Development of a Safety Monitoring and Assurance System for chilled food products

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Abstract

The principles of a novel chill chain management policy, coded Safety Monitoring and Assurance System (SMAS) for the optimisation of the distribution of chilled food products within the chill chain are developed. In this system, a new approach based on actual risk evaluation at important points of the chill chain is used in order to promote products to the next stage of distribution. This evaluation based on product’s time-temperature history, variation in product’s characteristics (e.g. $a_w$, pH, etc.), and the use of predictive models for the growth of food pathogens, allows to give priority to products in such a way that risk at consumption time is minimized. The effectiveness of SMAS was evaluated against the First In First Out (FIFO) approach, the current method for food distribution, in a case study on the risk of listeriosis of cooked ham using the Monte Carlo simulation technique. Furthermore, the two approaches were compared for their effect on the quality of the products in terms of remaining shelf life at the time of consumption. The results showed that following the SMAS approach the risk of listeriosis is significantly lower while the spoiled products at the time of consumption are significantly reduced compared to FIFO approach.

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1. Introduction

In the last decade, the apparent incidence of foodborne disease has increased worldwide, despite the introduction of HACCP, and the proliferation of food safety regulations (Maurice, 1994). The increased incidence of foodborne disease, caused,
among others, by changes in agricultural and food processing practices, increasing international trade, and social changes, stress the need for more effective food quality and safety assurance systems. Current approaches to food safety that rely heavily on regulatory inspection and sampling regimes cannot sufficiently guarantee consumer protection since 100% inspection and sampling is financially and logistically impossible (Armitage, 1997).

A modern quality and safety assurance system should rely on prevention through monitoring, recording and controlling of critical parameters during the entire product’s life cycle that includes the post-processing phase and extends to the time of use by the final consumer. Increasing attention is focused on the role and the logistics of transport, storage and handling, and the benefits of taking a supply chain perspective are being appreciated and pursued (Ross, 1996; Browne and Allen, 1998; Dubelaar et al., 2001; Broekmeulen, 2001; Tijkens et al., 2001). Temperature conditions in the chilled distribution chain determine the risk potential, the shelf life and final quality of chilled products processed and packed under Good Manufacturing Practices and Good Hygiene Practices (GMPs and GHPs). Since in practice significant deviations from specified conditions often occur, temperature monitoring and recording is a prerequisite for chain control and any logistics management system that aims on product quality optimisation at the consumer’s end (Wells and Singh, 1989).

Advance of predictive microbiology has allowed significant progress towards effective, validated modelling of food safety and quality. In the last decade, a large number of mathematical modelling studies on the effect of temperature, intrinsic characteristics (e.g. pH, $a_w$) and packaging environment (e.g. $pCO_2$) on the growth of spoilage and pathogenic bacteria has been published (Devlieghere et al., 1999, 2000, 2001; Koutsoumanis and Nychas, 2000; Koutsoumanis et al., 2000; Koutsoumanis, 2001). Identification of the critical parameters affecting food quality and safety and quantification through a systematic modelling approach will allow monitoring the quality and safety status of food products throughout the chill chain. Based on principles of modelling of the food spoilage and time–temperature monitoring a shelf life management system has been developed by Giannakourou et al. (2001). In the latter study, kinetic growth models of the specific spoilage organisms (SSO), the variability of the SSO initial population, shelf life studies and time–temperature monitoring were integrated into the Shelf Life Decision System (SLDS), which was demonstrated to be an effective tool for food chill chain management leading to optimisation of food quality at consumer’s end (Koutsoumanis et al., 2002). The latter concept in combination with the scientific approach with respect to the quantitative study of safety risk in foods will allow the undertaking of the next important step, i.e. the study and development of a management system that will assure both safety and quality in the food chill chain (Koutsoumanis et al., 2003).

In the present study, the principles of development of an intelligent Safety Monitoring and Assurance System (SMAS) are presented. The SMAS is an effective chill chain management tool that leads to an optimised distribution of risk and a significant quality improvement of foods at consumption time. It integrates kinetic models for food pathogens, variation in the intrinsic characteristics (e.g. pH, $a_w$) of products and time–temperature monitoring. The applicability and effectiveness of SMAS compared to the FIFO approach is demonstrated through a case study on cooked ham by comparing the safety risk and quality of the products at consumer’s end.

2. Materials and methods

2.1. Principles of the Safety Monitoring and Assurance System (SMAS)

The building blocks of SMAS are the validated growth model of the relevant food pathogen, information on the variability in product’s characteristics such as water activity, pH, concentration of preservatives and knowledge of the time–temperature history of the food products. The introduction of product’s characteristics and time–temperature history to the predictive model can lead to an estimation of the pathogen kinetic parameters such as the maximum specific growth rate $\mu_{\text{max}}$. Assuming conservatively that most of the pathogen growth occurring during actual distribution is in the exponential phase, the
potential growth of the pathogen on a specific product can be calculated from the following function:

$$\ln(N) = \mu_{\text{max}}(T, aw, \text{pH},...)t$$

The growth of the pathogen \(N_t\) on a product of known characteristics, at time \(t\), after exposure at a known variable temperature exposure, \(T(t)\), can be found based on Eq. (1) by calculating the integral of \(\mu_{\text{max}}[T(t)]dt\), from 0 to time \(t\). Using this approach the safety status of a product batch or even individual product units can be estimated at any point of the chill chain. This is the core calculation process on which SMAS is established. Based on the ability to accurately determine pathogen behavior, SMAS makes decisions at designated points with regards the distribution or stock rotation of the products, as will be detailed in Section 3.

2.2. Evaluation of SMAS effectiveness

In order to prove the effectiveness of the SMAS system, a case study on cooked ham was performed where a simulation of the results obtained through its application with respect to the risk of listeriosis of the products at their final destination was generated. A very useful technique to achieve this is Monte Carlo simulation (Cassin et al., 1998), facilitated by data and information provided by surveys on the conditions of the distribution chain. This numerical approach has been recently extensively applied for microbial risk assessment of food products (Whiting and Buchanan, 1997). It is based on the generation of hypothetical “scenarios” (Lammerding and Fazil, 2000) in terms of the values attributed to the identified factors during all the segments of the chill chain from production to final consumption. In the approach used in this work, values of controlling parameters (e.g. temperature or distribution product’s \(a_w\)) are treated as probability distributions, which represent uncertainty (lack of sufficient knowledge) or the commonly encountered variation in the parameter (Lindqvist and Westöö, 2000). The procedure, repeated several times, requires the random selection of a value from each of the probability distributions assigned for the input parameters, in order to calculate a mathematical solution, defined by the pathogens model used. In the present study the extended Ratkowsky model for the growth of \textit{Listeria monocytogenes} developed by Devlieghere et al. (2001) was used. The model was applied for 870 mg l\(^{-1}\) dissolved CO\(_2\) and 0% sodium lactate. At each iteration, a value is drawn from the defined distribution, i.e. values of higher probability are selected more frequently, calculations are performed and the results are stored. Eventually, the analysis provides a frequency distribution for the output of interest (\textit{L. monocytogenes} concentration at consumption time) that has taken into account the probability distribution of the input factors, instead of using a single-point estimate. In order to estimate the risk of listeriosis from \textit{L. monocytogenes} concentration the dose–response relationship of Farber et al. (1996) for the normal population and for a 50-g serving of cooked ham was used.

SMAS and FIFO approaches were also compared for their effect on the quality of the products in terms of remaining shelf life at the time of consumption. In foods where spoilage is caused by microbial activity, shelf life can be defined as the time required by the specific spoilage organisms (the organism responsible for spoilage) to grow from the initial level to a spoilage level (level at which spoilage is observed) (Koutsoumanis and Nychas, 2000). In the case of cooked ham, \textit{Lactobacillus sake} was chosen as the specific spoilage organisms with a spoilage level of \(10^7\) cfu/g (Devlieghere et al., 2000). The shelf life of cooked ham products managed with SMAS and FIFO was estimated at the time of consumption using the extended Ratkowsky model of \textit{L. sake} developed by Devlieghere et al. (1999). The model was applied for 870 mg l\(^{-1}\) dissolved CO\(_2\) and 0% sodium lactate.

3. Results and discussion

3.1. Development of SMAS

The SMAS decision making routine at a specified control point of the chill chain is based on the growth of the pathogen that has potentially occurred within the period between production and arrival of the product at the control point. The growth of the pathogen is estimated based on the product’s characteristics and the time–temperature history of the product using the appropriate predictive model. The above elements form the programme core of an integrated software that allows the calculation of
Fig. 1. SMAS logical diagram of the decision making routine at important control points of the distribution chain. Pathogen growth $N_t$ is computed for all product units, the distribution function of pathogen growth is constructed and decision for the further handling of each unit is taken based on its position within the distribution compared to the median growth ($N_{med}$).

Fig. 2. Initial microbiological (prevalence and concentration of $L. monocytogenes$, concentration of $L. sake$) and physicochemical ($a_w$) characteristics of cooked ham used in the Monte Carlo simulation study.
pathogen growth and safety risk of individual product units (e.g. small pallets, 5–10 kg boxes or even single packs) at strategic control points of the chill chain. Based on the probability distribution of the pathogen growth, it is possible to make decisions for optimal handling, shipping destination and stock rotation, aiming to obtain a narrow distribution of quality at the point of consumption. The logical diagram of the decision making routine is illustrated in Fig. 1. At a certain point of the chill chain, e.g. at a distribution center, product from the same initial shipment is split in half and is forwarded to two different retail markets, a close and a distant one that requires long transportation. The split could be random according to conventional, currently used First In First Out (FIFO) practice or it can be based on the actual risk of the product units and the developed decision system. For all units, the product’s identity is input (possibly through the scanning of a bar code) providing the information on product’s characteristics. Another input is the time–temperature history of the product, monitored possibly by time temperature integrators (TTI) (Taoukis and Labuza, 1989; Taoukis et al., 1999) or by electronic temperature data logger. This information directly fed into a portable unit with the SMAS software, is translated to safety status, $N_t$, based on the growth models of the pathogen of concern. Having calculated $N_t$ for all the n product units, a risk distribution for the products at the decision point is constructed. Based on the risk of each product unit relative to this distribution, decisions about its further handling are made.

Fig. 3. Illustration of the chill chain case used for the quantitative evaluation of the application of FIFO and SMAS management approaches to the final listeriosis risk and quality distribution of cooked ham. Consecutive stages and conditions and the two decision points are shown.
3.2. Evaluation of SMAS effectiveness

In order to simulate the results of the application of the developed SMAS system and quantitatively prove its effectiveness the described Monte Carlo method was applied. By taking into account the status of the product after production \((a_w\) value, prevalence and concentration of \(L.\ monocytogenes\) and concentration of \(L.\ sake\)) (Fig. 2) and various temperature distributions at different steps and alternative storage conditions, the distribution of the safety risk and the quality of the studied set of products at the final stage of consumption can be estimated. The objective is to demonstrate the minimization of final risk and optimization of quality with SMAS compared to the conventional FIFO based random practice. Different distribution scenarios or marketing routes were considered. The chilled chain scenario used in the present work (Fig. 3) consists of production, 8 h of transportation to the main distribution center, various time scenarios for chill transportation to the local market (2–24 h) or export markets (24–72), 6, 24 or 36 h at the retail storage and various time periods at the consumer’s refrigerator.

Two decision points are used to apply the SMAS approach. At the first decision point, the main distribution center, products are appropriately split and sent to the close local market or the distant export market based on product’s risk. At the second decision point, units are classified into three groups for successive stocking of the retail cabinets every 6 h with the products with higher potential risk promoted first. Without the use of SMAS, product split at the above two points with the common FIFO approach is random, since time in the chill chain for all products in consideration is the same.

The Monte Carlo simulation results for the risk of listeriosis associated with cooked ham distributed to local (a) and export (b) market are illustrated in Figs. 4 and 5. For the local market the risk distribution of products distributed based on SMAS and FIFO approach was found to be similar (Fig. 4). For the export market however, SMAS application led to a substantial shift of central tendency of the distribution to lower risk probabilities and a significant decrease of products with high risk (Fig. 5). This led to a lower risk of the total amount of product (local plus export market) (Fig. 6).

In addition to the reduction of listeriosis risk, SMAS led to a significant improvement of the quality
of the products at the time of consumption as it is shown in Figs. 7 and 8. In these figures the quality distribution at consumption time, i.e. the percentage of products that are of a certain quality, is shown. Quality is expressed as Remaining Shelf-life, the time for the product to reach a spoilage level of $10^7$ cfu/g at 0 °C. Negative values indicate products that have exceeded the limit of organoleptic acceptability before reaching the consumer’s table. For the export market with the FIFO system 12.54% of products were beyond acceptable quality at the time of consumption, whereas with SMAS unacceptable products were reduced to 4.32% (Fig. 7). Respectively, for both local and export market (Fig. 8) from 16% with FIFO, unacceptable products were reduced to 8.22% with SMAS.

The improvement of product’s quality due to application of SMAS is achieved despite the fact that the promotion of the product to the next stage of distribution is based exclusively on the pathogen risk. However, considering that SMAS function is based on the $a_w$ values of the product and the temperature history and that the later factors affect in a qualitatively similar manner the growth of both pathogen and spoilage bacteria, the improvement of both quality and safety of the products should be expected.

In conclusion, SMAS integrates kinetic models of food pathogens, data on intrinsic product’s characteristics and the time–temperature history, into an effective chill chain management tool that leads to minimized distribution of risk and an optimized distribution of quality, effectively reducing the percentage of high risk or spoiled products at consumption time.

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References


