Modelling and Reduction of Risk of Fresh Pork Products with SMAS: a TTI Based Chill Chain Management System

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Abstract

The most difficult to control segment that affects directly safety and quality of chilled meats is the actual chill chain. Application of an optimised management for chilled distribution requires continuous monitoring and control of storage conditions from production to consumption. A novel chill chain management policy, coded "Safety Monitoring and Assurance System" (SMAS) is applied, allowing to give priority to products in such a way that, compared to the First In First Out (FIFO) current approach, risk at consumption time is minimized and quality optimised. The principles of the SMAS management approach of chilled products are developed and implemented, in order to prove the benefits of this system against the traditional FIFO. The two alternative policies (FIFO and SMAS) were compared for their effect on the quality of the products in terms of remaining shelf life, as well as for the impact on the microbiological risk at the time of consumption. The simulation results showed that, applying SMAS approach leads to significant decrease of the risk of listeriosis of ground pork products, lowering, at the same time, the number of spoiled products at the time of consumption.

INTRODUCTION

Fresh meat products are perishable and even when packaged, distributed and stored properly can spoil in relatively short time. Overgrowth of incidental pathogenic bacteria like *Listeria monocytogenes*, Salmonella sp. and *Escherichia coli* followed by undercooking or inadequate preparation may be hazardous to the consumer. Current risk assessment studies show that foodborne disease remains a main concern. Low temperatures in the chill chain are crucial for the quality and safety of chilled meat. However temperature frequently deviate from specifications. Conditions during transportation and at the retail level are out of manufacturer's direct control and often deviate from specifications. Application of an optimized quality and safety assurance system for the chilled distribution of fresh meat and meat 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 (Taoukis and Labuza 1989, Taoukis 2001). The state of the TTI technology and of the scientific approach with regards 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 meat chill chain.

The objective of this work was to apply the recently introduced principles of SMAS- Safety Monitoring and Assurance System (Koutsoumanis et al., 2004). The SMAS is designed as 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 Time Temperature Integrators (TTI). The goal is to replace the conventional First In First Out (FIFO) approach with a system, based on actual risk evaluation at important points of the chill chain, through continuous product temperature monitoring with TTI.

MATERIALS AND METHODS

The building blocks SMAS include (a) validated models of microbial growth of pathogens and Specific Spoilage Organisms (SSO) for each different meat product, (b) information on the initial prevalence and distribution of the SSO, N_o (c) continuous temperature monitoring of the chill chain with Time Temperature Indicators and (d) correlation of sensory acceptability to a specific level of microbial load, N_S, that signals the end of the product shelf life. These elements are integrated in the SMAS algorithm, allowing for the estimation of the actual remaining shelf life and the risk assessment of each product unit, at selected points of the chill chain.

In order to prove the effectiveness of the SMAS system, simulation of the results obtained through its application with regards the risk of the products at their final destination was generated, using Monte Carlo simulation technique. It is based on the generation of hypothetical, realistic “scenarios”, including all the segments of the chill chain from production to final consumption. In the approach used in this work, data and information provided by surveys on the conditions of the distribution chain were used and values of controlling parameters (e.g. temperature) are treated as probability distributions.

RESULTS AND DISCUSSION

The SMAS decision criterion, at a certain point of the distribution chain, is based on the potential growth of the incidental pathogen within the period between production and arrival of the product at this point. The extent of this growth is estimated based on the product’s features and its time-temperature history, obtained from the attached Time Temperature Integrator. The above elements form the core of the mathematical algorithm, that applies predictive models to calculate the pathogen growth and the microbiological risk of individual products, at important control points of the chill chain. This information allowed for decision making on optimal handling, shipping destinations and improved stock rotation. The logic diagram of the decision making routine of SMAS is illustrated in Fig.1. In this case, the distribution center is chosen as the decision point for sending out products at different destinations. At that point, product from the same initial shipment is split in two equal parts and shipped to two different retail markets, a close and a distant one. The split could be random (since conventional FIFO policy accounts only for time which in this case is uniform), or based on the SMAS algorithm criteria i.e. the relative potential pathogen growth. Based on their temperature history, deduced from their TTI response, individual products are classified for growth (see distribution of microbial population in Fig 1) and the ones with higher relevant growth are promoted to the closer market for presumably sooner consumption. For all units, their unique identity and their time temperature history were inputs to this algorithm. The reliable implementation of SMAS system requires predictive models of pathogen growth for the specific food system and kinetic modeling of TTI response at a wide range of temperature conditions, and subsequent validation of the established models.

The principles of the TTI application are summarized in the scheme of Fig 2, and lies on the estimation of the time-temperature history of the product, at any point of its distribution, expressed as a time-integral, or, equivalently by an effective temperature (T_{eff}: the constant temperature, equal exposure to which, results in the microbial level as the variable temperature distribution, T(t)). Although application of the scheme in Fig.2 requires that the activation energies of TTI response and of growth are similar in order that ${T_{eff}}_{TTI}={T_{eff}}_{FOOD}$, a TTI with higher E_A could be used. This would conservatively give a higher T_{eff} by up to 2°C, thus the temperature history would be slightly exaggerated for all products, which will not affect the relevant product classification (in the distribution of Fig.1). According to the SMAS principles, the TTI information was translated to microbiological status of the food, based on the kinetics of the used TTI, which integrates the time-temperature history of each product into an effective temperature value, T_{eff}, and the growth models of the pathogen of concern. Having calculated the microbial level for all the n product units (N(t)i), the actual risk distribution for the products at the decision point is constructed.

Assuming the distribution scenario of Fig 3, the use of TTI and the SMAS system in the chill distribution of ground pork was assessed.

Microbial growth kinetic models for *Listeria monocytogenes* (E_A = 94.5 kJ/mol and μ_{ref} (at10°C) =0.058h^{-1}) and spoilage microorganisms, *Pseudomonas* (E_A = 73.1kJ/mol and shelf life at 0°C=190h) were developed, validated for dynamic conditions and used as the input data for the Monte Carlo simulation (Koutsoumanis, unpublished data, EC RTD project SMAS, QLK1-CT2002-02545). An initial load of $\log N_o$=0 for *L. monocytogenes* and $\log N_o$=3 for pseudomonads was used. For product management at the SMAS points, an enzymatic TTI (VITSAB® Type L10-3) (E_A = 158.5 kJ/mol and max response time (at 5°C) =150h) was modeled and applied (Giannakourou, unpublished data, EC RTD project SMAS, QLK1-CT2002-02545). For the stages of transportation to the distribution center, the supermarket storage and stocking of the retail fridge cabinets, and the domestic fridge, real time-temperature data from surveys were used (Giannakourou, unpublished data, EC RTD project SMAS, QLK1-CT2002-02545). After domestic storage, a cooking step was assumed (log reduction =3.0±1.5CFU/g) and a dose-response model (Farber et al., 1996) was applied for the estimation of the probability of illness.

Five thousand scenaria were used in the Monte Carlo routine. The results are illustrated in the form of two distribution diagrams. (Fig.4). SMAS effectiveness, compared to FIFO, in the chill chain optimization was established, leading to a reduction of risk of illness (Fig4a) and optimization of ground pork product quality at the time of consumption (Fig 4b).

CONCLUSIONS

The results support that SMAS policy substantially reduced risk probability and minimized products of ground pork of high risk, optimizing, at the same time, quality distribution.

Acknowledgement

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It does not necessarily reflect the Commissions views and in no way anticipates its future policy in this area.

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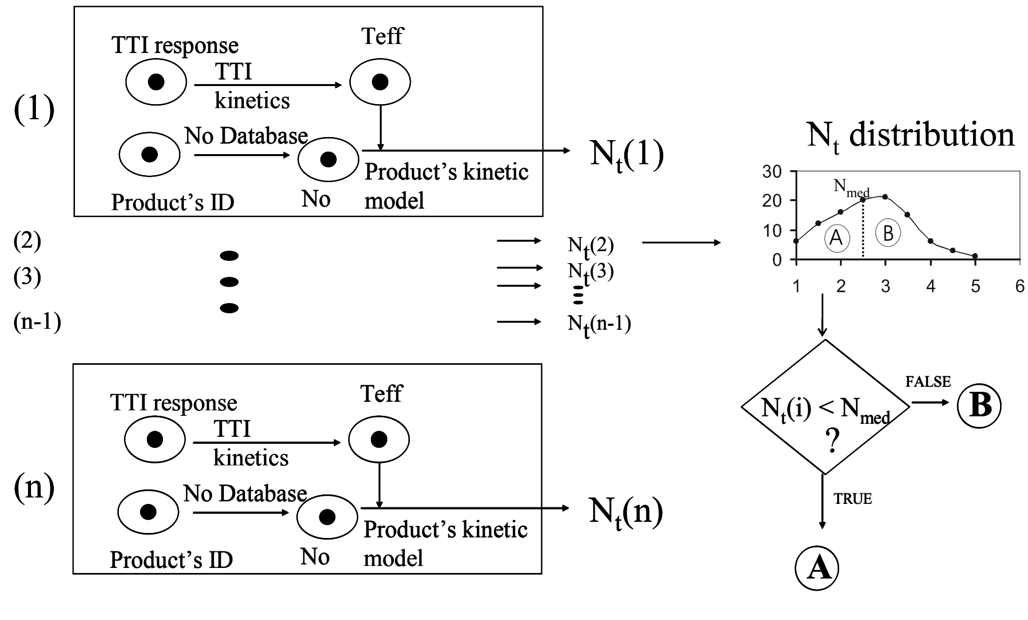

Fig 1 SMAS logical diagram of the decision making routine at important points of the distribution chain. The extent of pathogen growth N_t is calculated for all meat units and the decision for further handling is based on the position of each unit within the distribution, compared to the median growth (N_{med})

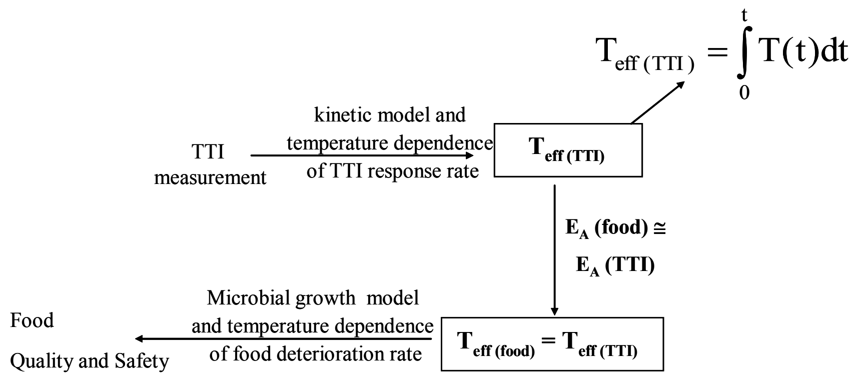

Fig 2 Schematic illustration of the correlation algorithm for the application of TTI as food quality and safety monitor.

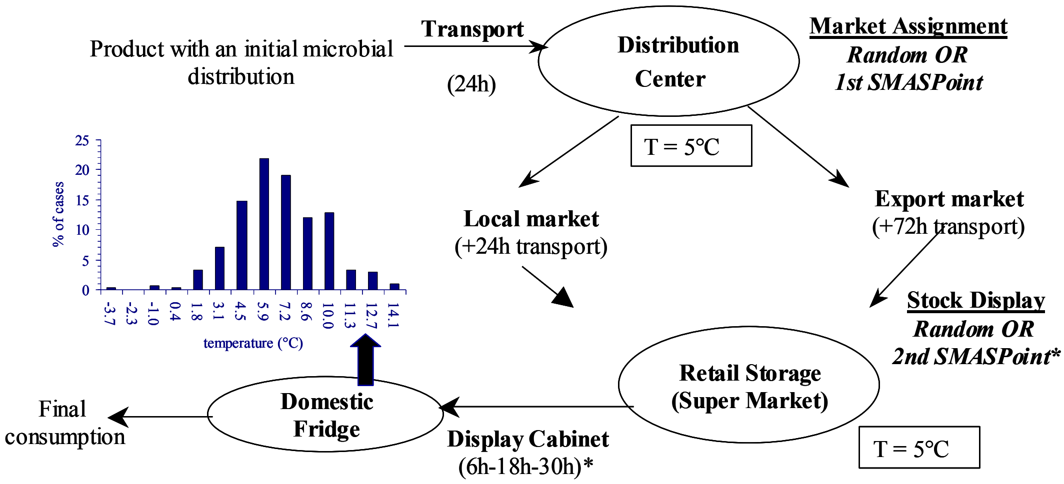

Fig 3 SMAS decision making routine at designated points of the distribution chain

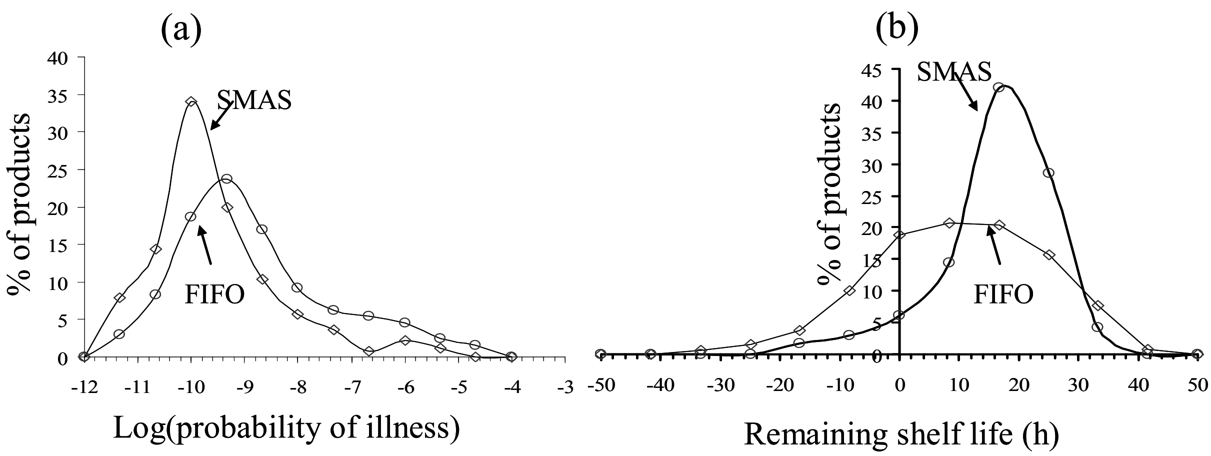

Fig 4: Distribution of (a) probability of illness associated with the consumption of one serving of cooked ground pork (50g) and (b) quality for ground pork products distributed to the distant market based on SMAS and FIFO approach