Cold Chain and Shelf Life Prediction of Refrigerated Fish – From Farm to Table

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Abstract. Fresh perishables are normally stored and distributed with a proper cold chain control in the supply chain from farm to retail. Usually, the consumers break the cold chain after the point of sale. The question is whether consumers are aware of requirements during the transport to and storage at home. The handling conditions and temperature changes can significantly decrease the shelf life and cause faster spoilage of food. The study presents two examples of shelf life prediction. The first one is based on temperature measurements of fish covered with ice in a Styrofoam box with supported information of environment temperatures in the cold store, uncooled car and refrigerator. In the second, measurements from first phase of storage on temperatures (0 °C–4 °C) were used with assumption of fish stored later on higher temperatures without ice. The results show important shortening of shelf life after the point of sale.

Keywords: Cold chain · Shelf life · Prediction · Fish supply chain

1 Introduction

Mainly, shelf life studies of seafood were performed by using kinetic models for growth of spoilage bacteria in various conditions. Higher temperatures increase rates of growth which is the reason for the use of cold chain monitoring in the supply chain. Consumers prefer buying fresh fish which is high quality food product that is labeled with capture date information [1]. The survey presented the conclusion that it is very important to give consumers the information on sensory and microbiological shelf life. Many shelf life prediction tools run simulations to provide that information in possible and expected scenarios based on real cold chain data [2]. Chemical methods were used to specify the shelf life at different storage temperatures. The study provided the information that the exposition time of fish at the point of sale (PoS) and in consumers' household is critical.

New technologies, time temperature integrators (TTI) were used to provide predictive modeling of seabream shelf life in the dynamic temperature conditions [3]. Tests were validated by experimental measurements of microbiological spoilage results. Radio frequency identification (RFID) can be successfully used in cold chain monitoring to provide temperatures of environment conditions and also products in the package [4]. The information could be used at the point of sale to calculate dynamic

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shelf life and presented to consumer on mobile devices. The development of sensors combining biochemical and microbial spoilage is getting a significant value in food supply chain [5]. The smart quality sensor was tested to measure quality and predict its progress in fresh cod under commercial ice storage conditions.

Unfortunately, the important phase of consumers handling fish is still not adequately evaluated and the information of remained shelf life before the preparation of fish isn't exactly specified and presented. Lately, consumers are well informed about the use of a slogan "From Farm to Fork" in connection to the place of origin and food traceability. All that is regulated by international and regional legislation and standards to provide the food quality and safety supported with shelf life information to consumers. The industrial relevance of selection and use of the optimal TTI smart label for monitoring food products allows reliable estimations of the remaining shelf life leading to improved management of the cold chain from production to the point of consumption [6].

Usually, consumers have the general information of food handling conditions during the storage. They also know the domestic refrigerator temperatures and home storage time of chilled food. The awareness of all that and their behavior at home have a great impact on food safety. A study was considering the above mentioned facts to couple them with a general rule that could be incorporated in shelf life studies [7] and safety risk assessment.

The focus of the presented cold chain study is the importance of integration of temperature monitoring during supply chain processes and modelling the transport and home conditions of consumers. Predicted shelf life results can be presented on mobile devices with recommendations of further storage and use of perishable food products. Implementations of various fixed and mobile sensor systems are available in cold stores and logistic processes and temperature measurements are collected and stored by supply chain partners. The last and most important step of sharing and making data public to perform detailed analysis is missing. The results could give all partners the approval of their work and provide confidence about the food quality and provenance to consumers.

This paper is organized as follows. Section 2 gives a description of cold chain divided in two phases. The first one is part of the controlled supply chain up to the point of sale and the second one continues during the consumers handling of product. In Sect. 3, the corresponding case study of temperature measurements with shelf life prediction results is presented. In the end, conclusions are made in Sect. 4.

2 Cold Chain

Cold chain (CC) systems are required in the food supply chain (SC) to monitor the handling conditions of products during processing, packaging, transport and storage phases to the point of sale. Various wireless sensors, other sensor and identification devices are connected to the internet and used to collect environment temperatures on regular basis [8]. Lately, they are well known as Internet of Things (IoT) and used in the supply chain.

Mostly, for perishable food real time data is provided in a form of temperature and sometimes humidity measurements from warehouses during the storage period and from trucks during short or long transport phases. Companies can use the data for their own management (automated reporting, improvements and alarms). Rarely, partners in the supply chain exchange that data and use it for determination of rejection problems at the delivery of food.

At the point of sale, consumers are not aware of the information collected or exchanged in the supply chain. They don't know whether there was something wrong with the product available for sale and can only believe what they are told. Usually, they are not aware of the importance of required conditions after purchase, including transport and storage at home. In case of highly perishable food products for which the cold chain was broken by different storage conditions it is very important to evaluate and consider changed shelf life information.

2.1 CC: From Farm to Sale

The supply chain of fresh and especially perishable food is well controlled in each phase. Figure 1 shows an example of measurements collected during transport (sensors are placed in the truck or van), warehousing with fixed temperature systems and at the point of sale in the retail. The final collection of cold chain measurements can be presented at the end after the exchange of data between all partners is performed.

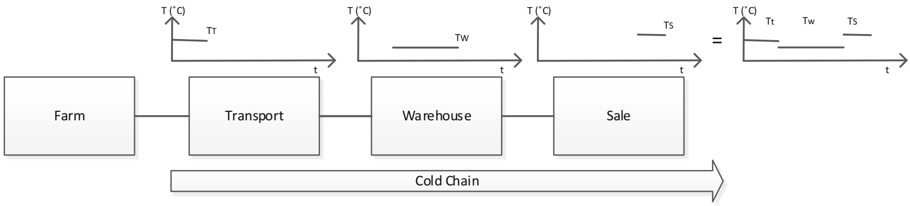

Fig. 1. Cold chain monitoring – temperatures are measured separately in each phase of the supply chain from the farm to the retail or other locations of sale (T_T – transport temperatures; T_W – warehouse temperatures; T_S – retail temperatures).

Figure 2 shows another option of measuring temperatures of product in the entire supply chain using the latest technology, smart RFID data loggers with temperature sensors, that are reusable and can be read at any time by mobile readers and presented to all partners in SC and consumers on mobile device.

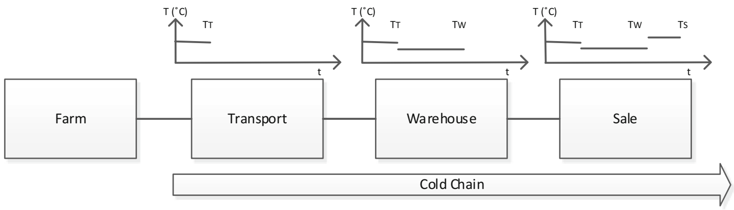

Fig. 2. Cold chain monitoring – temperatures are measured successively in all phases of the supply chain from the farm to the retail or other locations of sale.

2.2 CC: From Sale to Table

Cold chain is always broken at the point of sale. Consumers must have confidence in the product quality based on supply chain conditions. Afterwards, the product is transported in unsupervised environment to home for shorter period of time and will be then consumed shortly after the transport or stored in the fridge (Fig. 3). The cold chain monitoring can be then specified by the estimated temperature of 7 °C or 8 °C.

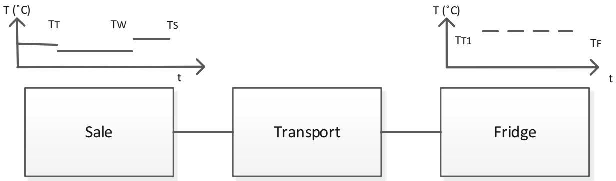

Fig. 3. Cold chain assumptions – temperatures are not measured after the sale. They could be estimated for the specific storage condition.

3 Shelf Life

The definition of shelf life is connected to recommendations of food producers and food industry about the maximum time for which food and their products can be stored under recommended conditions in the supply chain [9]. It is about the quality, health and freshness which are presented to the consumer at the point of sale. It is important to distinguish between high quality and edible shelf life when providing quality food products for higher prices.

Usually, the “expiry date” or “use before” are appointed and fixed in the processing phase to be printed on the label with recommended storage temperatures and attached to the package. The consumer has only the information for how long and how he should store the product before the use. Basically, the shelf life of food specified as a constant time interval as expiry date with specific conditions that will guarantee safety of products.

For example, the high quality shelf life of fish is 8 to 10 days when covered with ice and stored on temperatures between 0 °C and 4 °C. It is supposed that this was true in the supply chain that started at fish farm when fish was caught, packed and transported to the retail before was available for sale to the consumer.

3.1 Case Study

The aim of the presented study is shelf life prediction based on real data from temperature monitoring in fish cold chain during the storage process performed by company and data modeling of the transport and home conditions of consumers. The high quality shelf life evaluation will be presented to provide the actual information to the consumer. Fish was packed in the Styrofoam box and covered with melted ice. The cold chain was performed using RFID data loggers [4] with temperature sensor in the period of two days (from 16.7.2015, 14:15 to 18.7.2015, 11:15). Figure 4 shows environmental and fish temperatures measured during three phases of supply chain, starting in cold store (CS) with temperatures around 0 °C, continuing in transport (TR) in the car with high temperatures up to 30 °C and finally in the home refrigerator (R) with temperatures between 5 °C and 8 °C.

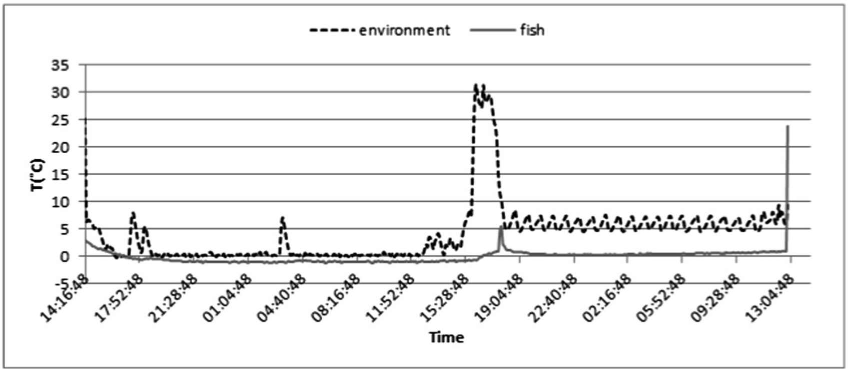

Fig. 4. Cold chain monitoring – environment and fish temperatures were measured in three phases including cold store (CS = 25 h), transport (TR = 2 h), refrigerator (R = 18 h).

3.2 Shelf Life Prediction

The proposed shelf life prediction model uses low level digital algorithm to translate periodic temperature measurements into remaining shelf life [10]. The calculation is based on the definition of start shelf life of X days at the temperature T. For each temperature measurement that is higher or lower than T, exists a different shelf life. For the corresponding time interval x (sampling interval) the product had been spent on temperature T. Therefore, an array of pairs T_i and X_i (Table 1) is defined for that product to get the best shelf life modelling. Additionally, the total shelf life at standard temperature is defined as X_s.

Table 1. High quality shelf life for seabass related to storage time and temperature.

T (°C)	X	T (°C)	X	T (°C)	X	T (°C)	X
0	8	8	2.7	16	1.1	24	0.75
1	6.5	9	2.35	17	1	25	0.73
2	5	10	2	18	0.92	26	0.71
3	4	11	1.75	19	0.89	27	0.69
4	3.5	12	1.5	20	0.85	28	0.67
5	3.35	13	1.4	21	0.83	29	0.62
6	3.15	14	1.3	22	0.8	30	0.6
7	3	15	1.2	23	0.78	31	0.57

The algorithm that performs calculations of updated remaining shelf life X_r is defined as follows:

1. Determine temperature T_i that is closest to the measured temperature T.
2. For temperature T_i look up the suitable value X_i shown in Table 1.
3. Calculate the ratio x/X_i for value X_i (fraction of the total shelf life since the last temperature measurement).
4. Multiply the ratio by total shelf life X_s to get incremental shelf life consumption in days defined as $X_{is} = x * (X_s/X_i)$.
5. Subtract the incremental shelf life from current estimate of remaining shelf life at standard temperature to get X_r.
6. Update $X_r = X_r - X_{is}$.

Shelf life prediction is presented for three scenarios to show the importance and the impact of cold chain in fish supply chain. The total shelf life X_s equals 8 days at storage temperatures between T = 0 °C and T = 4 °C. Table 2 presents high quality shelf life calculations (QSL-remain) at the end of the performed test and separately QSL that was consumed for the first phase in cold store (QSL_C-CS) and for the second phase in transport and refrigerator (QSL_C-TR&R).

Table 2. Quality shelf life (QSL-remain) calculations of seabass stored in Styrofoam box in days/hours (d/h).

Test	QSL_C-CS (d/h)	QSL_C-TR&R (d/h)	QSL-remain (d/h)
Fish (Fig. 4)	2/0	0/20	5/4
Environment (Fig. 4)	2/6	2/10	3/8
Fish: CS(0 °C) + TR(28 °C) + R(7 °C)	2/0	2/16	3/8
Fish: CS(0 °C) + TR(10 °C) + R(7 °C)	2/0	2/2	3/22

First two tests show QSL results based on real fish and environmental temperature measurements shown in Fig. 4. The QSL-remain differs for approximately two days which indicates that environment temperatures aren't adequate information according to the cold chain conditions of fish in the Styrofoam box.

Next two tests included estimated temperatures of fish stored in the Styrofoam box without ice. In the first one, the prediction results for temperatures in CS (0 °C), TR (28 °C) and R (7 °C) are the same for the QSL-remain of environmental measurements, but they are different for QSL_C-CS and QSL_C-TR&R according to alterations between real measurements and estimations. For lower estimates of temperatures during transport phase (TR = 10 °C) is the QSL-remain improved for 16 h. This indicates how is minimized the remained shelf life for 14 h in only two hours on 18 °C higher temperatures.

The impact of temperatures and time in the period of consumers transport and the storage of fish before the consumption is very important. Considering the assumption that supply chain handling conditions correspond to standardized regulations (fish package includes melted ice to sustain the required humidity and temperature T = 0 °C) and the remained shelf life is available at the point of sale, the consumers can be convinced about the fish quality. Usually, they are not aware of the fact how they affect the faster spoilage of fish afterwards. For each labeled fish, displayed for sale [11], are as a part of mandatory information included storage conditions (temperature) and one of the following information available as expiry date, best before date or use by date. In addition, food operators provide the voluntary information like date of catch/harvest, nutrition declarations and other information.

Table 3 provides calculations of remained shelf life to conform to the quality the consumer anticipates for the food he consumes. It provides and additional information to be included together with the verification of place of origin and other traceability information in mobile applications. Shelf life calculations are based on the information that will be received at the time of purchase concerning storage conditions of fish (T = 0 °C), total shelf life equals 8 days, and QSL_{SC}-remain was 5 days.

Table 3. The impact of time and temperatures on shelf life calculations during transport and storage phases at consumers home.

TR (Time, T) (h, °C)	QSL_C-TR (d/h)	R (T = 7 °C) (d)	QSL_C-R (d/h)	QSL-remain (d/h)
1: 0, 10, 20, 30	0/1, 0/4, 0/10, 0/14	1	2/16	2/7, 2/4, 1/22, 1/18
		2	5/8	–0/9, –0/12, –0/18, –0/22
2: 0, 10, 20, 30	0/2, 0/10, 0/23, 1/8	1	2/16	2/6, 1/22, 1/9, 1/0
3: 0, 10, 20, 30	0/3, 1/5, 2/20, 4/0	1	2/16	2/5, 1/3, –0/12, –1/16

In Table 3 are described three tests depending on time of transport (TR Time = 1, 2, 3 h) with four examples of possible temperatures (T = 0, 10, 20, 30 °C) during that time linked to fish in environmental conditions. Storage of fish in refrigerator (T = 7 °C and R Time = 1, 2 days) is included in each test.

The analysis of presented results show high importance of shortest possible time during transport and lowest temperatures. In three hours on temperature T = 30 °C the consumed QSL equals four days. In case of QSL-remain calculations for R = 2 days are shown negative values which indicate the expiry date of product. The QSL-remain is highly related with both parameters (T, Time) and should be considered by consumers which means that environment temperatures aren't adequate for cold chain conditions of fish.

4 Conclusion

The cold chain monitoring of fish supply chain was used to provide the shelf life predictions in the first phase from fish farm to the point of sale. These results should be presented to consumer because they do not have the impact on them but should be informed about the QSL_remain. Additionally, the next very important phase of consumers' involvement in cold chain from point of sale to the final preparation of food is analyzed with various options of time and temperatures scenarios to be used for remained shelf life calculations. The results can be used to give recommendations of how fish should be stored and for how long they can keep the quality and freshness of fish after the purchase.

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