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COLD CHAIN INTERRUPTION BY CONSUMERS SIGNIFICANTLY REDUCES SHELF LIFE OF VACUUM-PACKED PORK HAM SLICES

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The spoilage of meat products (N>5×10^6 CFU g^{-1}) can be delayed by cooling and low-temperature storage and transport. The highest extent of interruption in the cold chain occurs at the time of delivering the meat product to the individual's home after purchasing it. Consumer behaviour and the ambient temperature largely influence the shelf life of products. In our research, we examined the buying habits of customers in Hungary. Based on these results, we carried out the cold chain interruption of vacuum-packed sliced ham (1, 2, 3 h) under laboratory conditions, at temperatures of 15, 25, and 35 °C. The microbial count was determined by a quick method based on redox-potential measurement in two-three days until the products were deteriorated. Our experiments resulted in the expected outcomes; however, we concluded that even average customer habits (1 h cold chain interruption) at higher temperature periods (T>20 °C) decrease the shelf life of ham by 6 days. We set up a mathematical model through which the changes of microbial counts can be determined as a function of product temperature changes, the period of delivery, and the subsequent period of cold storage. R^2=0.9 correlation was given between predicted and measured microbial counts (logN).

Keywords: cold chain, shelf life, vacuum-packed sliced ham, microbial counts

Ensuring the cold chain is an essential condition for the quality and safety of several types of food (e.g. meats and meat products, dairy products, vegetables). Maintaining and controlling the cold chain is the mutual task of the members of the food chain (producer, manufacturer, distributor, and consumer). Factors influencing the cold chain and their impacts on food are the subjects of several scientific studies.

The FP7 project arranged by an organisation called FRISBEE – Food refrigeration innovations for safety, consumer benefit, environmental impact, and energy optimization along cold chain in Europe – uniting the research groups of several countries has examined the factors influencing the cold chain. Their interactions and also the environmental load of the cold chain were examined. Through experiments, the effect of fluctuating cold chain temperature on the shelf life of meats was presented (Duret et al., 2015). Gwanpua and co-workers (2015) considered the energy consumption and the effects of global warming as main aspects in evaluating not only food quality, but also the cold chain. They developed a software package, which optimizes the above listed parameters through the establishment of a cooling system. In the course of the organisation's studies, the quality of different products, including sliced pork products (cooked ham, cooked paté, and smoked ham), were examined

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in terms of different time-temperature profiles (Stahl et al., 2015). In its analysis covering several countries, the Frisbee project demonstrated the changes in the temperature of foods requiring refrigeration from their production to their consumption (Gogou et al., 2015). Changes in the temperature-time profile (Fig. 1) depend on the given food, the geographical location, and the weather. But it is rather apparent that the major negative impact on the cold chain takes place during the delivery of the product to the consumer's home after purchasing the product.

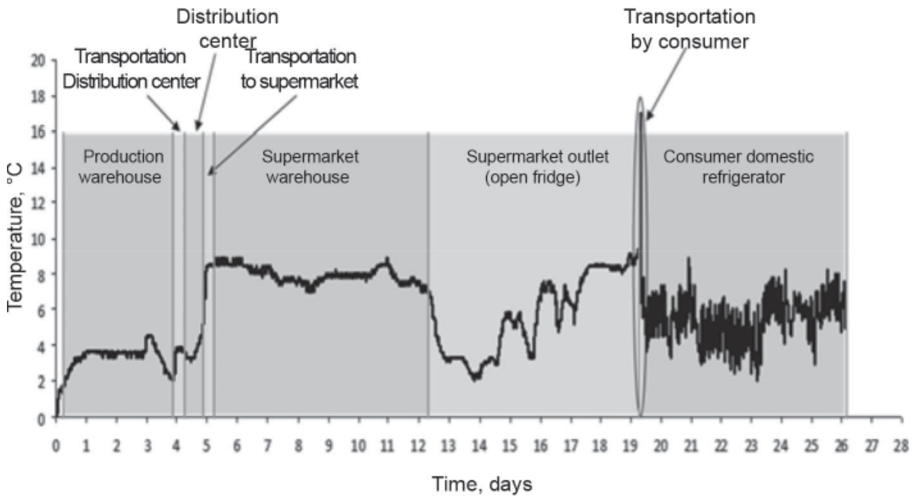

Fig. 1. Temperature-time profile of cold chain (Gogou et al., 2015)

The temperature parameters of the cold chain are also examined by other research groups. Jakubowski (2015) examined the temperature changes of the refrigeration compartments of vehicles transporting meat products. A number of studies point out that consumer habits may negatively affect the shelf lives, and that a critical point in the cold chain is the control of logistics (Jol et al., 2007; Leroy et al., 2009; Bieńczak, 2011; Koutsoumanis & Gougouli, 2015). Xu and co-workers (2014) lead the deterioration of products back to problems of cold chain logistics (CCLS), and developed a neural network model to mitigate risks. In the recent period, several researches have been aimed at expanding, verifying, or developing shelf life or microbial count growth models – e.g. Gompertz-model, Logistic-model, Baranyi model, Arrhenius and/or square root equations (McMeekin et al., 1997; Taoukis et al., 1999; Koutsoumanis et al., 2006; Mataragas et al., 2006; El Barbri et al., 2008; Kreyenschmidt et al., 2010; Shengping et al., 2013; Szczawińska et al., 2014). As the number, extent, and interactions of influencing parameters result in a high number of variations, forecasting may be of great help in applying food quality assurance systems.

Aerobic Colony Count (ACC), which is also called Total Viable Count (TVC), well expresses the quality of a food product, yet it cannot be applied to food safety. It can be used as a general quality indicator, for determining the extent of shelf life among others. Other regularly examined characteristics for qualification and shelf life determination of meat products are the levels of *Enterobacteriaceae,* coliforms, *Listeria monocytogenes*, and *Pseudomonas* spp. (Sagoo et al., 2007; Marcos et al., 2008; Tsironi et al., 2008; Zeleňáková et al., 2011; Bruckner et al., 2012). The permitted levels of microbiological contamination are regulated by different legislations in Hungary and in the European Union (Commission Regulation EC No. 2073/2005 on microbiological criteria for foodstuffs and 4/1998. decree of the Hungarian Ministry of Health on the permissible extent of the microbiological contaminants of foodstuffs (1998)).

1. Materials and methods

We chose a vacuum-packed sliced pork ham product to be the subject of our cold chain analysis and our examination of microbe count changes due to cold chain interruption. Hufi Hús Kft. (Budakalász, Hungary) provided a supply of its permanently available product for consumer assessment and shelf life tests.

For the cold chain temperature-time examinations OM-84-TMP type (Omega Engineering, Stamford, United States) and EBI 300 type (WTW GmbH Business Unit Ebro Electronic, Ingolstadt, Germany) data collectors were used. The data collectors were packed alongside the vacuum-packed product units and handed to registered customers. The stored information results of the returned data collectors were saved and assessed in the institute.

The microbial count was determined by a quick method based on redox-potential measurement at the Accredited Laboratory of the Department of Food Hygiene of Budapest University of Veterinary Medicine (Szakmár et al., 2006; Reichart et al., 2007). In order to carry out the microbial count tests, we conducted 1-h, 2-h, and 3-h cold chain interruptions on the 5th day after production. Modelling ambient temperatures, we set 15, 25, and 35 °C air space in our Certomat BS-1 (Sartorius Stedim Biotech GmbH, Göttingen, Germany) laboratory heating/cooling incubators. The cold chain interruption temperature-time combination resulted in 9 sample groups. The vacuum-packed samples were cooled down in a refrigerator of 5 °C temperature and were stored at this temperature until the determination of the microbial count. We examined samples stored at 5 °C temperature without cold chain interruption as control samples. The vacuum-packed samples contained 2 slices of ham (60 to 70 g). We commenced the determination of the microbial count on the day subsequent to the cold chain interruption – on the 6th day after production – and repeated the procedure every two days. The samples were prepared in accordance to the Standard ISO 7218:2007. We took 10 g of representative sample from each pack of the vacuum-packed sliced ham, and suspended the samples in 90 ml of peptone water. For the quick method based on redox-potential measurement, we placed 1 ml solution in each of the measuring capsules. Regarding the assessment, we considered samples as spoiled products with TVC>6.7 logCFU g^{-1}; and at TVC>7 logCFU g^{-1} value we were able to smell unpleasant odours.

Microsoft Excel and Statgraphics Centurion XVI programmes were used for processing and presentation of data, namely for calculation of multiple regressions.

2. Results and discussion

We collected data on consumers' habits four times. On the last two occasions, only consumers doing their shopping within their place of residence were involved. Based on the data of collectors placed on the product units, the characteristics of consumer cold chain interruption are summarised in Table 1. The time for delivering the product to the individuals' homes and the temperature of the product units were monitored continuously. The commencement of cold chain interruption was signalled by a rise in the product temperature when it was removed from the refrigerator units, and the re-refrigeration of the product was demonstrated by a decline in temperature after reaching the maximum value. The product temperature during delivery to the individual's home was influenced by the ambient temperature and the time period of the delivery. The period of cold chain interruption was also influenced by the temperature of consumer refrigerators (3–8 °C), which resulted in diverse re-cooling rates. Based on our results, we registered both the period of delivery to home as well as the maximum temperature of the product. From Table 1 it can be seen that for approximately 50% of the persons shopping within their residence, cold chain interruption lasts longer than 30 minutes but less than 1.5 hours. Shopping out of residence, the delivery period typically lasted longer. The cold chain interruption parameters for the laboratory conditions, under which the microbial studies were conducted, were set based on our results.

Table 1. Characteristics of consumer cold chain interruption in Hungary

Consumer cold chain interruption		October 2013		May 2014		August 2015	April 2016
Ambient temperature[a] (°C)		20.3		17.5		35.2	18.9
Number of consumers		19[b]	24[c]	16[b]	22[c]	25[b]	42[b]
Duration of delivery	t<0.5 h	1	0	3	0	5	10
	0.5 h<t<1.5 h	10	4	9	4	12	22
	1.5 h<t<2.5 h	7	16	4	13	7	9
	2.5 h<t	1	4	0	5	1	1
Maximum temperature of product	T<15 °C	5	0	4	7	2	10
	15 °C<T<20 °C	12	12	10	13	6	28
	20 °C<T<25 °C	2	10	2	2	9	4
	25 °C<T	0	2	0	0	8	0

[a]: average 3 h at purchase; [b]: delivered in residence; [c]: delivered from outside of residence (but within 30 km)

In Figure 2, as an example, the temperature-time profiles of the survey carried out at the end of October 2013 is presented. The ambient temperature is highlighted with a bold line. Thin continuous lines represent the temperature changes occurring as a result of purchases carried out by 19 customers shopping in their residence. In most cases, the temperature of the product was close to the ambient temperature before the product was refrigerated again. Customer No. G378 reached his or her home 6 h after purchasing, and until that time, the product was stored in the customer's car, therefore the temperature of the product exceeded the ambient temperature. An extreme example is the temperature profile of Customer No. G423 – demonstrated in the diagram by a dotted line – who left the product in the car and only placed it in the refrigerator the following morning. This latter result was not taken into consideration regarding our assessment, yet it is informative about consumer behaviour.

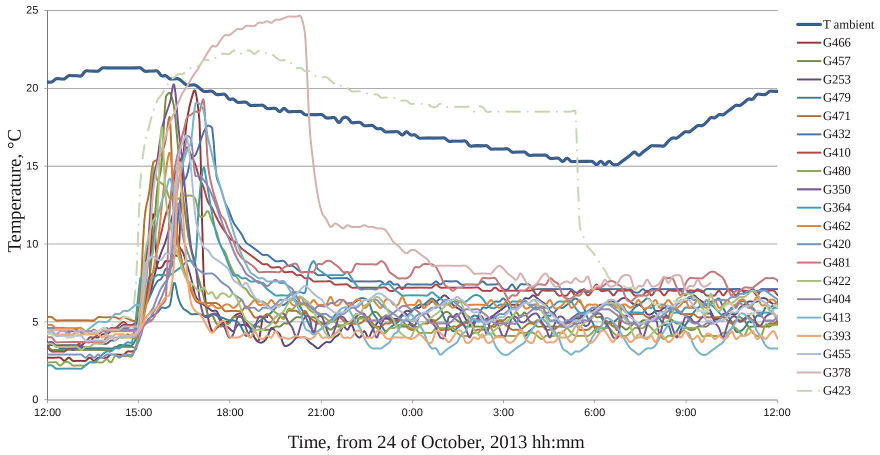

Fig. 2. The temperature of vacuum-packed ham products after purchasing as a function of time

For modelling cold chain interruption under laboratory conditions, the vacuum-packed ham slices were placed into 15, 25, and 35 °C incubators for 1, 2, and 3 h. The measured average temperature of the products was the adjusted incubator temperature ±0.5 °C. The modelled cold chain interruptions resulted in samples of diverse quality and shelf life. Figure 3 demonstrates some characteristic curves of the microbial count. The curve marked *0*h*WI* (without interruption) can be considered as reference, this sample was kept in a refrigerator continuously at 5 °C. Curves marked *dt*h*T*C represent cold chain interruptions for *dt* hours, at *T* °C temperature. The curves shown in the diagram well demonstrate that both the period of the cold chain interruption and the ambient temperature influence the shelf life of the given product.

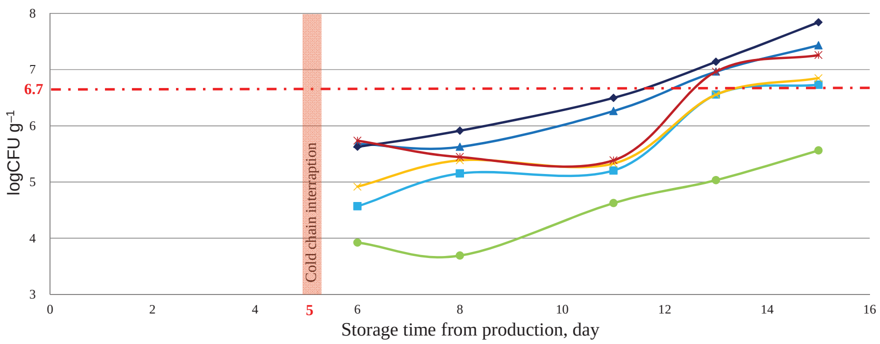

Fig. 3. Changes in the microbial status of vacuum-packed ham after cold chain interruption to different extents. *dt*h*T*C: product with *dt* hour interruption; *T* °C: average temperature of the product, and *0*h*WI:* without interruption
1h15C; 1h25C; 1h35C; 2h15C; 3h15C; 0hWI

Using our data we set up a model to estimate the microbial count based on 4 independent variable parameters. The independent variable parameters include the average temperature of the product during the cold chain interruption (*T*, °C), significantly influenced by the given ambient temperature; the period of interruption (*dt*, h); and also the time elapsed from the date of production (*τ*, day). The fourth independent variable parameter is the interaction between the average temperature of the product and the period of interruption, considered as a multiplication result.

$$logN=1.83+0.0771\cdot T+0.4831dt+0.2266\tau–0.0141\cdot T\cdot dt \text{ [logCFU g}^{-1}\text{]} \quad (1)$$

The independence of the variables applied in the model is verified by the statistical results presented in Table 2. The matching of microbial counts estimated by the model and obtained by laboratory measurement is presented in Figure 4. The correlation between the two values is R=0.9. Our model is applicable in case of $\log N_i$=2–4 logCFU g^{-1} initial TVC, a range of 5–30 °C storage temperature, and a maximum 3-h period of delivery to home.

From the first equation, using log*N*=6.7 logCFU g^{-1} value, the shelf life from the date of production can be expressed.

$$\tau_p=21.5–0.34\cdot T–2.132\cdot dt+0.0622\cdot T\cdot dt \text{ [day]} \quad (2)$$

Table 2. Multiple regression results for assessment of independent variables

Parameter	Estimate	Error	Statistic	P-value
Constant	1.8318	0.2447	7.4865	0
T (°C)	0.0771	0.0095	8.0918	0
dt (h)	0.4831	0.1074	4.4961	0
τ (day)	0.2266	0.0153	14.7704	0
T×dt	–0.0141	0.0047	–2.9810	0.0046

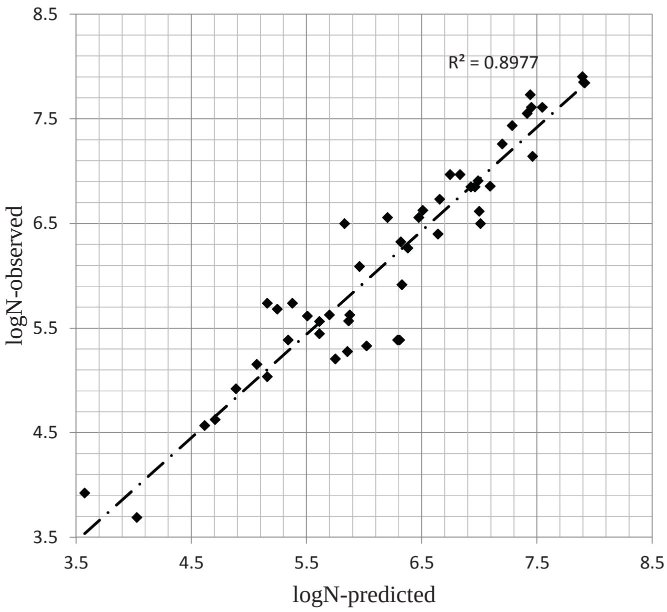

Fig. 4. Plot of *logN*

3. Conclusions

Our results support all former results of researches presented in the Introduction paragraph. In our research, we focused on consumer behaviour and highlighted the impacts of the period of delivering the products to home. We set up a model for vacuum-packed ham for which, using the value of $logN$=6.7 logCFU g^{-1}, the period for shelf life from the date of production can be expressed. An advantage of the model is that it concludes changes in microbial count ($logN$) from simple physical parameters (T, dt). The equation allows the calculation of the number of days required for a meat product to reach a microbial count characteristic to spoiled products depending on the conditions of delivering the product home. According to our model, it can be concluded that without cold chain interruption, by storing it at 5 °C, vacuum-packed ham slices can be preserved for 19.8 days. From the examples of Table 3, it can be seen that in case of a 1-h consumer cold chain interruption – that can be considered as an average value – if the product temperature reaches 20 °C, shelf life decreases by 6 days. Upon a three-hour cold chain interruption, when the product reaches 30 °C temperature, for example in case of shopping outside of consumers' place of residence in summer, shelf life is halved.

Table 3. Predicted shelf life of vacuum-packed ham slices, τ_p, (day)

Vacuum-packed ham slices		Average product temperature, T (°C) during cold chain interruption					
		5	10	15	20	25	30
Duration of cold chain interruption *dt*, (h)	0	19.8	18.1	16.4	14.7	13.0	11.3
	1		16.6	15.2	13.8	12.4	11.0
	2		15.1	14.0	12.9	11.8	10.8
	3		13.6	12.8	12.0	11.3	10.5

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