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# Use of RFID temperature monitoring to test and improve fish packing methods in styrofoam boxes

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ABSTRACT

To fulfil the temperature requirements of the cold chain, the fresh fish are usually packed, stored and transported to fish markets with ice in open styrofoam boxes. Some companies offer a more flexible service and they deliver the fish directly to private consumers. In these cases the fish are packed with artificial ice – hydrated and frozen gel pads in specially designed completely closed styrofoam boxes. This study presents the results of the comparison of seven packing methods with the aim to potentially improve them. The temperature outside and inside of the closed box and temperatures in the abdominal cavity of gutted sea bass (*Dicentrarchus labrax*) were measured during the logistics process using Radio Frequency Identification (RFID) technology. The aim of the presented study is to define the optimal cooling materials and methods for different handling options. As an important result, a new efficient, time and energy saving method of packing the fish with the combination of dry non-hydrated gel pads and wet ice instead of the use of frozen gel pads alone is proposed. This method ensures recommended storage temperatures between 0 °C and 4 °C and stable conditions inside the box at room temperatures (or higher) for a longer period of time under the same time-ambient conditions after delivery to the consumer. Furthermore it was established that the part of the ice that melted inside the box, due to higher ambient temperatures, was absorbed by the dry gel pad and only a small quantity of water remained on the bottom of the box.



## 1. Introduction

In recent years, consumers developed important health related attitudes which lead to increased demands for quality fish products (Pieniak et al., 2010). The proper handling in processing, storage and delivery is very important to ensure the EU food safety policy (Regulation, EC/178/2002). The sea bass is stored in the boxes and covered with ice to ensure handling temperatures from 0 to 4 °C (Poli et al., 2001). The quality processes during shelf life (6–10 days) are influenced by storage conditions in logistics processes. The freshness and shelf life predictions are usually based on chemical and electronic nose methods using sensorial and instrumental parameters. The study of different experiments revealed the possibility of describing the freshness decay and the threshold for about 8 days when the fish was preserved on melting ice. The reduction of temperatures by 1–2 °C can justify the extension of the shelf life to 2–3 days after purchase (Limbo et al., 2009).

The packing methods are very important and represent a value added service to affect the purchase decision (Olsson, 2010). The technological innovation provides quality measurements with expiration of food products to be included in the supply chain and available to consumers. Some studies showed surprising results about the practices of food safety and handling during and after purchase at home (Jevšnik et al., 2008). Often consumers do not use cooling bags for the transport and are not aware of the right storage temperatures of perishable food. The quantitative survey study in Slovenia showed that the consumers' education of food handling is very poor and inadequate. Similar results were obtained in Turkey (Bülent, 2013). The main conclusion was that the food handling practices in the domestic environment are of public concern with the media being very important for the dissemination of food safety concerns. In the last decade, traditional food packaging was replaced with so called active and intelligent solutions using time–temperature indicators and other similar options to delay the effect of the ambient temperature on the product (Brody et al., 2008). Commercial applications with 'smart' devices were developed and their importance was already recognised in the seafood industry. It is very important to provide the

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right packing method for the distribution process, to follow handling recommendations and to avoid increased temperatures in trucks during the exposure to ambient temperatures (Kim et al., 2013). Improper temperatures are associated with bacterial growth that can cause a substantial proportion of food borne disease. A study of an appropriate thermal insulation of two types of expanded polystyrene boxes in protecting super chilled fresh fish products was based on experimental and numerical investigation (Margeirsson et al., 2012; Pacquit et al., 2007). The experimental results showed that a new box type provides significantly better packaging conditions compared to the old box type.

New technologies enable the improvement or even replacement of traditional methods with many useful solutions that offer interaction between food, packaging and environment (Restuccia et al., 2010). The intelligent, active packing methods are supported by RFID systems and temperature monitoring in the cold chain. Recently, RFID smart tags are becoming an appropriate solution to measure the ambient and/or product temperatures in any type of packaging. They are available as semi-passive battery assisted sensor-enabled RFID data loggers (Abad et al., 2009; Delen et al., 2011). The battery energy is only used for supporting the additional functionality of temperature monitoring. The energy for initialisation and reading functionalities is supported by RFID readers (Trebar et al., 2013). The demonstration of an international fresh fish logistic chain with RFID smart tags was validated (Abad et al., 2009). The results proved important advantages regarding the use of temperature monitoring with wireless reading and writing in real time at any time in the chain. Very often, long distance shipments are not supported with the information about the product conditions (Delen et al., 2011). As the air flow and temperatures can vary in different areas inside the containers, the proper monitoring can be performed with RFID-based sensors. The temperatures of the product and surrounding environment are the most important factors to affect the product quality evaluation (Wang et al., 2010). RFID data loggers have been demonstrated as a useful tool of temperature monitoring inside a cooled vehicle to analyse the changes of food quality and freshness.

The aim of the presented study was to define the optimal cooling materials and methods for fresh fish packing. Several handling options were considered, including a new RFID technology approach. The temperature monitoring was performed with RFID data loggers in the logistics phase. The experiments and analysis were developed as the part of the traceability system in the EU project "RFID from Farm to Fork" (F2F, 2013) where RFID technology was used in the implementation of a web-based solution in the supply chain of farmed sea bass to demonstrate tracking of data forward in the chain and tracing the data backwards to present the consumer with all applicable information at the point of sale. The main purpose of the proposed solution was to give all stakeholders in the supply chain, including consumers, a time–temperature indication of fish handling with the monitoring results in combination with the traceability data.

The paper is structured as follows. Section 2 provides an overview of fish packing methods, RFID technology and cold chain monitoring scenarios in styrofoam boxes during the logistics process. Section 3 introduces results with temperature graphs of several experiments to present the benefits of the proposed innovative solution of the combination of the dry, non-hydrated gel pad and wet ice in the box to maintain necessary cooling conditions. Finally, the conclusion gives some interesting outcomes, further ideas and possibilities to improve RFID monitoring.

## 2. Materials and methods

### 2.1. Fish packing methods and materials

To guarantee the required temperatures until the delivery, fresh fish are normally packed in opened perforated or closed styrofoam boxes covered with wet ice. When the ice melts, the water flows out from the perforated box but stays inside the closed box resulting in a drop of product quality due to water exposure.

Prior to the present study the Fonda Fish Farm (Fonda, 2013) was packing the fish destined for the delivery to the private consumer in a closed styrofoam box described below and shown in Fig. 1 with one stripe of frozen gel placed on top of the fish (FG). In comparison to the usage of wet ice alone this method proved to be an improvement for the company. It kept the content of the box cold for the needed time, while keeping it dry and in the same time humid enough for efficient fish storage. Nevertheless the company was searching for a way to control the efficiency of their packing method and potentially improve it.

In the present study, packing methods depend on the packaging material and on the type of cooling agents used in the box. Closed styrofoam boxes, wet ice (WI), dry ice (DI) and gel pads were used in monitoring experiments. Gel pads consist of cooling powder packed and sealed in polyethylene cells, called PolarPads (Gel pad, 2013). They are available in a dry, non-hydrated form, in rolled strips which need to be cut, placed into a container with tap water for at least 10 min and after that into a freezer until they are completely frozen and ready for use.

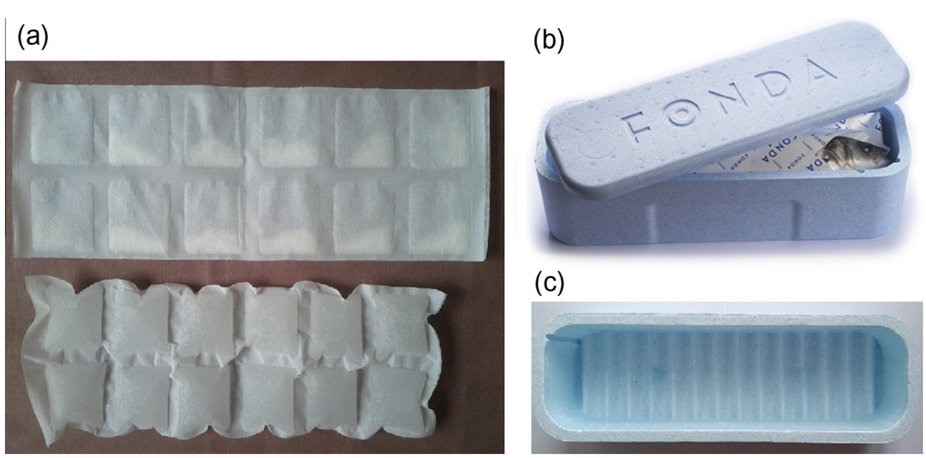


**Fig. 1.** A stripe of dry, non-hydrated, gel pad (above) and a stripe of hydrated and frozen gel pad (below) (a); packed styrofoam box for fish delivery (b); empty styrofoam box with wave shaped bottom (c).

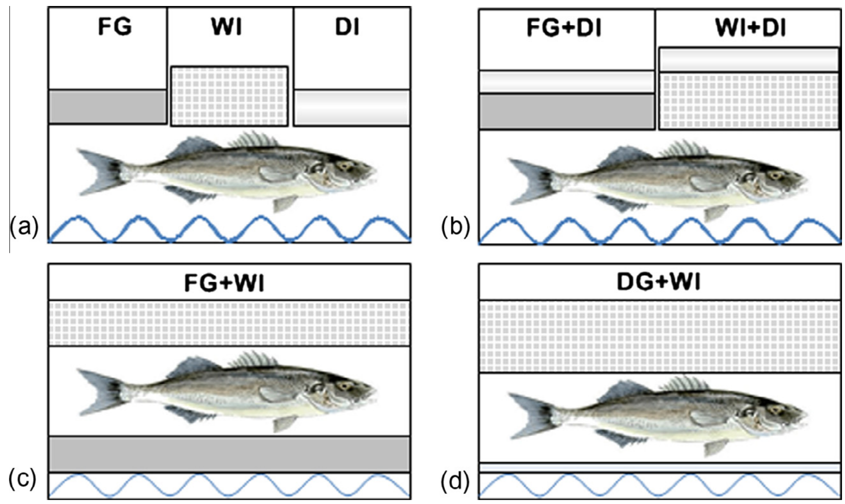


**Fig. 2.** Fish packing methods: (a) frozen gel pad on top of the fish (FG); wet ice on top of the fish (WI); dry ice on top of the fish (DI); (b) combination of frozen gel pad and dry ice on top of the fish (FG + DI); combination of wet ice and dry ice on top of the fish (WI + DI); (c) combination of frozen gel pad under and wet ice on top of the fish (FG + WI); (d) new combination of dry, non-hydrated gel pad under and wet ice on top of the fish (DG + WI).

Fig. 1(a) shows a dry, non-hydrated (DG) and hydrated, frozen gel pad (FG) that were used in cold chain experiments. The Fonda Fish Farm uses a specially designed styrofoam box (Fig. 1(b)) to keep up to 3 kg of fish cold during storage and transport. It is 15 mm thick and made of a lightweight material, composed of 80% air, it is easy to carry, transport and is a great insulator. The cover is 30 mm thick. The bottom of the box is wave shaped and suited to contain up to 500 ml of water (Fig. 1(c)).

Styrofoam by itself is not a cooling body; it merely holds the energy of the packed content. For this reason the cooling material and airtight seal of the box are both required to fully maintain the coldness of fish. The closed styrofoam box is used to guarantee the desired temperature conditions of the fish during the delivery to private consumers. This includes short time storage in the cold store, transport in cooled vans and the time when the box is kept in warmer rooms at homes or offices after delivery but before consumption or further storage in the fridge. Seven types of fish packing methods were used in the experiments (Fig. 2). Three of the options contained in a box one cooling material on top of the fish (Fig. 2(a)), either: one stripe of hydrated and frozen gel pad (FG); or 1000 g wet ice (WI), or 200 g dry ice (DI). Another two options contained in a box a combination of two types of cooling materials on top of the fish (Fig. 2(b)), either: one stripe of hydrated and frozen gel pad and 200 g dry ice (FG + DI), or 1000 g wet ice and 200 g dry ice (WI + DI). The last two options contained in a box one cooling material under the fish and the other one on top of the fish: Fig. 2(c) shows one stripe of frozen gel and 1000 g wet ice (FG + WI); and Fig. 2(d) shows one stripe of dry, non-hydrated gel pad and 1000 g wet ice (DG + WI).

Each cold chain experiment was performed with the specified quantity of fish (2 fish in the box, approximate weight of 500 g each) and the specified quantity of cooling material. All the experiments were performed during the regular catch and the Fonda Fish Farm was the company providing origin of the sea bass throughout the supply chain. On the catch day, the sea bass used in the experiment were about 3 years of age.

### *2.2. RFID monitoring system*

The monitoring experiments in the present study were performed with the SL900A data logger that is an EPC Class 3 (cool-Log™) sensory tag chip which enables RFID automatic data logging applications with various sensor functions (ams R&D, 2013). This device offers automatic tracking, monitoring and records information about any goods in any supply chain or cold chain logistics process. Furthermore, the important features are the shelf-life algorithm, the anti-collision algorithm, the multilevel data protection, automatic sensor signal acquisition, programmable, scanning, and interrupt modes of data logging from an integrated temperature sensor, and the use of additional external analogue sensors. The temperatures are measured in the range from −40 °C to +80 °C with the accuracy of ±0.5 °C. The confidence interval was determined by the producer in calibration phase of a SL900A data logger and is constant for the whole temperature range.

Every test with temperature data loggers (TDLs) included the following steps: (i) initialisation of logging type (each measurement, or only measurements that fall out of limits) and two other parameters (log interval, measurement limits); (ii) start logging of TDLs – temperatures are measured and stored in the chip memory; (iii) set up the experimental placement of TDLs in each box; (iv) removal of TDLs; (v) stop logging of TDLs and collection of temperature measurements; and (vi) data analysis. TDLs were set up with fixed parameters for all experiments: (i) logging type: each measurement was stored; (ii) log interval: 6 min; (iii) measurement limits: $T(\text{low}) = 0$ °C (the lowest temperature in the box) and $T(\text{high}) = 12$ °C (the highest temperature in the processing room).

The working process of TDLs was supported by a fixed UHF RFID reader (ams R&D, 2013) connected to a computer. It was used at the beginning of each experiment in the initialisation phase to set up monitoring parameters and to start the process of measuring and storing temperatures. At the end of the experiment, it was used to stop the monitoring process, read temperature measurements and store them for further analysis. The data was stored as time–temperature samples with fixed size specified by the duration of the experiment and log interval. Statistical treatment of data involved the measures of central tendency (mean, standard deviation) to correctly interpret the results of TDLs for individual cooling materials in different monitoring conditions. The process control was evaluated with scatter charts to examine the values inside the limits of recommended storing temperatures.

### *2.3. Cold chain implementation*

The temperature monitoring was performed during the pilot implementation of the RFID system funded by the European

Union project "RFID from Farm to Fork" – RFID-F2F in years 2011 and 2012. Additional experiments and final implementations of FG and DG + WI packing methods were evaluated in year 2013. The Fonda company runs a fish farm situated in the northern part of the Adriatic Sea and was participating in the deployment and evaluation of the traceability system (F2F, 2013). The main objectives were the implementation of RFID technology in the fish supply chain to ensure traceability and to provide producers and consumers important information about the product.

Temperature data loggers (SL900A) were set up to monitor cold chain conditions as: (i) ambient temperatures using TDL outside, on the box; (ii) temperatures of the air inside the closed box when TDL was placed above the ice or frozen gel pads; (iii) temperatures inside the closed box when TDL was placed between the fresh fish covered with ice or frozen gel; (iv) fish temperatures when TDL was placed in the abdominal cavity of gutted fish.

The monitoring was implemented in the following steps of the supply chain: (i) packing in the processing room (TDLs were initialised and set up according to the fish packing methods); (ii) logistics (the box was transported in a cooled van to the cold store where it was stored overnight and the next day transported to the delivery location); (iii) delivery location (the delivered box was put in the fridge at temperatures lower than 8 °C and/or left in a room, office, etc. at higher temperatures, between 20 °C and 25 °C).

### 2.4. Field tests

The optimisation of fish packing was based on measuring ambient, fish and box temperatures, delivery time, type and quantity of cooling material (dry, non-hydrated gel pads (DG), frozen gel pads (FG), wet ice (WI), and dry ice (DI)) and the organoleptic properties of the fish.

The temperature monitoring was carried out in the fish supply chain process to evaluate the packing methods in the styrofoam box. The total of thirteen experiments were performed during the period of two years (May 2011–August 2013) with various packing methods under different cold chain conditions. Each individual experiment was comprised of two or more, up to six packing methods. The frozen gel pad (FG) packing method was used in seven, the wet ice (WI) in three, the combination of frozen gel pad and wet ice (FG + WI) in four and the combination of dry gel pad and wet ice (DG + WI) in seven experiments. The dry ice (DI) was added in one experiment to evaluate the potential improvement of cooling conditions in the box for short and long time period alone and together with other two cooling materials (frozen gel pad and wet ice). The ambient temperatures were measured manually in the first five experiments and with RFID data loggers (TDLs) in all the others. The comparison of temperature measurements in an individual test was performed according to packing method by using two boxes with the same setup of fish, cooling material and placement of TDLs. The results were statistically equivalent for mean and standard deviation values with regard to the sensor accuracy of TDLs.

In the first year, temperatures for the established packing method of the closed box with the frozen gel pads (FG) were inspected. They were measured in the abdominal cavity of gutted fish (Fig. 3(a)) and between the fish (Fig. 3(b)). The hydrated, and frozen gel pad (FG) was placed on the top of the fish which was wrapped in plastic foil (Fig. 3(c)). The ambient temperature was measured outside on the box during the logistics process, from the time when the fish were packed until the time of the delivery to the customer.

The new type of packing (DG + WI) was used in the second year of the project and afterwards adopted by the Fonda company for the deliveries of fish to private customers. The dry, non-hydrated gel pad (DG) was placed on the wave shaped bottom of the box (Fig. 4(a)) to absorb the water coming from the melted ice. During the logistics process from the time when the fish were packed until the delivery to the customer the temperatures were inspected inside the gutted fish (Fig. 4(b)) and inside the box (Fig. 4(c)). The ambient temperature outside the box was measured in the same way as in earlier tests.

The last step of the experiments was the delivery of boxes to the laboratory in Ljubljana. In some tests, it was placed in the fridge or


**Fig. 3.** Packing and monitoring temperatures (FG): in the gutted fish-TDL 1 (a); between the fish-TDL2 (b); placement of the hydrated and frozen gel pad on top of the fish in the box (c).


**Fig. 4.** Packing and monitoring temperatures (DG + WI): dry, non-hydrated gel pad on the bottom of the box (a); monitoring temperatures in the gutted fish-TDL 1 (b); monitoring temperatures in the box-TDL 2 (c).

other places with different ambient conditions to analyse the temperatures of the fish after the delivery. TDLs were removed and temperatures were read with a RFID reader and stored for further analysis of data. At the end of each test, the box was also visually examined to establish the quantity of the water in the box when wet ice was used.

## 3. Results and discussion

### *3.1. Monitoring characterisation*

The cold chain experiments were performed in the everyday fish supply chain with continuous monitoring of temperatures which started by including TDLs in the packaging process. At the delivery, TDLs were removed and each box was inspected in order to determine the quantity of water. The box with the hydrated, frozen gel pad (FG) did not contain any water while the box with the wet ice or the combination of dry, non-hydrated gel pad and wet ice (DG + WI) contained ice on top of the fish, a more or less hydrated gel pad under it and a small quantity of water on the bottom of the box. The quantity of ice still present in the box and the quantity of the water were dependent on the ambient temperatures and the duration of the test. Higher ambient temperatures during the deliveries and storage outside the fridge caused faster melting of ice but not an immediate increase of fish temperatures during the experiment period.

### *3.2. Temperature monitoring results*

Seven scenarios of packing methods were implemented and analysed during shorter and longer logistics processes to demonstrate the time frame in which the temperatures were acceptable to sustain the cold chain. Two experiments in Fig. 5 and one in Fig. 6 present monitoring results of six specified cooling materials (FG, WI, FG + WI, DI, FG + DI, WI + DI) which show their ranking based on temperature measurements and differences according to ambient temperatures. The impact of dry ice (DI) added to other cooling materials is detailed in Fig. 7. The following six experiments (Figs. 8 and 9) explore various ambient conditions with the results of temperature changes for the new packing method (DI + WI). The last experiment (Fig. 10) presents the comparison of the two most useful and applicable cooling methods (FG and DG + WI).

The first five experiments were performed with three types of packing methods using a hydrated and frozen gel pad (FG), wet ice (WI) and their combination (FG + WI). The ambient temperature was controlled manually at every phase of handling the boxes and written in paper form by hand using a room and van recording thermometer. Fig. 5 shows two of the experiments with measured temperatures in the box with TDLs placed between the fish and log interval equal to 5 min. The first experiment (FG (1), WI (1), FG + WI (1)) was performed for the duration of 67 h with several changes of ambient temperatures from 1 °C up to 22.5 °C in the logistics and storage processes. The temperature inside the box was secured at the recommended interval between 0 °C and 4 °C in case of the use of FG (1) packing for 32 h, WI (1) packing for 47 h, and FG + WI (1) packing for 50 h independently from ambient conditions. After that, temperatures were rising faster and nearly reached the ambient temperature when the experiment was stopped. At that moment the ice melted completely in boxes with WI (1) and FG + WI (1) packing methods. Consequently, the fish were partly submersed in water and the temperature inside the box and the temperature of the fish nearly reached the ambient temperature.

The temperatures in the FG (1) packing method were increasing and decreasing based on the changes of the ambient temperature (Ambient (1)). These fluctuations were identified with the delay of changes inside the box in all experiments with frozen gel pad used as a cooling material. The temperature was measured

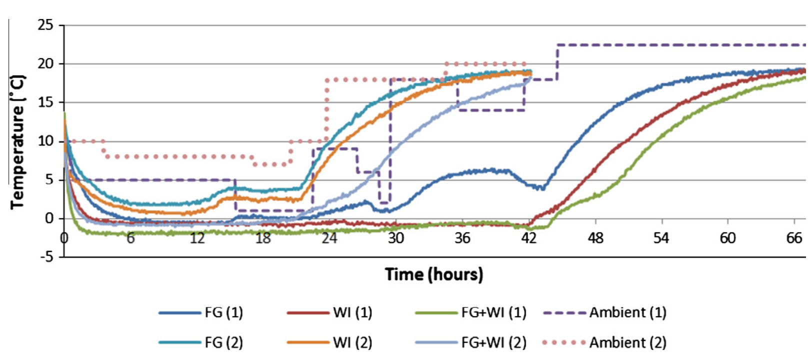


**Fig. 5.** Monitoring temperatures of three types of packing methods with manually measured ambient temperatures for the duration of 67 h in the first experiment (1) and for 42 h in the second experiment (2) with log time of 5 min.

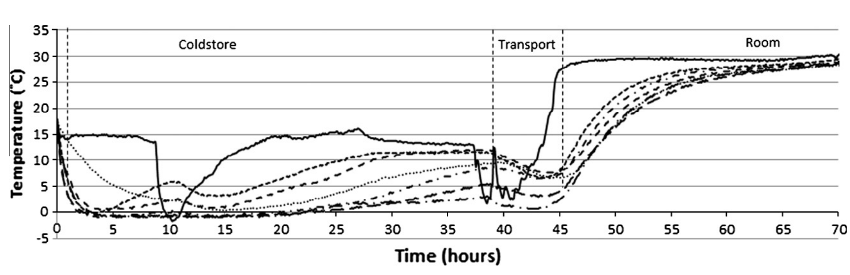


**Fig. 6.** Monitoring temperatures of six types of packing methods for the duration of 70 h (24–26/8/2011) .

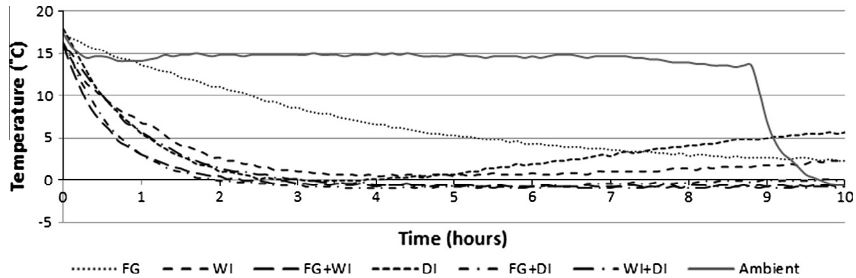


**Fig. 7.** Cooling temperatures of six packages for the first 10 h of storage in the processing phase and transport to cold store.

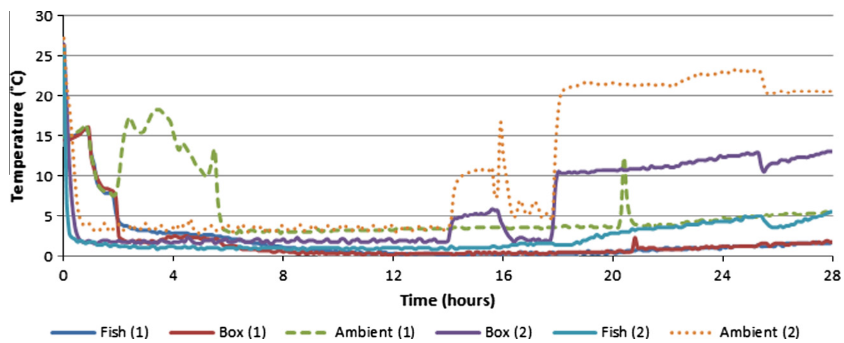


**Fig. 8.** Monitoring temperatures of DG + WI packing type during logistics and storage processes for the duration of 28 h: experiment (1) consists of packing, transport in a car, storage at home; experiment (2) consists of packing, cold store, transport in a cooled van, storage in office and room.

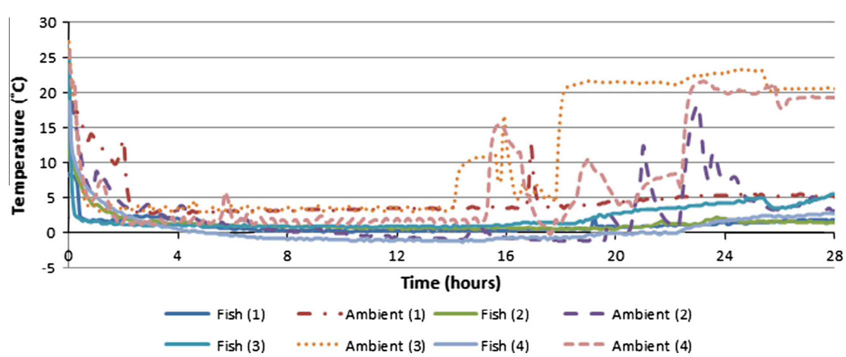


**Fig. 9.** Monitoring temperatures of DG + WI packing type in four experiments for the duration of 28 h.

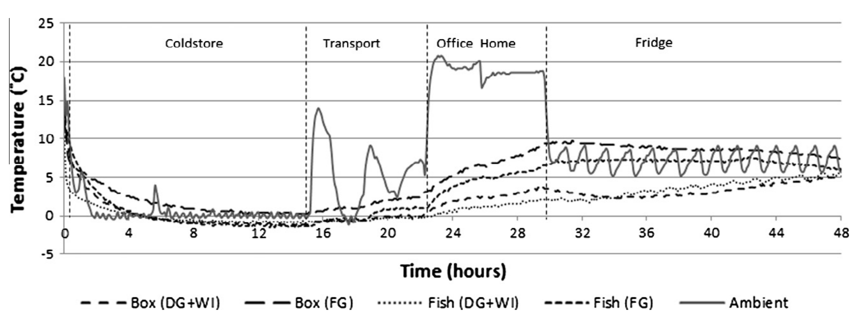


**Fig. 10.** Comparison of FG and DG + WI packing methods for the duration of 48 h (16–18/09/2013).

between the fish on the bottom of the box. The cooling effect of frozen gel pad on the top of fish was reduced with time and the temperature on the bottom of the box started to rise with higher ambient temperatures. By being exposed to lower temperatures it began to decrease with a certain delay. These fluctuations depend on the insulation characteristics of styrofoam material, the temperature differences and state of cooling material which define the temperature holding times inside the box (Burgess, 1999). They were observed twice in the experiment, the first time during the transport in the afternoon between hours 24 and 30 (changes of temperature from 9 °C to 6 °C) and the second time during the night between hours 35 and 41 when temperatures in the room decreased for 4 °C due to weather conditions during the experiment in May 2011.

The second experiment in Fig. 5 (FG (2), WI (2), FG + WI (2)) was performed under similar conditions in cold store and with higher ambient temperatures (Ambient (2)) during the logistics and storage for the period of 42 h. The temperature inside the box was on the interval between 0 °C and 4 °C in case of the use of FG (2) packing for 20 h, WI (2) packing for 22 h, and FG + WI (2) packing for 26 h according to rising temperatures in the transport. After that, temperatures were rising faster and nearly reached the ambient temperature when the experiment was stopped. At the end of experiment the ice was completely melted in boxes with WI (2) and FG + WI (2) packing methods.

The main difference between the two experiments was in more frequent changes between higher and lower temperatures (Ambient (1)) and substantial higher ambient temperatures (Ambient (2)) during the logistics and after the delivery to the customer. In the case of frozen gel pads (FG) alone, the fish need a longer cooling time than in the other two (WI, FG + WI) packing methods used.

The advantage of the use of dry ice in the process of chilling the fish was proven in some cases (Sasi et al., 2000). To test the possibility of accelerating the initial fish cooling phase the dry ice (DI) was used. A sixth experiment was performed with the same setup of packing three boxes as in the first set of experiments (FG, WI, FG + WI) and another three boxes using dry ice (DI, FG + DI, WI + DI). Fig. 6 shows fish temperatures in the box and measurements of ambient temperatures using TDLs in the abdominal cavity of the fish for the duration of 70 h, including the time of the storage in the cold store, transport processes and room storage. In these tests it was noticed that the ambient temperature has an important impact on the results.

The results of dry ice (DI) show that this type of cooling material can accelerate the cooling process of a fish in the beginning but does not have a long term impact on the fish temperatures inside the box. This is an important result considering the cost of dry ice production and handling. The temperature results can be categorised according to long term requirements of assuring the lowest temperatures for different packages in the following order:

1. FG + WI and WI + DI package types ensured the recommended lowest temperatures under 4 °C as long as ambient temperatures were around 15 °C or less.
2. FG and FG + DI package types were comparable to FG + WI and WI + DI for about 18 h. After that, the temperature of the fish began to increase faster in package FG and slower in FG + DI. The highest temperatures reached 10 °C in the cold store and after that they start decreasing when the package was placed in a cooled van.
3. WI and DI package types were initially chilled very fast. Temperatures started to rise faster in DI where the initial impact of chilling with dry ice is very short lived and after that the control of the low temperature inside the box was lost due to the absence of the cooling material. The WI package gave similar results, retaining lower temperatures longer due to the influence of the presence of the wet ice which melted comparatively slower.

The relatively high ambient temperatures in the cold store (up to 15 °C) were due to a warm summer period with frequent deliveries of fish through the door that was open most of the time. Furthermore the storage was completely full of boxes with fish which also influenced the cooling capacity of the system. Similarly to the first experiments it was observed that when the change from higher to lower ambient temperatures occurred, the fish temperatures also decreased with a delay. When ambient temperature reached 28 °C all package temperatures reached 25 °C and even higher values by the time the test was finished.

In the experiment presented in Fig. 6 the initial process of cooling the fish in six boxes from 18 °C down to 0 °C was observed in more details (Fig. 7). The temperature decrease was the slowest in FG, very similar but much faster in WI, DI and WI + DI. The best results were obtained in packages with a combination of frozen gel and wet ice (FG + WI) and a combination of frozen gel and dry ice (FG + DI).

The analyses of presented results showed that the hydrated, frozen gel pad (FG) has limited cooling abilities. The advantage of this packing method is the dry content of the box, while keeping it humid enough for efficient fish storage. The frozen material melts, but does not leave any free water in the box. The costly downside is that it requires an additional phase of preparation. Gel pads needs to be immersed in water for a few minutes to hydrate and then transferred into the freezer. All this is time consuming and requires additional resources (energy, water, space, time and manipulation).

For deliveries performed by the company with the cooled vans directly to the customer's home, the detailed analysis of the DG + WI packing method was performed. Additionally, the ambient temperature was measured with RFID data loggers which gave more accurate and detailed results. During storage and transportation the wet ice in the box gradually melted and the water was absorbed by the gel pad situated on the bottom of the box. Eventually, a part of melted ice passed the gel pad and accumulated under it in the wave shaped bottom of the box, thus the fish never rested in the water.

Furthermore, using the DG + WI packing method the performance in different conditions (cold store, transport with private car and cooled van, home storage) has been tested. Fig. 8 shows two experiments with ambient temperatures, the temperature of the fish and the temperature inside the box. In the first experiment, the ambient temperature (Ambient (1)) has been up to 18 °C during the transport in the car and under 4 °C during storage in the cold store and on the fish stall. After packing, the temperature of the box (Box (1)) dropped in two hours under 2 °C and remained between 0 and 1 °C throughout the storage time. The temperature of the fish (Fish (1)) decreased slower from 4 °C than in the box but also remained between 0 and 1 °C throughout the whole storage time. The box was opened in the room the next morning (after 20 h) to check the quantity of ice on the top of the fish, the fish appearance and as a result the measured ambient and box temperatures changed for first 10 h as is shown in the graph. The box was left on the fish stall for the next 8 h where the ambient temperatures were slightly higher which also caused a small rise in the temperatures of the fish and the inside of the box.

The results of the second experiment in which the fish were transported from the processing to the cold store with temperatures set up to 4 °C (Ambient (2)). On the next morning, the box was transported to Ljubljana in a transport vehicle with cold storage at an average 10 °C, then left in the office for an additional 7 h at 20–24 °C and in the afternoon transported home by a private car and opened at 9 pm to read, store and analyse the data. After packing, the temperature in the box and the fish (Box (2), Fish (2)) dropped very fast and remained under 2 °C. The temperature of the fish slowly increased and reached 5 °C after the box was stored at room temperature for more than 6 h. The temperature inside the box was changing (increases, decreases) in dependence on the ambient temperature and the quantity of cooling material.

After that, the cold chain experiments were used to analyse the different temperature conditions of handling the logistics part and customers' storage of the fish in the traceability system. Fig. 9 shows the results of four experiments in which the fish were transported from the processing to the cold store with the ambient temperatures set up to 15 °C in the first case (Ambient (1)) and up to 4 °C in the other three cases. On the next morning, the box was transported to Ljubljana in a transport vehicle with cold storage at an average 15 °C, then left in the fridge at 4 °C or in the office at 20–24 °C and in the afternoon transported home by a private car between half and one hour, left in the room (Ambient (3), Ambient (4)) or in the fridge (Ambient (1), Ambient (2)) and opened after 28 h to read, store and analyse the data. All four experiments show that fish temperatures were in the recommended range from 2 °C to 4 °C. The packing method DG + WI ensured fast decrease of fish temperature down to 2 °C and only in the case of longer period with high ambient temperatures (Ambient (3)) the temperature of the fish slowly increased and reached 5 °C after the box was stored at room temperature for more than 8 h.

The thirteenth experiment was performed for a more detailed comparison between FG and DG + WI packing methods (Fig. 10) under the same ambient conditions using two boxes with an equal quantity of fish (two fishes in each box weighted approximately 1000 g). The results are presented for the four phases of handling the box after the TDLs were added in the processing room ($T$ = 15 °C, time = 1 h) and as soon as the fish were cleaned and packed. The monitoring phase includes: (i) cold store ($T$ = 1 °C, time = 14 h); (ii) transport to the laboratory in Ljubljana ($T$ = 0–14 °C, time = 7 h); (iii) office and home ($T$ = 18 °C to 21 °C, time = 8 h); and (iv) fridge ($T$ = 5 °C to 14 °C, time = 18 h). This graph shows that DG + WI is a more suitable packing method as it ensures lower temperatures of fish for a longer time. At the end of the experiment only a small amount of water was found on the bottom of the box while most of the melted ice had been absorbed by the dry gel pad. The quality properties (smell, appearance of the skin, eyes, gills and the meat firmness) of the fish were also controlled. In both packing methods the fish appeared fresh, firm to the touch and the gills were a bit red. However a slight difference could be observed between the two packing methods. In the case of DG + WI packing method there was absolutely no unpleasant odour present and the surface (skin and eyes) of the fish was shiny in contrast in the case of FG packing method a slight unpleasant odour developed in the box and the surface of the fish appeared a bit drier.

The experiment with two packing methods (FG and DG + WI) was performed with duplicated logging of temperatures of the fish and the ambient. The results of two samples for each packing method and two ambient samples were analysed. The normal distribution parameters, mean ($\mu$) and standard deviations ($\sigma$) were calculated for each sample with 480 measurements. The results are presented with six normal curves (Fig. 11) grouped by two for the duplicate use of TDLs: (i) the concentrated distribution shows that temperatures are bunched up close to the mean on both sides of mean for the fish in DG + WI packing method (Fish1 (DG + WI): $\mu$ = 1.0, $\sigma$ = 1.7, Fish2 (DG + WI): $\mu$ = 1.2, $\sigma$ = 1.8); (ii) less concentrated distribution is received for fish in FG packing method (Fish1 (FG): $\mu$ = 3.9, $\sigma$ = 3.6, Fish2 (FG): $\mu$ = 3.5, $\sigma$ = 3.6); (iii) the flat distribution with temperatures spread out is significant for the ambient (Ambient1: $\mu$ = 6.6, $\sigma$ = 6.7, Ambient2: $\mu$ = 6.3, $\sigma$ = 6.6). The duplicate samples give very similar mean and standard deviation values which is shown as almost one distribution curve for FG, DG + WI and ambient measurements.

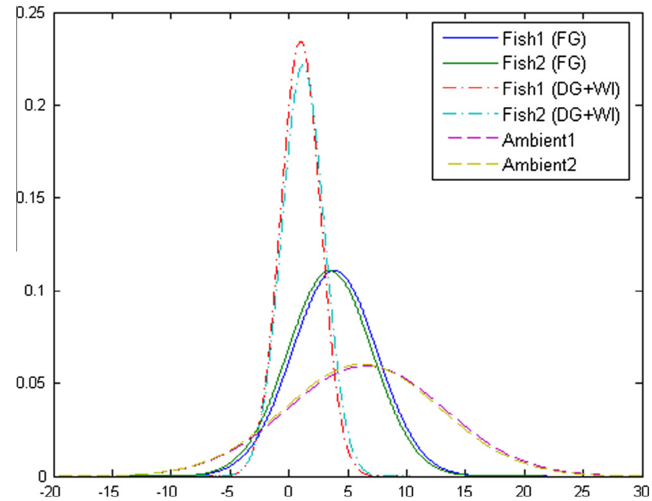


**Fig. 11.** Mean and standard deviation curve: Fish1 (FG): $\mu$ = 3.9, $\sigma$ = 3.6, Fish2 (FG): $\mu$ = 3.5, $\sigma$ = 3.6, Fish1 (DG + WI): $\mu$ = 1.0, $\sigma$ = 1.7, Fish2 (DG + WI): $\mu$ = 1.2, $\sigma$ = 1.8, (Ambient1: $\mu$ = 6.6, $\sigma$ = 6.7, Ambient2: $\mu$ = 6.3, $\sigma$ = 6.6).

### 3.3. Comparison of packing methods

In the last two years of cold chain monitoring as part of the implementation in the supply chain traceability pilot RFID-F2F experiments were performed and the results were analysed, discussed with the company's management, other experts and also customers. The findings were very valuable to show the use of RFID technology in the logistics process by measuring recommended temperatures inside the box for several packing methods.

Thirteen experiments with different packing methods, under different ambient conditions and during the logistics and storage processes were presented to show measured temperatures obtained with RFID data loggers in real conditions. The results include the handling of sea bass by the company during their logistics supply chain. Furthermore, a very important part of the analysis was the handling of the fish after the delivery which is normally in the consumer's domain. Further analysis and comparison of the results are described according to ambient temperature ($aT$) in Table 1.

The experiments revealed the important finding for the company to ensure that private customers properly handle and manage fresh fish even in cases of higher ambient temperatures. It was also demonstrated that the proposed packaging can be used to prolong the domestic storage in the fridge. This information is of a great importance and could be used as common guidance for the domestic audience about food handling after purchase. Additionally, the industrial sector and research audience could develop the practice of monitoring the product cold chain and provide the information to the media and other interested bodies.

Based on the results of tests in different conditions and use of seven different packing methods of fish in closed styrofoam boxes with various cooling materials the conclusions for the preferred choice of DG + WI are summarised in Table 2. The presented method with dry gel pad and wet ice (DG + WI) replaced the use of frozen gel pads (FG). It ensures better preservation of the fish and does not increase the volume of the transporting package. The cost of cooling material is approximately in the same range as the old package except that the process of hydrating the dry gel pad and freezing it before the use is eliminated and replaced by adding wet ice during the packing process. The wet ice is already produced in the company by the machine and used for packing fish in open styrofoam boxes for the delivery to retail and other customers. The company recognizes the large reduction in the time spent and energy used in preparing the frozen gel pads.

A long period of monitoring the temperatures in the fish supply chain was also used in the dissemination process of pilot implementation in the EU project (F2F, 2013). The system was presented to consumers at two locations, the fish market and in a supermarket where Fonda sea bass is sold. The consumers' interest in the presented results was very high. This was confirmation of the

**Table 1**
Temperature monitoring results of fish cold chain (company logistics and customers handling).

| Packing method | Processing and transport | Cold store | Transport (cooled van or private car) | Storage (office, home and fridge) |
|---|---|---|---|---|
| FG, WI, FG + WI (Fig. 5) | *aT*: 25–5 °C Cooling of fish is fast for WI, FG + WI and slow for FG | *aT*: 5 °C Fish temperatures are between 0 °C and 5 °C | *aT*: 2–8 °C Fish temperatures in FG start rising | *aT*: 18–23 °C Fish temperatures in FG are much higher than in WI and FG + WI |
| FG, WI, DI, FG + WI, FG + DI, WI + DI (Figs. 6 and 7) | *aT*: 17–15 °C Cooling of fish is faster in packages with DI | *aT*: 15–0 °C Fish cooled to 0 °C, except in FG due to low cooling capability | *aT*: 2–15 °C Fish temperatures in FG + WI, WI + DI start rising much later than in the others | *aT*: 28 °C Temperatures rise very fast and almost reached *aT* at the end of the test |
| DG + WI cold store, transport and home (Fig. 8) | *aT*: 16–8 °C Cooling of fish: | (1) Box was not in cold store | (1) *aT*: 2–16 °C Temperatures are low, 2 °C | (1) *aT*: 3–5 °C Temperatures of fish are not changed |
| | (1) Slow, 4 h<br>(2) Fast, 15 min | (2) *aT*: 4 °C Fish temperatures are constant, 1 °C | (2) *aT*: 8–18 °C Temperatures inside the box rise | (2) *aT*: 21–24 °C Temperatures of fish are rising |
| DG + WI (Fig. 9) | *aT*: 24–4 °C Cooling of fish is fast, up to 2 h | *aT*: 4 °C Fish temperatures are constant in each experiment, 0 °C, 1 °C, 2 °C | *aT*: 4–16 °C Fish temperatures rise up to 2 °C | *aT*: 20–24 °C Fish temperatures rise slowly up to 5 °C |
| Comparison: FG, DG + WI (Fig. 10) | *aT*: 25–5 °C Cooling with DG + WI is faster than with FG | *aT*: 4–0 °C Fish temperatures are a constant 0 °C, temperature inside the box are higher for FG | *aT*: 0–14 °C Fish temperatures rise slower than temperatures inside the box | *aT*: 5–21 °C Temperatures of fish and inside the box reached the fridge temperature |

**Table 2**
Comparison of packing methods: hydrated and frozen gel pad (FG); dry, non-hydrated gel pad and wet ice (DG + WI).

| Description | Hydrated and frozen gel pad (FG) | Dry gel pad and wet ice (DG + WI) |
|---|---|---|
| Cooling time of fish to recommended storage temperature (0–4 °C) – depends on ambient temperature | From 4 h to 8 h | From 30 min to 4 h |
| Time period of fish temperature under 4 °C | Up to 24 h (cold store and transport) | Up to 48 h (cold store, transport, office and fridge) |
| Water in the delivered box | No | Yes – small quantity. |
| Fish in the water | No | No – water is only in the wave shaped bottom part of the box |
| Preservation performance based on the quality properties | Slight unpleasant odour<br>Dryer, less shiny skin and eyes | No unpleasant odour<br>Shiny skin and eyes |
| Optimisation of packing process | No | Yes – direct use of dry gel pad, without hydrating and freezing gel pads before – shorter packing process |

importance of cold chain monitoring systems which should be used for perishable food transportation and specially recommended in cases of high ambient temperature.

## 4. Conclusions

Cold chain of sea bass was evaluated with different packing methods in a closed styrofoam box to obtain time and temperature dependence of the product according to the ambient temperatures. The monitoring system gives the producer and consumer the information about the product handling. The temperatures were measured during the logistics process of the company and prolonged from the delivery location in the laboratory to the home storage before the fish was consumed. The experiments confirmed that the cooling conditions of fish could be enhanced with the combination of two cooling materials, wet ice (WI) and dry, non-hydrated gel pads (DG). The dry gel pad, placed on the bottom of the box under the fish covered with wet ice absorbed the cold water during the melting of the wet ice. This actually optimises the packing process and minimises the final quantity of water in the box.

The DG + WI packing method was proven to be superior, because of faster initial cooling of the fish and longer maintenance of a lower temperature in the box. The comparison of classic (FG) and new (DG + WI) package revealed differences and improvements that provide the evidence of benefits in better preserving the fish quality and business process optimization to lower the cost of packing process in the company. The most important findings were the better preservation capacity and the possibility of eliminating the preparation of frozen gel pads which requires about one hour per each day; saving the electrical energy due to the elimination of the freezer in the processing while there is no need for freezing and storing gel pads. The number of frozen gel pads is varying according to the customer orders from fifty up to one hundred which requires the stock of the maximum expected amount per each day. Third and also very useful characteristic of new package profile is the larger period of required handling temperatures between 0 °C and 4 °C on high ambient temperatures even up to 40 h.

The use of dry ice (DI) revealed a higher initial cooling rate of fish in comparison to other tested cooling materials. But it had a short lived effect and did not improve the overall performance of packing methods (DI, FG + DI, WI + DI). Although the fish were wrapped in a plastic foil for protection of their surfaces from the direct contact with the cooling material, the use of dry ice damaged the surface of the fish to some extent and fish lost the fresh appearance. In addition, the use dry ice requires special purchases and operations in the business process and would increase the cost of the fish significantly.

The possibility of measuring the temperatures of a product inside the packaging box has great importance for the food industry during longer periods of storage and transportation. The development of real time alarm systems can be based on temperature monitoring as part of the traceability systems which are becoming very useful and data which can be used for shelf life calculations.

Further research plans include the use of RFID data loggers to perform a shelf life study based on actual time–temperature monitoring under different exposure conditions to calculate the prediction of remaining shelf life in the consumer chain. The quality of a product, the expiry date and the available shelf life predictions could be used to develop triggering alarms when something goes wrong in the supply chain.

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