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

K. Koutsoumanis[1*], P. S. Taoukis[2] and G.J.E. Nychas[3]
1. Aristotle University of Thessaloniki, Faculty of Agriculture, Dept. of Food Science and Technology, Lab. of Food Hygiene and Microbiology, Thessaloniki, Greece, kkoutsou@agro.auth.gr
2. National Technical University of Athens, School of Chemical Engineering, Laboratory of Food Chemistry and Technology, 5 Iroon Polytechniou, 15780 Zografou, Greece, taoukis@chemeng.ntua.gr
3. Agricultural University of Athens, Department of Food Science and Technology, Laboratory of Microbiology & Biotechnology of Foods, Iera Odos 75, Athens 11855, Greece, gjn@aua.gr

ABSTRACT

The principles of a safety management system for the optimisation of the distribution of chilled food products at the time of consumption are developed. In this system, instead of the conventional first in first out (FIFO) method 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 continuous product temperature monitoring, possibly by Time Temperature Integrators (TTI), and the use of predictive models for the growth of food pathogens, allow to give priority to products in such a way that risk at consumption time is minimized. Following this chill chain management policy, coded “Safety Monitoring and Assurance System” (SMAS) the potential of unsafe products are significantly reduced, and the consumers receive products of low risk and more uniform quality.

INTRODUCTION

In the last decade, the incidence of foodborne disease has increased in Europe, despite the introduction of HACCP, and the proliferation of food safety regulations. The increased incidence of foodborne disease, caused 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.

Application of an optimized quality and safety assurance system for the chilled distribution of chilled food products requires continuous monitoring and control of storage conditions, from production to consumption. Time Temperature Integrators (TTI) allow such control down to product unit level. TTI can show an easily measurable, time and temperature dependent change that cumulatively reflects the time-temperature history of the food product. In order to establish an accurate and reliable correlation between the response of TTI and the risk potential of food products, a thorough kinetic study of the behaviour of relevant food pathogens is essential. Advance of predictive microbiology has allowed significant progress towards effective, validated modelling of food safety. The last decade, a large number of mathematical modelling studies on the effect of temperature, intrinsic characteristics (eg. pH, a_w) and packaging environment (e.g.pCO_2) on the growth of pathogenic bacteria has been published. Based on principles of modelling of the food spoilage and the TTI response 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 TTI responses 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 state of the TTI technology and of the scientific approach with respect to the quantitative study of safety risk in foods allows the undertaking of the next important step i.e. the study and development of a TTI based management system that will assure both safety and quality in the food chill chain.

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 optimised distribution of risk at consumption time. It integrates kinetic models for food pathogens, variation in the intrinsic characteristics (eg. pH, a_w) of products and the capacity to continuously monitor temperature history with TTI. The applicability and effectiveness of SMAS compared to the FIFO approach is demonstrated by comparing the risk of food products at consumer's end.

MATERIALS AND METHODS

The building blocks of SMAS are the predictive model of the relevant food pathogen and the kinetics of response of the appropriate Time Temperature Integrator. The basic principles of TTI application has been described in detail by Taoukis and Labuza (1989). Assuming conservatively that most of the pathogen growth occuring during actual distribution is in the exponential phase, the potential growth of the pathogen can be calculation from the following function:

$$\ln(N/N_o)=\mu_{max}(T)\,t \qquad (1)$$

The population of the pathogen N_t, at time t, after exposure of the product at a known variable temperature exposure, T(t), can be found based on equation (1) by calculating the integral of $\mu_{max}[T(t)]$ dt, from 0 to time t. We can define the effective temperature, T_{eff}, as the constant temperature, equal exposure to which, results in the same microbial level N_t, as the variable temperature distribution, T(t). The same kinetic approach is used to model the measurable change X of the TTI. The response function, F(X), is determined, such that $F(X)=k_It$, with k an Arrhenius (or Belehradek) function of T. For an indicator exposed to the same temperature distribution, T(t), as the food product, and corresponding to an effective temperature T_{eff}, the value of the response function will be

$$F(X)_t = k_{I T_{eff}}\, t = k_{I ref} \exp\left[\frac{-E_{AI}}{R}\left(\frac{1}{T_{eff}}-\frac{1}{T_{ref}}\right)\right] t \qquad (2)$$

where k_{Iref} and E_{AI} are the Arrhenius parameters of the indicator. By solving equation (2), the T_{eff} of the exposure is derived. With the T_{eff} and the pathogen kinetic parameters of the food known, the population of the pathogen N_t is calculated from Equation (1) for $\mu_{max} = \mu_{max}(T_{eff})$. This process is the core calculation process on which the SMAS is established. Based on the ability to accurately determine the potential growth of the pathogen, the SMAS makes decisions at designated points with respect to the distribution or stock rotation of the products, as will be detailed in the results section.

In order to prove the effectiveness of the SMAS system, simulation of the results obtained through its application with respect to the risk of the products at their final destination was generated. A very useful technique to achieve this is Monte Carlo simulation, 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. It is based on the generation of hypothetical "scenarios" 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 of a_w values) are treated as probability distributions, which represent uncertainty (lack of sufficient knowledge) or the commonly encountered variation in the parameter. 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 mathematical model used. 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 (risk), that has taken into account the probability distribution of the input factors, instead of using a single-point estimate.

RESULTS AND DISCUSSION

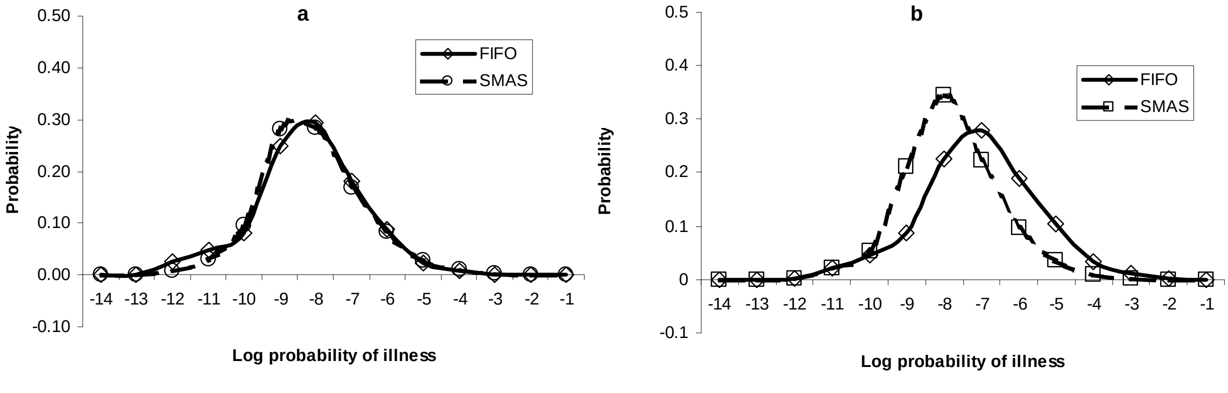
The SMAS decision making routine at a hypothetical control point of the chill chain is based on the growth of the pathogen occurred within the period between production and arrival of the product at the control point . For example, at any point of chilled chain e.g. a distribution center, product from 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 FIFO (First In First Out) 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). Also the response of the TTI, cumulatively expressing the temperature exposure of the product, is input either electronically as a signal of a suitable optical reader or as a keyed in visual reading. This information directly fed into a portable unit with the SMAS software, is translated to safety status, N_t, based on the kinetics of the used TTI, which integrates the time-temperature history of each product into an effective temperature value, T_{eff}, (Equation 2) and the growth models of the pathogen of concern. Having calculated N_t for all the n product units, the actual 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.

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 accounting for initial level and a_w variation, various temperature distributions at different steps and alternative storage conditions, the distribution of the risk of the studied set of products at the final stage of consumption can be estimated. The objective is to demonstrate the optimization of final risk 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 consists of production (where product's a_w distribution is measured and input in the database), 8 h of transportation to the main distribution center, various time scenarios for chill transportation to the local market (2- 24h) 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 3 groups for successive stocking of the retail cabinets every 6 h with the products with higher pathogenic growth 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 Figure 1. For the local market the risk distribution of products distributed based on SMAS and FIFO approach was found to be similar. 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.

Figure 1. Distribution of probability of illness associated with the consumption of one serving of cooked ham for products distributed to the local (a) and export (b) market based on SMAS and FIFO approach



In conclusion, SMAS integrates kinetic models of food pathogens, data on intrinsic product's characteristics and the capacity to continuously monitor temperature history with Time Temperature Integrators, into an effective chill chain management tool that leads to an optimized distribution of risk at consumption time, effectively reducing the percentage of products with high risk.

Acknowledgement: This study has been partly carried out with the financial support of the Commission of the European Communities, specific RTD program "Quality of Life and Management of Living Resources", Key Action 1-Health Food and Environment, Project N° QLK1-CT2002-02545

REFERENCES

Giannakourou M., K. Koutsoumanis, G.J.E. Nychas and P. S. Taoukis (2001) Development and assessment of an intelligent Shelf life Desicion System (SLDS) for quality optimization of the food chill chain. J. Food Prot. 64, 1051-1057

Koutsoumanis, K., M. Giannakourou, P. S. Taoukis, and G.J.E. Nychas (2002) Application of SLDs (Shelf life Decision system) to marine cultured fish quality. *Int. Journal of Food Microbiol.* 73, 375-382

Taoukis P.S., and T.P. Labuza. 1989. Applicability of Time Temperature Indicators as shelf life monitors of food products. J Food Sci 54(4): 783-788.