IMPROVED EFFICIENCY AND REAL TIME TEMPERATURE MONITORING IN THE FOOD SUPPLY CHAIN

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ABSTRACT

Within the EC Project CHILL-ON, supply chain management of perishable food is seen as the process of planning, implementing, and controlling operations to ensure traceability and maintain low temperature as efficiently as possible. The key issues in food production, namely safety coupled with industry's demand for transparency and quality assurance, are the main objectives of the various tools being developed in the CHILL-ON project. The concept of the Chain Information Management System, called “TRACECHILL”, is to tackle the most crucial points and design and implement novel solutions for the cold chain. This includes chilling technologies, real time temperature monitoring, logistic traceability, smart labels as time temperature indicators (TTIs) and molecular diagnostic tools (qPCR) for pathogenic and spoilage bacteria. Quantitative Microbial Risk Assessment and Shelf Life Prediction models have been developed and linked with a decision support system for immediate responses to potential hazards in the food supply chain.

1. INTRODUCTION

The transparency of the food supply chain is debated globally and despite regulatory framework and industrial standards, the performance of traceability systems has been inadequate as seen by numerous surveys on ineffective recall procedures in the case of contamination of food products and actual food related outbreaks. In the cold chain, the weak links are often the transport and the handover points (Raab *et al.*, 2008). Goods are left for extended time at temperatures exceeding their optimum range, which may result in spoilage and enhanced potential for growth of pathogenic bacteria. Temperature monitoring throughout the chold chain providing supply chain actors access to the temperature history in real time has been an issue of discussion and potential benefits regarding supply chain management, less waste and improved transparency are obvious.

Technologies are now available within the CHILL-ON project to implement a holistic traceability and temperature monitoring system. This project is a reaction to the need to support research and development in this area, which was already identified by the European Commission in 2004. To ensure transferability of technologies and applications to different products, the project is focusing on both fish and poultry supply chains. The holistic approach adopted by R&D partners and software and hardware commercial enterprises targets the delivery of a complete and integrated solution based on the CHILL-ON concept (Figure 1). The developed technologies include improved chilling and packaging concepts with TTIs, continuous monitoring of temperature by T-sensors, Data Acquisition Management (DAM) and Mobile and Stationary Management Units (MMU/SMU) for data acquisition and data transfer to the TRACECHILL server. A Geographic Information System (GIS) and SCM software provide immediate logistic information. The system includes a Decision Support System (DSS) fed by time/temperature data and information on microbial contamination as an input to QMRA and SLP models, giving real time display of temperature history and prediction of quality and potential microbial hazard. CHILL-ON technologies can thus support electronic management decisions and have an impact on economic and environmental values for food companies by minimizing perishable waste and enhancing sustainability of the supply chain.

Herein, the current status of the developments in the CHILL-ON project will be summarized and the implementation of the technologies and their validation in field trials will be described.

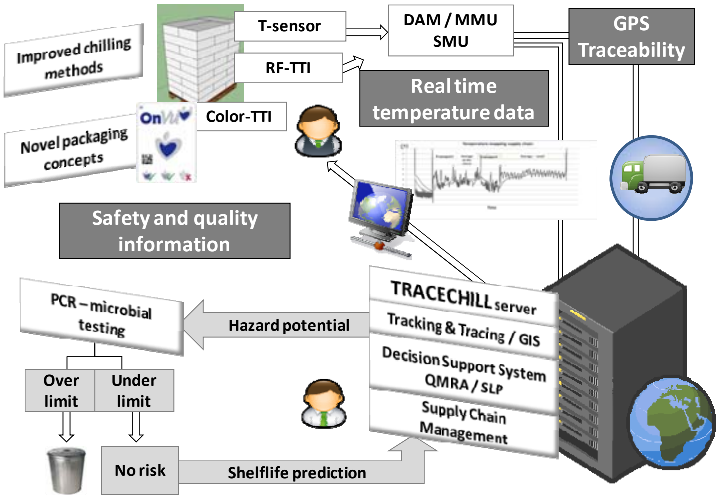

Figure 1. CHILL-ON conceptual approach to monitor quality, safety and traceability in food supply chains

2. INDUSTRY REQUIREMENTS

CHILL-ON technologies are aiming at providing supply chain actors with tools to monitor HACCP (Hazard Analysis and Critical Control Points) and facilitate the implementation of traceability, safety and quality measures according to legal and commercial requirements. The concept of the TRACECHILL system is to tackle the most crucial points within a full supply chain: continuous temperature monitoring, temperature abuse identification, detection of microbial food contamination, quick tracking and tracing of products.

In focus group discussions with industry stakeholders on the potential implementation of the CHILL-ON technologies, fish producers have shown great interest to be able to monitor their products in case something goes wrong in the supply chain, especially during transport to distant markets. The producer would then be able to intervene much sooner than is possible today and could thus direct the product either off the market if spoiled or to other production of less value with lower quality requirements. A very important aspect in today‘s supply chains is: who gets the blame when something goes wrong? Today, this is difficult to decide upon because of the blindness in the chains, where actors only see „one up“ and „one down“ in the chain as required by regulations.

It is common in the fish supply chain that the producers are not responsible for the transport of products, but instead the transport is bought from a logistic company. Therefore, producers have limited control over the shipment and can only ensure consumer satisfaction based on trust in the logistics and the condition of the product at the time of shipping. In the typical supply chain of fresh fish from Iceland to markets in Europe, the processor receives information on origin, logistic details and condition of the catch from the previous link. Temperature is registered in the processing and quality control is performed before the product leaves the processing plant. Transport to market takes two to four days and includes both trucking and transport by air or ship. The logistic companies are commonly not interested in showing temperature monitoring data throughout the transport in food supply chains (Raab *et al*., 2009). This may be explained by various broken links in the cold chain related to handover points. For example, uncontrollable temperature fluctuations may occur during loading and unloading of airplane freight. Transport by ship may offer better temperature control which will result in consistent quality of products (Mai *et al*., submitted).

3. CHILL-ON TECHNOLOGICAL DEVELOPMENTS

3.1. Chilling technologies for improved quality of fish products

Development and implementation of new chilling technologies and packaging methods to offer fish products with sufficient keeping quality is important to meet increasing demand for fresh fish products on the market. Within the CHILL-ON project various chilling techniques such as liquid cooling (LC), partial freezing and low temperature during storage and transport (<0°C) have been studied and their efficiency evaluated to maintain quality and extend shelf life of fresh fish products packed in EPS boxes. The effect of different cooling conditions on sensory quality and the growth of specific spoilage bacteria (SSO) *Photobacterium phosphoreum*, *Pseudomonas spp* and H_2S producing bacteria has been the focus in ongoing experiments. The aim has been to provide data for validating shelf life prediction models and to study the effect of different freshness of the raw material and MA packaging (Magnússon *et al*., 2009). MA packaging can further extend freshness charecteristics and the shelf life of superchilled products to at least 21 d. compared with 16 or 17 d. under superchilled storage alone (-0.9°C) (Wang *et al*., 2008). When applying liquid cooling, increased salt concentration effectively reduces the temperature of the chilling media, however, uptake of salt and partial freezing of the muscle is of concern and has to be carefully monitored. Lauzon *et al*., (2009) studied the effect of brining, modified atmosphere packaging (MAP), and superchilling on the quality changes and shelf life of cod loins. The shelf life of MA-packed unbrined loins was about 14 to 15 d at 0° C but 21 d at -2°C. Thus, synergism of combined superchilling (-2°C) and MA led to a considerable shelf life increase for unbrined loins (Lauzon *et al*., 2009).

A new chilling technology based on processing fillets in a superchilled state by applying CBC (Contact blast freezing and cool air blasting) (Skaginn hf., Iceland) has been studied in the CHILL-ON project. The impact of CBC cooling on the temperature maintenance of fillets undergoing temperature fluctuations in the supply chain has been found to be considerable when compared to liquid cooling (LC) in process or untreated fillets. CBC cooling can lead to freshness and shelf life extension in particular when combined with further storage at temperatures below 0°C (Olafsdottir *et al*., 2006a). When packed in EPS boxes, this is an advantageous method for fillets to be shipped as fresh products since low temperature and quality of products can be maintained despite breakage in the cold chain. Currently studies are ongoing to compare the impact of thermal load on CP (corrugated plastic) boxes compared with products stored in EPS boxes (Margeirsson *et al*., submitted).

3.2. Rapid microbial detection techniques based on qPCR

Diagnostic DNA based tests applying quantitative Polymerase Chain Reaction (qPCR) for rapid detection of pathogenic and spoilage bacteria have been applied in the CHILL-ON project to verify the number of spoilage bacteria and pathogens. Enabling technologies for identification of biological components at several levels of the supply chain and linking this information with systems for automatic data capture and transmission has been suggested to improve transparency in the food supply chain (Marmiroli and Maestry, 2009). The goal is to link traceability with rapid analytical procedures based on DNA analysis where the analysis time can be about 3 to 4 hours, while conventional methods based on cultivation take 3 to 5 days.

Test kits are currently available for food pathogenic bacteria i.e. *Salmonella enterica*, *Listeria monocytogenes*, *Campylobacter jejuni*, *Escherichia coli*, S*taphylococcus aureus* and hygienic markers (Marmiroli, *et al*., 2008). The CHILL-ON project has conducted surveys among food operators in over 50 companies in 10 countries concerning the current status of microbiological controls in the poultry supply chain. Over 90% of companies perform controls for *Salmonella*, *Listeria monocytogenes* and *Campylobacter*. More than 60% of companies check for the presence of *Escherichia coli* and S*taphylococcus aureus*. Other microorganisms are of interest to less than 40%: *Pseudomonas*, C*lostridium*, lactic acid bacteria, *Bacillus cereus* and *Streptococcus*. Companies also indicated assays for microbial markers for hygienic performance i.e. Enterobacteriaceae, coliforms, aerobics mesophyls, enterococci, moulds and yeasts (Marmiroli, *et al*., 2008).

According to the survey, DNA based tests are currently performed mainly with the aid of analytical laboratories outdoor or, in big companies having their own laboratories. A general requirement was for rapid tests which may give results in 2-4 hours or at least within the same day of sampling (Marmiroli *et al*., 2008).

For industrial implementation of PCR test kits developed within the CHILL-ON project, validation of their performance has been obtained in ring trials between laboratories to verify their correlation to conventional methods. Results are available on comparison of test kits for the quantification of *Salmonella enterica* in poultry meat by real-time PCR with conventional methods (Agrimonti *et al*, submitted).

In recent years, the new diagnostic methods for various bacteria have mostly been focused on food safety and the detection of pathogens. However, in the Chill-on project, efforts have been focused on developing kits for the specific spoilage organisms in fish. A rapid quantitative monitoring method for the common fish spoilage organisms, belonging to the genus Pseudomonas has been reported by Reynisson *et al*. (2008). The study shows that it is possible to quantify accurately Pseudomonas in fish using real-time PCR and the method takes less than 5 h from sampling to results. The short detection time of the method can provide the fish industry with an important tool for quality control and processing management.

Furthermore, a conventional cultivation and cultivation independent approaches were used to investigate the bacterial succession during storage of lightly salted or non salted cod loins at chilled and superchilled temperatures. The studies confirmed the importance of *P. phosphoreum* as a spoilage organism during storage of cod loins at low temperatures. The methods used compensate each other, thus giving more detailed data on bacterial population developments during spoilage (Reynisson *et al*., 2009).

3.3. Predictive models for microbial risk assessment and shelf life

Quantitative Microbial Risk Assessment (QMRA) model based on HACCP principles and dynamic models for microbial growth and Shelf Life Prediction (SLP), have been constructed using data from studies on growth of pathogenic and spoilage bacteria in poultry under isothermal temperature conditions (Gospavic *et al*., 2008). Baranyi and Roberts and modified Gompertz models have been applied for the prediction of growth of Pseudomonas spp. in poultry under variable temperature conditions. The secondary models used are the Ratkowsky model (square root model) in both cases. The results implied that both alternative approaches are suitable for modelling the microbial growth of *Pseudomonas spp.* in poultry for predicting the shelf life under dynamic temperature conditions (Gospavic *et al*., 2008).

An overall concept for a generic model of shelf life dynamics in support of cold chain management in pork and poultry supply chains has been suggested by Raab *et al*., 2008. The model consists of three models: a shelf life model, an inter-organisational cold chain model and a temperature mapping model that includes a heat transfer model. In this concept the shelf life is predicted based on the growth of *Pseudomonas spp*. The results show that even though *Pseudomonas spp.* is the main spoilage organism in pork and poultry its growth is dependent upon type of meat and therefore, models need to be adapted to each product type.

Furthermore, models for the main spoilage bacteria in fish *Photobacterium phosphoreum*, *Pseudomonas spp* and *H_2S-producers*, have been developed based on data from isothermal conditions (unpublished data; Olafsdottir *et al*., 2006b). The developed models have been validated with data from shelf life studies in pilot experiments where temperature fluctuation have been induced or different raw material handling applied to simulate actual chain scenarios (Olafsdottir *et al*., 2006a, Lauzon *et al*., 2009, Magnusson *et al*., submitted). Temperature data from continuous monitoring in the supply chain and initial microbial count is the input for SLP models to evaluate the remaining shelf life. These models are currently being tested in field trials for cod in the CHILL-ON project.

3.4. Time Temperature Indicators (TTI)

Various types of Time Temperature Indicators (TTI) have been studied to use in combination with different food products to indicate their shelf life. TTIs show a measurable time and temperature dependent change that cumulatively reflects the time-temperature history of the food product. When the TTIs are applied it is necessary to know the kinetics of the spoilage changes as discussed above and the kinetics of the TTIs´ responses. In the CHILL-ON project OnVu^{TM} label from Freshpoint has been applied that relies on the properties of organic materials that change color according to the accumulated temperature history of the product. These materials form the basis of a pigment which is used to formulate their intelligent ink. The TTI becomes dark when activated (by UV light) and then progressively gets lighter over time and depending on the temperature history. A detailed investigation of the behavior of a new printable photochromic time–temperature indicator (TTI) was conducted to characterise its properties under specific temperature conditions and to analyse the influence of ultra-violet (UV) light irradiation (activation) on the discolouration process. The results showed that it is possible to define the shelf life of a TTI by different charging times. This novel TTI constitutes a reliable tool to monitor the cold chains of a broad range of food products on their way from production to consumption. As has been suggested earlier, this investigation supported the view that implementations of photochromic TTIs combined with effective information management systems would strongly support cold chain management in food supply chains which would result in less waste and cost reduction (Kreyenschmidt *et al*., 2009).

3.5. Temperature monitoring, Decision Support System and Supply Chain Management

The possibility to have access to temperature information in real time is the main strength of the CHILL-ON concept. Developments of commercial, remote T-sensors, RFID technologies and data capture possibilities have been immense over the last years. Within the CHILL-ON project such devices have been developed and prototype versions are currently being tested in field trials. Commercial enterprises in the CHILL-ON consortium are responsible for the technological developments in this area. The measurement range, battery life, and data capture possibilities need to be adapted to the usability in the chain. Temperature loggers have been applied in mapping experiments to identify the main gaps in the chain and to determine the target criteria for issuing alerts in the Decision Support System for effective supply chain management. This system is now being challenged in field trials in the project.

4. IMPLEMENTATION OF CHILL-ON TECHNOLOGIES IN FIELD TRIALS

The pro-active approach of the CHILL-ON project includes in-depth analysis of each step of the chilled supply chain for fish and poultry, identification of user requirements and development of new technological concepts. The CHILL-ON technologies will support industry needs to fulfill regulatory and customer requirements. Optimized chilling procedures and maintenance of low temperature throughout the supply chain can be controlled by innovative packaging concepts and monitored by rapid diagnostic microbial test kits and visual color change of time temperature indicators (TTIs). The implementation of the CHILL-ON technologies is now ongoing in selected supply chains (poultry in Europe, Atlantic cod from Iceland and salmon from Norway to France). The challenge is to perform simultaneous validation of the technologies to achieve a holistic and realistic evaluation of the success of the technologies to provide supply chain actors with an electronic Supply Chain Management and Decision Support System.

4.1. Step Analysis and Action Points - SAAP

The implementation of the CHILL-ON technologies in field trials is a challenge for the CHILL-ON consortium since this requires partners to work for extended time on-site in the industry settings and active collaboration of different stakeholders with various cultural, language and business background is needed. The common goals, commitment and understanding among the different scientific disciplines had to be ensured. Therefore, an important part of the project has been the preparation for the field trials by using a Step Analysis and Action Points (SAAP) approach, based on risk based procedures according to HACCP methodologies and in-depth analysis of all steps in the supply chains. The seven HACCP principles are applied as guidelines to carry out the SAAP procedure. Food companies have implemented HACCP and are familiar with the procedures, moreover the CHILL-ON technologies should comply with and enhance the efficiency of systems which are already in place to monitor and control risks in the chain. All steps in the supply chains are analyzed and in that way, the HACCP concept is implemented throughout the supply chain. In each step, all possibilities are evaluated which can impact the functionality of the CHILL-ON technologies.

The SAAP procedure is a documentation framework for operators with reference to standard operation protocols (SOP) for all technologies, detailed process descriptions and temperature mapping of supply chains, procedures for functional testing of technologies, verification of their performance and further validation by comparison with reference methods. The SAAP is an effective tool to gain an overview and describe procedures, where the requirements of all stakeholders are communicated. Terms of reference documents (ToR) describe the boundaries of the field trial scenarios, timelines and allocation of technologies in each

step. SAAP takes into account the established preventive measures and standard operating procedures at action points where CHILL-ON technologies are challenged by setting target criteria for monitoring and control, followed by verification and validation procedures.
The potential risks which may hinder technologies to record temperature, transmit information, retrieve information on location and perform sampling and analysis related to microbial hazards or quality are evaluated. Risk assessment and establishment of effective contingency plans ensures the successful implementation of the CHILL-ON concept. One of the key preparatory activities is training of potential users of the technologies and for this purpose, application sheets have been developed to use in training of field trial operators.

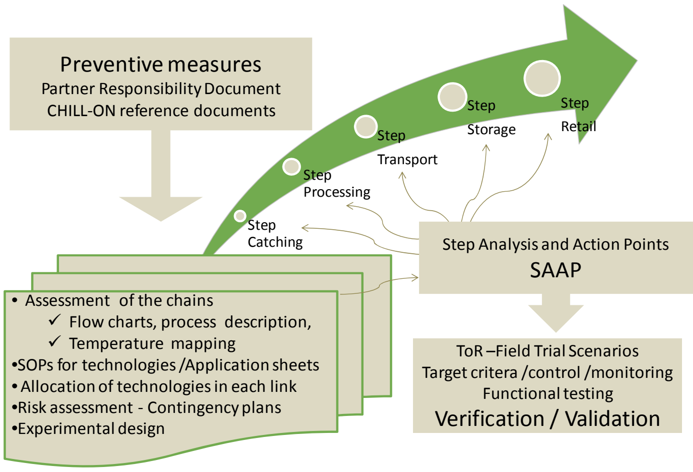

Figure 2. SAAP framework for implementing CHILL-ON technologies in field trials

5. ADOPTION OF TRACEABILITY SYSTEMS IN FOOD INDUSTRY / CHILL-ON SURVEYS

Traceability, mainly paper-based and relying on bar codes, has been applied in fish supply chains for several years in compliance with legislative and market requirements. The adoption of new traceability solution(s) such as radio-frequency identification (RFID)-based systems can increase benefits for the stakeholders. A study within the CHILL-ON project by Mai *et al.* (2009) presents the benefits of traceability perceived by a number of fisheries companies operating at different links of the supply chains. The results have strengthened arguments on costs shifting among the stakeholders in a supply chain. It was shown that the seafood processing company pays much for what is needed, resulting in some negative NPVs, while the trading company can expect steady benefits (Mai, 2009).
Many countries, including China, have implemented traceability systems to increase vertical coordination and guarantee safety in fish products. A study within CHILL-ON based on a survey provided information on consumers' awareness to quality and safety of fish products, purchasing behavior, and willingness to pay (WTP) for safe fish products in Beijing, China (Feng *et al.*, 2009). The results show a shortage of safety knowledge among customers concerning fish products, including processing, storage, and the traceability system. The age of consumers, educational level, the perception of safety and the average price, are the main determinants of Beijing consumer's WTP for the traceable products. On average, consumers are willing to pay a 6% premium for safe, traceable fish products over the price of non-traced products of uncertain safety.
The adoption of traceability systems in Chinese fishery process enterprises was reported by the Chinese partners in the CHILL-ON project, based on a survey on 21 tilapia enterprises in provinces in China. The results show that for all the enterprises, the common incentive factors influencing traceability system adoption are improvement of product quality, need of healthy consumption and improvement of management style, also, different ownership enterprises have different preference motives. The function of traceability system is recognized by most enterprises, but traceability system is adopted mainly in large enterprises.

Inconsistent traceability standard, high costs, lack of necessary conditions and little government support are the main barriers of system adoption for small and medium-sized enterprises (Feng *et al*., 2009).
Recent research on traceability systems in China focus on technology innovation, traceability system management, and determinants of traceability system implementation. Traceability system can effectively trace food quality and reduce safety scares. However, according to a study linked to the CHILL-ON project in China on the operating mechanisms of traceability systems in agro food, four criteria are proposed to analyze strengths and limitations of the operating mechanisms. The result shows that an integrated mechanism of i.e. government and enterprises is needed to implement traceability systems in agribusiness (Zhang *et al*., submitted).

6. DISCUSSION

The CHILL-ON concept is about increasing trust in the perishable food supply chain by implementing optimized chilling and novel packaging technologies, real time information on temperature history of products, as well as diagnostic tools for rapid detection of spoilage and pathogenic bacteria to enhance transparency for consumers and improve quality and safety information for fish and poultry. The current discussion between technology developers and stakeholders is on "who would cover the cost of implementation of monitoring technologies like the CHILL-ON project can offer"? Producers are generally not ready to pay for the extra information, if the product is delivered and accepted on arrival in the markets. However, if microbial counts and temperature history of the products are known for a reasonable price and in short time, then a system like TRACECHILL could be a great opportunity for business, especially if it offers efficient quality control. The calculated current remaining shelf life of a product and its location could minimize the time needed to identify a product's marketability. In the case of any potential hazards, such a system would facilitate recall procedures or any actions necessary to minimize risks. Moreover the CHILL-ON technologies will also have an impact on economic and sustainable values for food companies. Logistic companies and retailers have so far not been the driving force in implementation of transparent temperature history of food products. Insurance companies as potential beneficiaries of such transparent systems may motivate implementation to ensure timely responses to potential temperature hazards and preventive measures to minimize damages. An open innovation approach is needed to successfully implement new traceability and monitoring systems in the whole cold chain with an active participation of all stakeholders involved in the food supply chain. The responsibility and sharing of costs needs to be openly discussed for the benefit of a safe and transparent food supply chain which consumers can trust.

NOMENCLATURE

QMRA	Quantitative Micriobial Risk Assessment
SLP	Shelf Life Prediction
qPCR	Quantitative Polymerase Chain Reaction
SCM	Supply Chain Management
DSS	Decision Support System
GIS	Geographical Information System
SSO	Specific Spoilage Organism
SAAP	Step Analysis and Action points
HACCP	Hazard Analysis and Critical Control Points

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