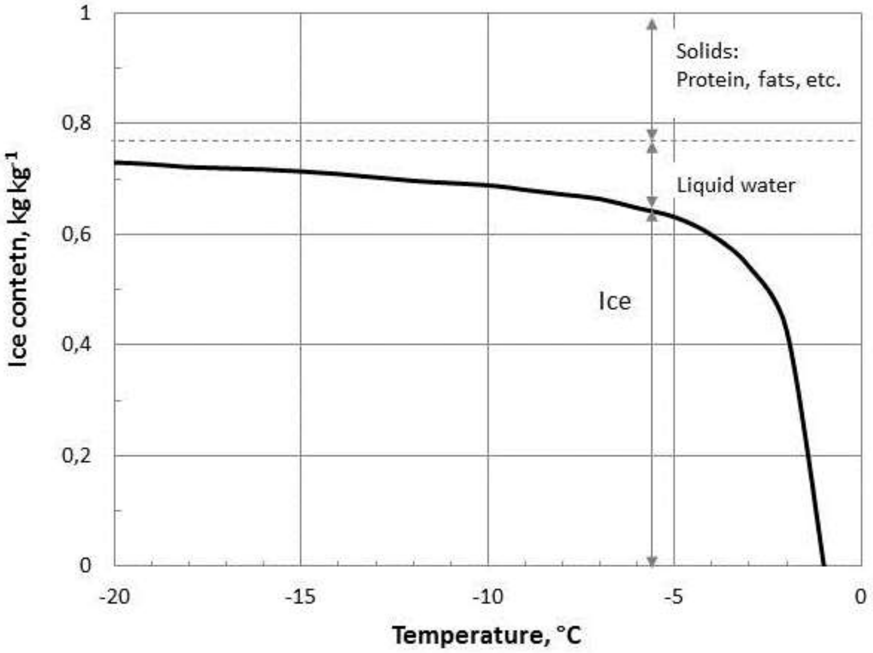


**Figure 4: Ice content in food products on the example of codfish filets, according to Valentas (1997) [7].**

In literature several methods are described to obtain superchilling conditions in food products. In order to reach superchilled conditions, it is necessary to identify the temperature at which the product will form/contain the desired amount of ice. One of the easiest, but not best, method is when the product is placed at this temperature in a storage room. The product will reach superchilled conditions after a certain time, depending on the heat transfer between product and storage environment. However, experimental investigations show a rather poor control of the ice fraction, when the product is simply placed in at a certain superchilled temperature. The ice formation will be highly time consuming (>1-2 days) and will vary with the effective heat resistance of the product and storage system. Hence, placing the product at superchilled storage condition results in two practical problems: First, the storage facility will function as a partial freezer, which gives challenges for dimensioning, packaging, temperature distribution and control of ice fraction. Second, the time to build up the amount of partial ice will be very long, since the heat transfer is limited by the low temperature difference between product and ambient condition as well as the heat transfer resistance and product variations.

SINTEF has evaluated and tested a superchilling concept which is based on fast initial shell freezing using a conventional blast freezer before storing the product at superchilling temperatures. During blast freezing the outer layer of the product is frozen. The freezing time is relatively short, only 1-3 minutes, depending on product and size of product. Because of the high heat transfer coefficient and a freezing air temperature of ca -40 ºC, the freezing time is relatively short. The conditions need to be precisely evaluated with respect to freezing time, product size, heat transfer coefficient and temperature difference (between air and product) in order to result in the correct amount of ice formation. The aim of the blast freezing is to produce all ice which is required during superchilled storage before the product is put into storage. By this procedure it is ensured that the superchilled storage only needs to sustain a certain temperature and that no heat load is created for ice formation.

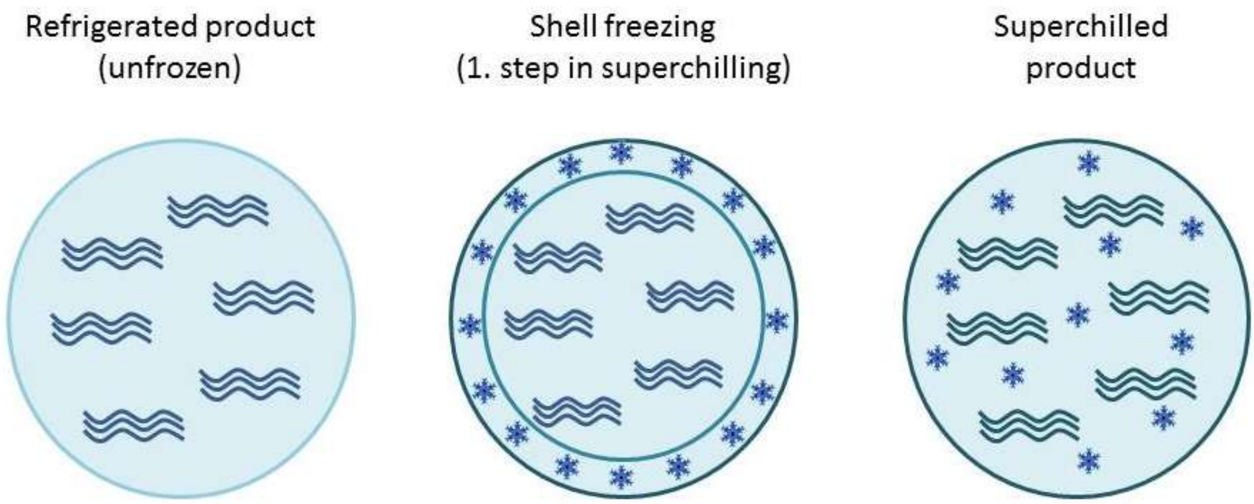


**Figure 5: The different steps in superchilling of food: The present water in the product is partially frozen and after a certain time mixture of water and ice is present inside the structure of the product.**

During storage of superchilled food products, the ice in the outer shell of the product will slowly distribute evenly through the food matrix, thus the shell-frozen ice will disappear, and the product will appear as fresh. As a final result, the superchilled product will have a certain amount of ice evenly distributed through the product and the product temperature is below its initial freezing point. The appearance of the product is still like an ordinary refrigerated product and it is not possible to feel or see the present ice fraction. The relation between the ice fraction and the storage temperature is given for some selected products in Table 7. This topic is discussed extensively in literature (Valentas 1997, ASHRAE 2006), however, with focus on the complete temperature range for freezing (down to -25°C). It is therefore recommended to determine this relation in more details for specific products in the temperature range of superchilling.

**Table 7: Relation between storage temperature and ice fraction for some selected products[8]. Product variations make it necessary to evaluate the ice fraction individually.**

| Product | Storage temperature (superchilled) | Ice fraction | Initial freezing point |
|---|---|---|---|
| Salmon filet | -1.8 °C | 6.3 % | -1.6 °C |
| | -2.2 °C | 18.2 % | |
| | -2.6 °C | 26.9 % | |
| Trout | -2.2 °C | 8.2 % | -2.0 °C |
| | -2.6 °C | 21.8 % | |
| | -3.0 °C | 27.0 % | |
| Mackerel | -1.8 °C | 6.3 % | -1.6 °C |
| | -2.2 °C | 18.2 % | |
| | -2.6 °C | 29.3 % | |
| Herring | -1.8 °C | 4.0 % | -1.6 °C |
| | -2.2 °C | 11.6 % | |
| | -2.6 °C | 18.7 % | |
| Cod (aquaculture) | -1.2 °C | 10.2 % | -1.0 °C |
| | -1.6 °C | 27.9 % | |
| | -2.0 °C | 38.6 % | |
| Beef, lean (Valentas 1997) | -1.0 °C | 5 % | n.a. |
| | -2.0 °C | 45 % | |

[8] Tolstorebrov, I., et al. (2014). "A DSC study of phase transition in muscle and oil of the main commercial fish species from the North-Atlantic." Food Research International 55(0): 303-310.

## 3 State-of-the-Art

The main reason to apply the superchilling concept to a product is the possibility to extend the shelf life of the fresh product. The shelf life of a product depends on several factors where the storage temperature has a dominating influence. Other factors like processing hygiene, mechanical stress, packaging and product variations will also have an influence, which makes comparative evaluations of different studies difficult. However, the temperature in superchilled storage is around 5 – 10 Kelvin lower compared to traditional refrigerated storage and this temperature reduction is accomplished by the superchilling concept.

Duun and Rustad [9] were investigating superchilling of farmed cod fillets and showed an increased shelf life of around 2 weeks compared to chilled ice storage. The drip loss for the superchilled cod was lower, however, the liquid loss by low-speed centrifugation was higher in superchilled cod fillets. This was explained by the freeze denaturation of muscle proteins. It was outlined that the superchilling process needs to be optimized with respect to freezing rate and degree of superchilling in order to minimize protein denaturation while sustaining a sufficient low temperature to ensure a shelf life increase[9].

The influence of superchilled storage on pork roast was investigated by the same group[10]. The superchilled storage time was 16 weeks for vacuum-packed pork roast at a temperature of -2.0°C and compared with chilled storage at 3.5 °C. The sensory quality was evaluated as good and the microbiological count was low during the whole storage period. Again, the drip loss was lower for superchilled products. The group claims that the shelf life can be extended from 2 to 16 weeks when superchilling is applied. However, they also outline the importance of maintaining a stable temperature with very low fluctuation during superchilled storage.

The superchilling of farmed Atlantic salmon at storage temperatures of -1.4 °C and -3.6 °C was compared with chilled ice storage (storage temperature of around 0 °C) in another investigation[11]. For the ice-chilled salmon, a storage time of 17-21 days was determined, while the storage time for the superchilled salmons was doubled. No different shelf life for superchilled salmon stored at -1.4°C and -3.6°C was reported. Drip loss was identified as a major problem for superchilled salmon. The textural hardness was higher in superchilled salmon at -3.6°C and a higher protein denaturation was found for the samples from -1.4°C. Based on these findings, a superchilling temperatures somewhere between -1.4°C and -3.6°C was recommended for salmon, and salmon was considered as better suited for superchilling than cod. Similar results were achieved for rested Atlantic salmon[12].

In a national Norwegian project [13] it was investigated how superchilling can be applied for fresh lamb (lamb-leg). A superchilling temperature of -1.6 °C extended the shelf life from 21 days to 40 days (90 % increase).

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[9] Duun, A. S. and T. Rustad (2007). "Quality changes during superchilled storage of cod (Gadus morhua) fillets." Food Chemistry 105(3): 1067-1075.

[10] Duun, A. S., et al. (2008). "Quality changes during superchilled storage of pork roast." LWT - Food Science and Technology 41(10): 2136-2143.

[11] Duun, A. S. and T. Rustad (2008). "Quality of superchilled vacuum packed Atlantic salmon (Salmo salar) fillets stored at −1.4 and −3.6 °C." Food Chemistry 106(1): 122-131.

[12] Erikson, U., et al. (2011). "Superchilling of rested Atlantic salmon: Different chilling strategies and effects on fish and fillet quality." Food Chemistry 127(4): 1427-1437.

[13] Norwegian Research Council (2016). "Optimal verdikjede for ferskt lam (project 210643) https://www.forskningsradet.no/prosjektbanken/#!/project/210643/no."

The project also investigated how to implement the superchilling concept in the production and installed a blast freezing system in an existing production line hereby reducing the processing time by 1 day. This resulted in a reduction of production costs as secondary effect. The colour and pH-value of the superchilled lamb did not vary compare to traditional chilled lamb, but drip loss was higher. The extended shelf life made it possible to reduce the demand on product freezing. This reduced the demand for freezing from 40 % down to 10 % and the energy demand by 13 %. Freezing and thawing causes leakage of proteins and other substances from the cell and for lamb the activity of the lysosomal protease cathepsin B was used to demonstrate that superchilled meat has less freeze damage compare to frozen meat[14]. However, compared to fresh meat a certain higher amount of damage occurred in the superchilled meat. In general, the work showed that superchilling leads to some freeze/thaw damage compared to conventional refrigerated meat, but the damage was less compared to frozen meat.

Claussen[15] reported for superchilled chicken meat an increase in shelf life from 15 to 30 days. However, it was not further specified at which temperature the meat was stored and other quality aspects were also not investigated in this paper.

In all performed experiments reported, the holding temperature of the storage was set in order to match the obtained ice fraction in the product from shell freezing. However, there was a general lack of information on the actual ice fraction in the investigations, because of challenges with measuring the ice fraction online[16]. In most cases, the ice fraction is determined with a disruptive method in preliminary tests for certain products.

The low temperature and the partial ice content in products stored at superchilling temperatures, will result in a delayed growth of bacteria and microorganisms. The rapid chilling due to shell freezing will stop this growth and partly destroy or damage surface bacterial activity, which is beneficial for the superchilling concept in general[17]. Figure 6 shows some examples of achieved reduced growth rates (CFU = Colony Forming Unit). The shelf life of food is based on a quality limit of $10^7$ CFU. Above this value food is considered unfit for human consumption.

**Table 8: Shelf life extension for selected meat and fish products in comparative studies with conventional refrigeration**

| Product | Superchilled storage temperature | Increase shelf life compare to conventional refrigeration |
|---|---|---|
| Cod fillets (farmed) | -2.2 °C | + 14 days |
| Pork roast | -2.0 °C | + 14 weeks |
| Atlantic salmon (farmed) | -1.4 °C and -3.6 °C | + 17 – 21 days |
| Chicken | n.a. | + 15 days |
| Lamb-leg, fresh | -1.6 °C | + 19 days |

[14] Friestad, E. and T. Rustad (2014). Superkjølt lam: Studier av proteolytiske enzymer. Superchilled Lamb: Studies of Proteolytic Enzymes, Institutt for bioteknologi.
[15] Claussen, I. C. (2011). Superchilling concepts enabling safe, high quality and long term storage of foods 11th International Congress on Engineering and Food (ICEF11) Procedia Food Science 1 (2011) 1907-1909.
[16] Stevik, A. M., et al. (2010). "Ice fraction assessment by near-infrared spectroscopy enhancing automated superchilling process lines." Journal of Food Engineering 100(1): 169-177.
[17] Magnussen, O. M., et al. (2008). "Advances in superchilling of food - Process characteristics and product quality." Trends in Food Science & Technology 19(8): 418-424.

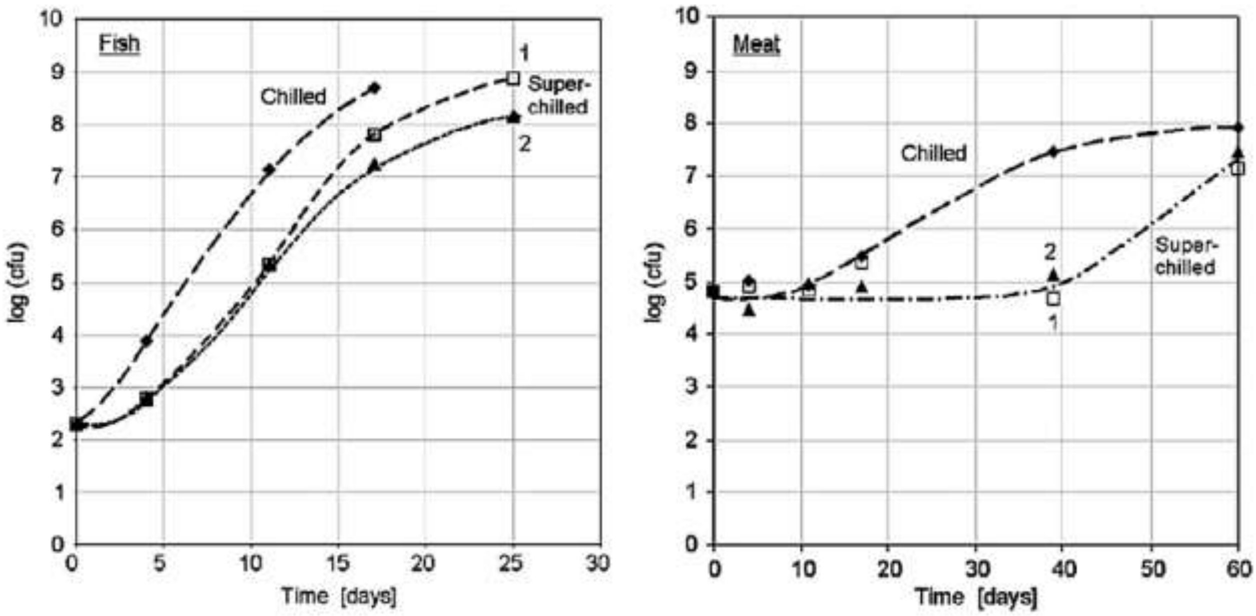


**Figure 6: Growth of aerobic bacteria on superchilled and ordinary stored fish (salmon) and meat products (pork); from Magnussen, Haugland et al. 2008. 1 and 2 refer to low and high ice content respectively. CFU is Colony Forming Unit.**

Superchilling is mostly investigated for meat and fish products, where a shell freezing process was applied upfront on the superchilled storage. Significant increases in shelf life are reported, which are generally related to the lower storage temperature compared to conventional refrigeration. The superchilling process is accompanied by some quality losses or alterations like higher drip loss, which can be explained by the presence of ice in the food matrix. Storage parameters like temperature fluctuation or packaging can influence and eventuallyimprove the shelf life of superchilled products additionally. Table 2 gives an overview about the reported shelf life extension in literature for certain products. It is important to notice that the determined shelf life extensions are obtained in comparative studies. Product variations and different processing routines will influence on the result, however they will not account for the achieved shelf life increases.

## 4 The potential of superchilling for organic food producers

The cold chain in the industry today consists of refrigeration (+4 °C to 8 °C) and freezing (-20 °C to -25 °C) of food products. This is true for both conventional and organic cold chains. The implementation of a new process will require equipment which can supply a stable temperature around -2 °C and, in addition, a shell-freezing process. There is no technological challenge to supply refrigeration at this temperature, yet it requires modified refrigeration equipment from the supply industry and the willingness to implement a new concept in the cold chains. The additional processing equipment and modified storage conditions for superchilled products can be a barrier for the implementation for small-scale producers. However, innovative new solutions are often implemented in small or medium sized production facilities, since the production is more flexible and the market potential is more promising for these producers.

So far, two processing lines for superchilling of fish and meat products have been implemented in the Norwegian food industry, but until now the concept is not used in substantial amount in European or other markets. Superchilling can be used in different ways and under different aspects in the cold chain for organic products:

1. **Extended shelf life:** The most obvious advantage is the extended shelf life for superchilled products compared to conventional refrigerated products. Products with long transportation or high seasonal variations can apparently benefit from this extension. In addition, products which are only produced in limited amounts can extend their availability to the marked or reach far distance markets. The extended shelf life is maybe the most important potential for organic meat and fish producers. With this technology, it will be possible to reach far distant markets which is an important aspect in order to overcome the geographical long distances, especially in Norway. Consequently, the organic products can compete when it comes to shelf life and quality in the supermarkets, since conventional large-scale producers have a better-developed (and faster) distribution network.
2. **Substitution of food freezing:** Overproduction of meat and fish products are often frozen in order to preserve it for future sales. However, it is normally possible to achieve a higher price for fresh products despite the fact that freezing and freeze-storage is costly. The superchilling concept offers the possibility to store at least a certain amount of the overproduction without freezing and sell it within reasonable time as fresh. A higher market price can be achieved while at the same time the energy demand (for freezing) in the production is reduced. In the above mentioned case for Norwegian lamb, the energy demand of the production was reduced by 13 % by partially substituting freezing with superchilling.
3. **Transportation:** High quality fish products, like Atlantic salmon, are quite often transported on chilled ice, either on the road but also by air transport. Approximately 25-30 % of the transported weight is ice, while the remaining 70-75 % of the transported weight is the valuable product. The transportation of ice is quite cost-intensive and at the same time it produces an environmental impact (carbon footprint). By using a superchilled product the necessity for ice during transportation can be reduced or avoided. The ice present inside the product functions as thermal inertia and provides the necessary chilling under transportation. By applying this concept it would be possible to reduce the transported weight and volume by 25-30 %. Or in other words: 4 truckloads with chilled ice boxes can be reduced to 3 truckloads with superchilled product while the same amount of sellable product is transported. It must be noticed that hereby the extended shelf life of the superchilled product transported is reduced since the partial ice fraction is reduced during transportation. However, also a longer shelf life compared to traditionally transported products will be achieved.

4. **Shorter processing time:** Conventional chilling is a time consuming operation which needs to be implemented in the production line. Superchilling, with initial blast freezing, can reduce process time and lower the product temperature before storage. Hereby it is possible increase the capacity of existing production lines or to compensate for varying production capacities.
5. **Other effects:** Superchilling is one of the first unit operations in a production line and can increase product yields e.g. due to higher firmness before skinning [18] or deboning. The rigidity of the product is in general higher for superchilled products. This can be beneficial for product handling, e.g. during fileting, slicing or automated packaging.

The superchilling concept can be implemented in existing production facilities, by the implementation of a blast freezer, which can be operated continuously. The specific chilling rate is accelerated since the heat transfer and the temperature difference in blast freezing is high. Therefore, it is relatively easy to produce superchilled products. However, superchilled storage requires a re-design of existing storage and refrigeration systems. The temperature of the refrigeration equipment must be reduced, but even more important, it must be ensured that the temperature variations and distribution in the storage rooms are small. A temperature fluctuation of ± 1 Kelvin is standard in conventional refrigerated storage. If a superchilled product is exposed to such fluctuations, it can result in continuous thawing and re-freezing of the ice inside the food matrix. This will have a poor influence on the product quality and stability. The performed investigations in the laboratory have normally a temperature stability of ±0.2 Kelvin. For industrial superchilling systems it must be carefully evaluated which temperature variation are acceptable. The authors recommend a temperature fluctuation as small as possible and to investigate the influence of temperature fluctuation further.

[18] Stevik, A. M. and I. C. Claussen (2011). "Industrial superchilling, a practical approach." Procedia Food Science 1: 1265-1271.

## 4.1 Challenges in Superchilling

For dimensioning and controlling of the superchilling process it is important to calculate the correct chilling time and temperature distribution (e.g. for blast freezer), because the amount of ice formed during superchilling is of great importance for the whole process. The latent heat of freezing results in a sharp decrease of enthalpy in the temperature range commonly applied for the process and consequently, even minor temperature changes can result in a significant change of the ice fraction. Food products normally consist of a complex matrix of water, protein, carbohydrates and fats, and the water is bound by different mechanisms. General equations for calculation therefore always have some uncertainties. Future work should find improved calculation methods and simulation tools fitting to superchilling. This is especially important for products that vary in shape and size.

Another challenge is the optimized determination of the degree of superchilling required for a sufficient improvement of shelf life while achieving acceptable quality attributes. Most investigations were focusing on an ice fraction between 10 % and 20 %, because the achieved quality reduction (compared to refrigerated products) was minor, while for ice fractions higher than e.g. 30 %, significant drip loss will occur. The superchilled storage temperature was set in order to demonstrate the potential of the concept compared to refrigerated storage. For a specific product, it must be determined which ice fraction or storage temperature is optimum with respect to reduced bacteria and microorganism growth and acceptable quality changes.

The industry requires in general effective and flexible processing equipment, which preserve a premium quality product. Superchilling offers certain possibilities for the industry, but the question is if they are promising enough to make the concept commercially interesting. The commercial interest will most likely be the main driving force for industrial implementation and the change from conventional freezing and refrigeration towards superchilling requires a certain readiness to take a certain risk. Superchilling will also demand more accurate information on product variation and flow, which is especially challenging for small scale producers. In addition, the equipment suppliers will meet higher requirements regarding energy and thermodynamic competence. It can be assumed that, especially in the beginning, most of the technology will be experimentally developed.

The consumer awareness for superchilled products is currently low (or not existing) and it might be a general challenge to get consumer acceptance for a third cold chain product. This aspect is currently not under evaluation.

## 5 Conclusion

Organic production in Norway is a niche market and only 1.6 % of the sold products in supermarkets are organic. For meat products, only 1 % of the meat is organic and around 50 % of the produced organic meat is sold under conventional, non-organic labels. The reasons for this development were not analysed. Long, time-consuming transportation in the cold chain from small or medium scale producers to the final consumer might be one of the reasons. Extension of shelf life due to superchilling of organic meat and fish products could help to provide the market with fresh-like, high quality organic products. The increased availability of organic meat and fish products at the market can trigger future consumer demand and help to increase the market share of organic products.

Controlled partial freezing or superchilling of food products can result in significant shelf life extensions during the cold chain. Between 10 % and 20 % of the water content of the food is frozen, and the ice functions as a thermal inertia during storage and transportation. Superchilled products in general have an extended shelf life and the technology shows good potential for implementation in the cold chain, since the product quality is comparable with that of refrigerated products. Superchilling in industry can also reduce the use of freezing/thawing for production buffers and thereby reduce labour, energy costs and product weight losses.

Superchilled products sustain quality parameters commonly associated with fresh/unfrozen products. However, some increase in product drip loss may occur during storage. Implementation of superchilling in industrial process plants and routines require a strict temperature control in the cold chain. Understanding and quantifying thermo-physical processes at and inside the food surface are important for the optimal design of superchilling equipment and packaging systems for food products.

The concept of superchilling is a new and improved cold chain process which is aiming to increase the shelf life of refrigerated products and sustain fresh-like appearance by applying partial freezing. This requires the implementation of a new temperature level (at approximately -2°C) for the storage of products in the cold chain. In order to achieve sufficient process control it is recommended to implement a fast partial freezing in the first segments of the production line. Promising results have been achieved with blast or impingement freezing. Significant shelf life extensions are demonstrated in literature for certain superchilled meat and fish products. The concept can be used to substitute chilled ice transportation, which will have a direct impact on the carbon footprint in the transport sector. Superchilling has the potential to reduce a substantial impact from currently wasted meat and fish volumes; especially in high-income regions with already existing cold chains, hereby contributing significantly to global food security. For industrial implementation, existing or modified equipment from today's cold chain can be used, but superchilling requires improved process control.

R&D has clearly identified the potential of this technology, especially for meat (chicken, lamb, pork) and fish (salmon, cod) products. However the industry has somewhat overlooked this technology, despite the clear benefits, the relative simple implementation also in existing production lines and the high technological readiness level. The first industrial implementations have demonstrated positive effects on shelf life, product quality, production yield, energy demand and production costs.

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